THE CORRECT PROFESSIONAL ATTITUDE

INSTALLING and SERVICING RADIOS

36RH

YOU ARE STARTING YOUR ADVANCED COURSE

This book is the FIRST LESSON of your Advanced Specializing Course

S24-2-641

Printed in U.S.A.

PIONEER HOME STUDY RADIO SCHOOL

NRI

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

FOREWORD

Ordinary Radio service men, and many dealers, are inclined to overlook what they consider minor details, and so very often come to grief. You might ask some of them what their installation technique is and they would probably tell you "Haul a set to the customer's home and stick it up."

But study this lesson carefully, and you'll find that the subject cannot be dismissed as casually as all this. The real Radio-Trician has a very definite, well thought out technique for installation, as well as for any service he may be called on for.

The greatest thing for a Radio-Trician is to be able to plan his moves beforehand so that when he gets on a job he doesn't waste any time wondering what he should do first.

This book will serve as an introduction to the entire course on service technique, besides going into detail on set installation. It may seem to require more thought—more things may seem to be involved than at first sight. But that won't worry you. Follow out these instructions and soon they will be second nature to you. Remember it is often the little things by which you are judged. Start right now to pay attention to detail.

J. E. SMITH.

1940 Edition

A LESSON TEXT OF THE N. R. I. COURSE
WHICH TRAINS YOU TO BECOME A
RADIOTRICIAN & TELETRICIAN
(REGISTERED U. S. PATENT OFFICE) (REGISTERED U. S. PATENT OFFICE)

NCP2M741

Printed in U. S. A.

The Correct Professional Attitude

THE JOB OF BEING A SERVICEMAN

THE RADIO-TRICIAN * is a highly important link in the Radio Industry. No matter how good a receiver is, unless it is properly installed and serviced, it will not give satisfactory service. For this reason manufacturers realize their dependency on Radio-Tricians. Thus the Radio-Trician is not only an important link, but a powerful one. He is the man who comes in personal contact with Radio set owners—it is on him that set owners rely for continued satisfactory reception.

Because of the importance of Radio in our modern world, and because the Radio-Trician fills such an important place in Radio, he must be more than a mechanic—he is a professional, and his attitude toward his work should be as professional as that of the doctor or lawyer.

That he must have expert knowledge goes without saying. He must know the "ins" and the "outs" of Radio, the "how" and the "why." He must be able to put his knowledge to work; he must have confidence in his knowledge and so be able to inspire confidence in his employer or customers. He must never be satisfied with the knowledge he has. Radio is growing fast—he must grow along with it. He should be interested in the work of other Radio-Tricians and learn what he can from them as well as from current Radio magazines and service manuals of new receivers.

But expert knowledge is not enough for a Radio success, surprising as it may seem. If a Radio-Trician has an improper attitude toward his work, if he is gruff, curt or careless, if he is untidy in appearance, he isn't going to please his employer or his customers no matter how much he knows, and it won't be long until he finds *some one else handling his jobs.*

The qualities of the perfect Radio-Trician, besides expert knowledge, can be listed as follows: Business-like Attitude,† Dependability, Fair Dealing, Courtesy, Neatness. Each of these is of sufficient importance to be considered in detail, a plan which we shall follow.

BUSINESS-LIKE ATTITUDE. No matter how much a Radio-Trician knows, unless he has or can develop a business-like attitude, he will find the road to success hard and long. The

* The title "Radio-Trician" is a Trade Mark, duly registered in the U. S. Patent Office, and is reserved for the sole use of N.R.I.-trained men.

† A successful business requires sound salesmanship, records and merchandising methods, subjects taken up elsewhere in the course.

first essential of a proper attitude is nothing more or less than self-confidence—you must know exactly what to do at the proper time and be able to go ahead and do it. Of course, if something should turn up that you cannot handle, don't *bluff*. Nothing disgusts an employer or a customer more than a serviceman who tries to get by on bluffing ability instead of servicing ability.

Plan ahead. When you apply for a job, study up on the receivers your prospective employer handles. When you get a telephone call for service, get the facts correctly; the name and address of your customer, of course, and whatever information you can get on the type of receiver and the kind of trouble the owner is having with it.

A serviceman who is not methodical, accurate and careful can never develop a business-like attitude. But these qualities make a man confident in himself and enable him to inspire confidence in others. However, don't forget that self-assurance, with nothing to back it up, is not what we mean by self-confidence. The confidence the Radio-Trician has in himself is born of knowledge and the ability to plan his moves before tackling a job.

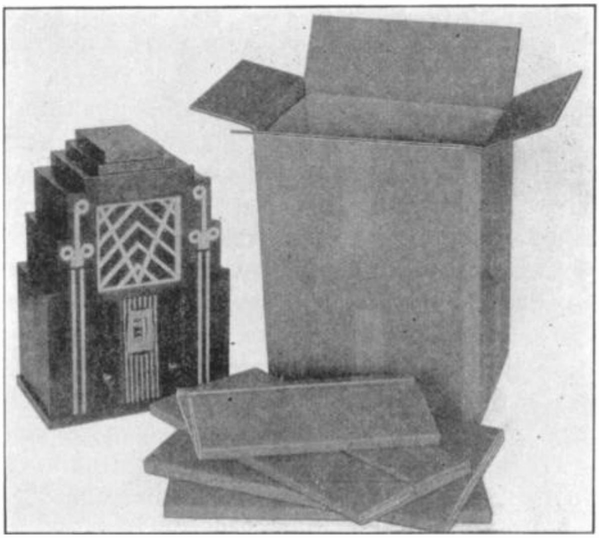
FAIR DEALING. Any business man who wants to be able to look forward to a large future business must be scrupulously fair in all his dealings with the public. Some business men make the mistake of seeing only present profits, but they eventually find, often to their sorrow, that it doesn't pay. Suppose a man takes his car to a garage and tells the mechanic that a spark plug is fouled, causing the motor to miss fire. The spark plug possibly needs only to be cleaned, but the garage man sees a chance to sell a whole set of spark plugs, counting on the ignorance of the car owner.

This may be considered good business by some people, but it really isn't. The business that follows practices of this sort is not going to thrive.

Some Radio servicemen, seeing a chance for present profit, tell a set owner that he needs all new tubes, when he knows that one new tube will do the trick—or the trouble may even be elsewhere, just a minor adjustment may be needed. Is this good business? Not at all. The chances are 90 to 1 that the set owner is going to find out he has been tricked and he isn't going to keep the fact to himself. One job of this kind and a serviceman will get more adverse advertising than the favorable advertising from several jobs well done. As they say, bad news travels faster than good news.

It is never wise to trade on the ignorance of a set owner. People often know more than we give them credit for. But no matter how little or how much you think a man knows, treat him as you would want him to treat you if the situation was reversed, and you were the customer, he the Radio-Trician.

In cases where only a minor adjustment is needed, or where a man requests a bit of information that you can give him, don't make the mistake of withholding information unless it is really so technical that he himself admits he can't understand it. You may lose a job or two by making it possible for a man to handle it himself, but you will have made a friend, and when he does need expert help he will come to you.



COURTESY HINDE & DAUCH PAPER COMPANY

Typical packing for midget receivers.

Build for the future always. And remember that fair dealing will make friends for you and your business, that a reputation for fair dealing is worth thousands of dollars to the Radio-Trician who has built his business along the lines of "fair play to all."

DEPENDABILITY is really a matter of playing fair with your customers in the matter of promises. If you promise to call at a home to examine a set at seven o'clock Monday evening, be there at seven o'clock Monday evening. If you say that you will have a set ready for use at a certain time, have it ready by that time.

In the matter of making appointments, remember that your customer is the one to be pleased. Let him set the time and the date as far as possible. Line up your work so everything can be ready at the time promised.

The best way to manage is to have a small note-book in which you can keep a record of appointments, jobs on hand, and the date on which each job is to be completed. Be methodical in this, and you'll never find that you are expected to be in two places at one time—you'll never disappoint a customer.

If you have a great deal of work on hand, don't take another job and trust to luck that you'll be able to get at it some time or other. Unless you can be sure about completing a job for a certain date, don't promise it for that date. You may lose a job or two by sticking to your schedule, but you will be building up a reputation for dependability, worth much more than one or two lost jobs.

COURTESY is nothing more than common politeness, which should be genuine and habitual. You might say that this is a very trivial matter, that of course you are never impolite and that you don't see why it should be in this book. But courtesy is a peculiar thing. Many people think they are perfectly courteous, they intend to be, and yet the effect they have on others is just the opposite.

Therefore, watch your *manner*, not only your *manners*. Look at yourself as if you were another person. Are you inclined to be abrupt, hasty, thoughtless? Often when you are out on a job, the set owner or his family may watch you and ask questions. They may bother you. You may think some of their questions foolish. But don't show it for a moment. If some one suggests that you do something a certain way which you know is not the proper way, be tactful. Explain why your method is better, prove it if possible, but never be curt, never argue or give the impression that only you know and everybody else is wrong.

Of course, there is such a thing as overdoing politeness. Courtesy must be natural, never forced or carried to extremes. Everything you say and do should be in good taste—and your politeness should never be conspicuous.

A man who is quietly courteous, friendly and tolerant, makes personal friends rapidly. Customers who are friends introduce *their* friends, and it is in this way that a well-founded business grows.

NEATNESS is another of those things we take for granted. But here again we should attempt to see ourselves as others see us. Looking down, our shoes may appear dusty, but not too dusty. We walk into a customer's home, and the first thing that strikes his eye is our dirty shoes. We go into the room where the Radio set is; we turn the control dials. Does the set owner and his family see how expertly we handle the dials? No; they notice that our hands have not been washed very recently, that our finger nails need attention, that our shirt cuff is dirty.

Most people put a great deal of faith in appearances. They judge a man, first of all, by his appearance. Consequently, the Radio-Trician must pay attention to the way he looks. This does not mean that clothing must be expensive and new. Clothing may be well worn, even mended, and still be neat.

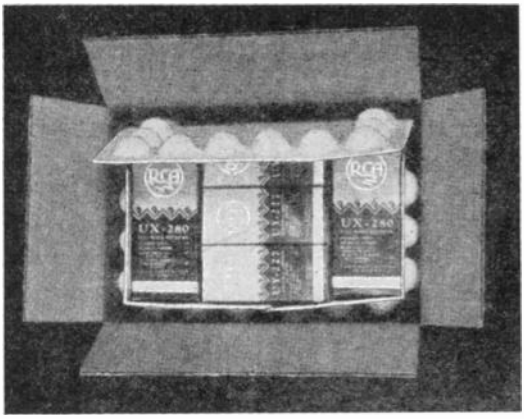


Illustration showing a complete kit of tubes previously tested to go with a given receiver.

These personal things impress a customer without his realizing it. In our modern world they are rather taken for granted, but lack of neatness is noticed immediately and gives an unfavorable impression.

Then there is a neatness in working methods. Tools and parts should not be scattered about on floors and chairs when working away from the shop. Your work should always be characterized by neatness. Confine your work to as small a space as possible. Keep parts and tools arranged in order. The same applies to the tool kit. Things should not be just thrown together so that it is necessary to empty everything out just to find a certain piece of wire, or a certain tool. There is nothing that creates a worse impression than taking time to look for misplaced tools or parts, or finding that a very much needed tool was carelessly left at home or in the shop.

Installing and Servicing Radios

PREPARING A RECEIVER FOR INSTALLATION

The installation of a receiver in a customer's home is a job which some servicemen think too unimportant to make a study of. Of course, these men are wrong. They get a set from the factory, unpack it, cart it to the customer's home, set it up and forget about it. Then they are surprised when they are called back because the receiver is not functioning properly and surprised when finally the customer is thoroughly disgusted with the set, even though it may be of a very good make.

It must be borne in mind always that when a man buys a radio set he isn't interested primarily in it as a piece of furniture —he doesn't buy it so he can have a beautiful piece of mechanism to look at; he buys it for his *entertainment, pleasure, amusement* and *education.*

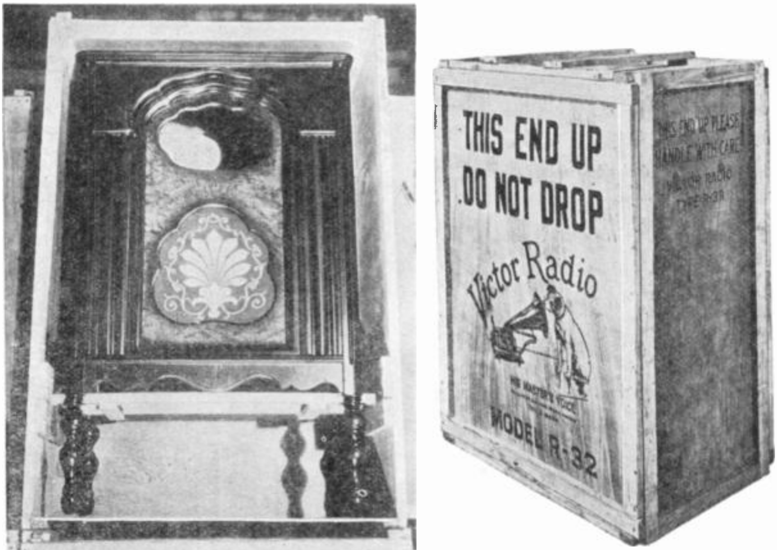
For this reason, a set should be thoroughly tested before it is placed in a customer's home. A Radio-Trician must be well acquainted with the characteristics of a particular set (all sets, even of the same make, have their individual peculiarities). Then when the set is properly installed, it will work well immediately and the customer will get a good *first* impression of his purchase, which means a great deal, for first impressions are lasting impressions.

Care should be exercised in handling a receiver at all times, even before it reaches your shop. If you don't go to the freight station for it yourself, be sure that the person or company that handles your drayage is careful and responsible. Radio sets, no matter how well packed, should not be jarred excessively or allowed to drop.

After all shipments are unpacked, carefully examine all wrappings before they are thrown away to make sure that no small part has been overlooked. Most shipments have packing slips with them, listing all the separate items. Parts received should be checked against this slip. The time to make a claim for missing articles is right after parts have been received and unpacked. Likewise, any claim for damaged goods should be reported immediately to the company making the delivery. If any damage is noticed while unpacking, stop unpacking. Ask the transportation company to send its claim agent to inspect the shipment. In his presence complete the unpacking so your claims for damage will be approved.

HOW RECEIVERS AND ACCESSORIES ARE PACKED. Servicemen should be familiar with the usual methods of packing receivers, consoles and tubes for shipment. Packing is important to the manufacturer and distributor if the equipment is to reach the dealer intact.

Universal, midget and small receivers are usually packed in corrugated paper boxes. Generally the correct tubes are inserted into the sockets, surrounded by tissue paper or soft packing



COURTESY ATLAS PLYWOOD CORP., BOSTON, MASS.

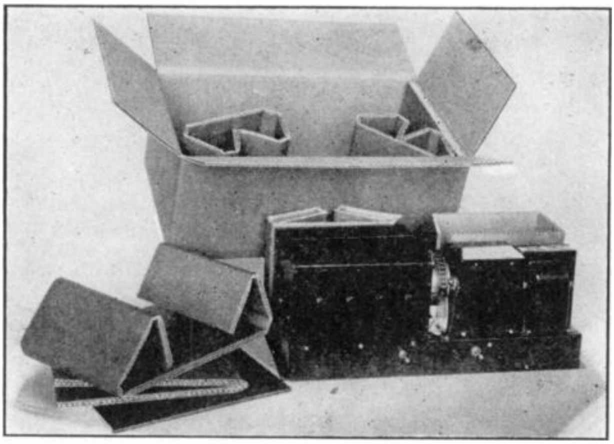
Plywood box used by manufacturers to ship large consoles and cabinets. Note the lower console supports keep the cabinet off its legs. Excelsior pads (straw or wood fiber wrapped in paper) keep the cabinet away from the inside of the box.

material which will not create a fibrous dust. If the tubes are surrounded by a shield, they are protected from the shield by crumpled tissue paper. The receiver is then wrapped in manilla or wax-treated paper, kept in place with gummed tape. The paper carton is much larger than the receiver so that the machine may be separated from the outside carton by special corrugated pads. Thus the machine is protected from surface damage should sharp objects pierce the outside of the carton. The use of pads, cushions the machine in transit, preventing transmission of shocks to the receiver.

The chassis—that is, the main structure consisting of the R.F. amplifier, detector, audio amplifier, power pack and the speaker—either as a single unit or as several units may be packed for transportation in a corrugated carton properly cushioned. The tubes may or may not be in the chassis sockets. In such cases the console, if one is a part of the shipment, will be forwarded in a plywood box.

Most manufacturers carefully anchor the chassis and speaker into the console and send the entire receiver as a single package. In the latter case the tubes are often shipped separately,* if they are included as part of the receiver.

Considerable care should be exercised in removing consoles



COURTESY HINDE & DAUCH PAPER COMPANY

How chassis are shipped in corrugated paper cartons.

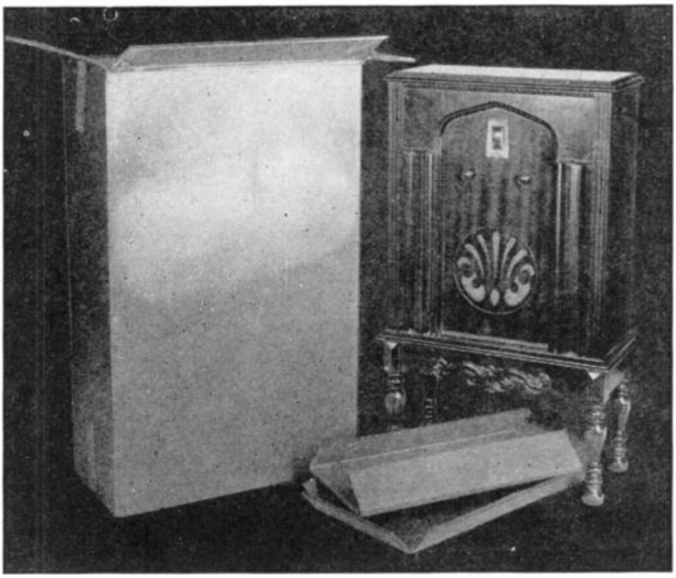
from the shipping box. Most consoles are wrapped in paper before being put in the wooden packing boxes and firmly held in place by sturdy cross pieces in the boxes. Inspection of the packing boxes will show which side was put on last. Remove this side. If it is screwed on, take out all the screws carefully; if nailed on, see that every nail is withdrawn so that the side can be lifted off—not pulled off.

If the side is nailed on, nails should be pulled out with a regular nail puller. If one is not available, pry loose one corner so as to withdraw some of the nails slightly and expose their

* With the advent of the dome type tube, where the elements are supported by a mica ring in the dome, it has been found safe to ship all tubes in the chassis, in or out of the cabinet.

heads. Then draw these nails with a claw hammer. Never leave nails in the side or bend them over. Remove them completely. Then pry some more nails loose and continue until the whole side can be lifted off.

It is common practice to screw the back of the cabinet to the back of the packing case. Remove these screws and the screws that anchor the cross pieces to the sides. Do not remove the screws which hold the cabinet to the cross supports. Now the cabinet can be lifted or slid out of the packing box easily. Never



COURTESY HINDE & DAUCH PAPER COMPANY

How small consoles are packed in corrugated paper cartons.

"yank" or force a set out of its packing box. Remove all cross pieces or wooden supports necessary for packing.

The next step is to remove the paper wrapping. It should be cut, preferably with a blunt pair of scissors, so that it can be lifted off. It should never be pulled or torn off, because the edges may be sharp and will be very likely to scratch the finish of the cabinet unless taken off very carefully.

Always be very careful of the finish. Moving a large console is a two-man job, and even then care must be exercised that buttons or buckles do not come in contact with the finish—even slight scratches will mar the surface so that it does not look like new. Don't push consoles around unless they have special gliders.

Corrugated paper cartons are easier to open. After the receiver is inserted in the carton, surrounded by the packing material, the four flaps of the open side are closed down. Usually two short flaps are turned down first and then the final two which then cover the entire side. Gummed paper strips are then used to seal all exposed edges, the one across the center to the sides of the carton being the most vital seal. In opening a corrugated carton, a blunt end knife is used to break the seal, and if the flaps have not been cemented with water glass or glue, the side opens up. Where cement is used, the flaps will have to be torn apart.

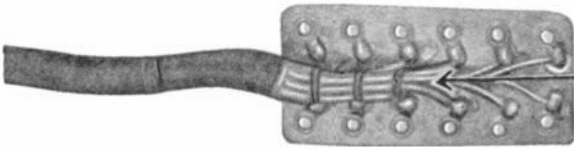
The removed machine should be freed of all shipping accessories, as they are not needed in the installed machine. Especial attention should be given to the wedges or bolts which may be used to anchor the chassis to the console. Some set makers design their chassis to float on rubber in the console, but in shipment lock the chassis to console. Be sure that in such cases the chassis is freed.

When a set of tubes comes with the receiver and they are not inserted into the sockets, they will be shipped in a corrugated paper carton and as a set of tested tubes. Large dealers may buy tubes in quantity and in the original factory packages. They usually come in cartons of 25 or 50, each tube in its own paper carton and the lot packed in a corrugated paper carton padded with a special fiber pad having numerous cup-shaped projections.

VISUAL INSPECTION, SHOP TESTS AND ASSEMBLY. When all the separate parts have been unpacked and checked against your order and the packing slip, give them a thorough physical examination. Go over the connections, look for loose screws and bolts, if the chassis is open inspect the wiring for broken wires, see that wires are not shorted, be sure that control grid wires with the top connector are intact, parts like the transformers, variable or fixed condensers are solidly attached and see that all controls turn easily and are not out of place. When a loose part is found when unpacking, the examination should be quite rigid. Minor defects should be corrected in the manner suggested by the kind of damage. Major defects due to transportation should be called immediately to the attention of the transportation company and, if possible, before the machine is totally unpacked. In this way a claim for damages is convincing.

Receivers should be bench tested before placed on display, on demonstration or delivered to the home. Rigid tests insure perfect performance and save you a lot of future embarrassment and comebacks. Receivers delivered to you in cabinets should be tested as is, but, if the chassis comes separate, test the chassis and speaker as a working unit before installing in the cabinet. In case of an internal defect you will save the trouble of removing the chassis from the console.

In most A.C. and D.C. power socket operated chassis the R.F., detector, A.F. and power pack system are a single unit. An approved flexible cord with a socket cap permits connection to the power supply. The loudspeaker if excited by the power pack will have a four or five wire cord connection to the chassis by means of what appears to be a modified socket and tube base with prongs. The actual plug-in system may vary, although occasionally you will find the speaker-chassis connection a permanent one. Magnetic type or permanent magnet moving coil



Type of terminal strips used to connect RF-detector chassis to power pack A.F. chassis when built separately. Bolt and nut system usually found on power pack chassis.

speakers require no power connection, and usually the two leads of the speaker are inserted into binding post, pin jack, or spring type connectors provided for on the chassis.

In a few cases the chassis may come in three units—the R.F. and detector as one unit, the audio system and power pack as the second unit, and the speaker. Usually the speaker will connect to the power pack unit in the manner just described. The power pack and audio unit will connect to the R.F.-detector unit through a multi-wire cable. The latter is necessary to supply operating voltages and to connect the audio signal circuits. The cable from the R.F. system may terminate in a multi-prong plug which fits into a multi-prong receptacle located in the power unit. They are usually constructed so they may be connected in only one way. In some cases the cable leads terminate in spade type lugs, which are bolted to screw type posts located on a terminal board on the power pack. The cable leads are either color coded or tagged so that they may be properly connected to the screw terminals. You may find the instructions as to the proper connections in the shipment or in the service booklet.

With battery operated receivers the required A, B and C batteries or the B and C battery converters will come from stock or as part of the shipment, and must be connected to the chassis by means of the multi-lead cable which is always coded.

The socket powered receiver should then be connected to the power supply, after the line voltage adjustment on the power pack unit is set to the line voltage at the shop. Most receivers are shipped to operate at 115 volts, plus or minus 5 volts. In many cases a switch allows the receiver to operate at HIGH or LOW voltages. When the line voltage tends to be above 115 it is turned to the HIGH position, and when the voltage runs below 110 volts it is set in the LOW position.

Receivers may have a small cartridge fuse with one swivel contact so that it can be set in any of two or three positions, or two or three parallel fuse receptacles may be used. These positions are usually marked 100, 110 and 120 volts. Always place the fuse in the position corresponding to the normal line voltage. In case of doubt, always use the high voltage position so that, if a high line voltage appears, the parts will not be unduly strained.

A number of receivers use what is known as a line ballast—a resistance, placed in series with the primary of the power transformer, which automatically stabilizes the secondary voltages. The net primary voltage is about 85 volts, even though the line voltage varies between 90 to 135 volts. A few battery receivers use one or more filament current ballasts to prevent excessive voltage which destroys the fragile filaments of the 2 volt tubes. In one case, the two ballasts were built into a single tube structure. The ballast must be inserted into its socket before connecting the receiver to the power supply. The power line used on the test bench should be protected with 3 or 5 ampere fuses.

The sockets in most receivers are embossed with the number corresponding to the type of tube needed for that position. Only tested tubes should be used. Tubes inserted in the receiver should have been tested in a counter or bench tube tester for shorted elements, open filament and transconductance. Where the chassis are already in the consoles, it may be difficult to read these markings, in which case the tube layout given in the service manual or the special sticker attached to the cabinet may be used as a guide. After connecting the aerial and ground to the receiver, the power is turned on and a broadcast is tuned in.

Assuming that the set sounds normal, the next step is to align the tubes for best positions. To do this it is best to connect a modulated R.F. service oscillator to the input and an output meter to the voice coil of the speaker or to the plate-chassis of one of the output tubes. Adjust the signal generator so the output meter reads mid-scale or in case of A.V.C. sets, to below the threshold sensitivity. Now you should interchange similar tubes (except the A.V.C. tube) until the maximum output reading is obtained. Push-pull tubes may be checked to see that each draws similar plate current (use a plate break-in adapter). An A.V.C. tube, not used as a detector, is checked by inserting it after the receiver has been tuned to a weak signal. If the output is not decreased under these conditions and there is a well defined threshold control, the tube is satisfactory. This alignment or "pep up" process is considered in detail elsewhere in the course.

The signal generator should be disconnected, local and distant stations tuned in to give you a general idea about the sensitivity and selectivity of the receiver. Unless you have a standard signal generator (they are not required by the average serviceman), these tests must be based on experience, and the perform-

Type of plug attached to speaker cable which usually has 4 or 5 prongs. They plug into a 4 or 5 prong socket situated on the chassis.

ance of similar machines, in the shop locality under the conditions peculiar to the season when the test is made.

You should check the action of the volume control, especially its ability to cut down local stations. If the set has A.V.C., tune through several stations at normal volume and be reasonably sure that the locals and powerful nearby stations do not blast in. Where inter-carrier noise suppression is a feature of the receiver, be sure that it works or at least adjust this feature (if such an adjustment is provided for) to what experience will teach you to be the correct cut-off sensitivity. (Should also be set in the customer's home.) Be sure that the tuning indicator works, by actual tuning in with it one or more stations.

Once you realize that the ultimate customer really uses the frequency calibration on the selector dial, you will never fail to check its correctness. A reliable receiver will not be far off, although in shipment the dial may have slipped. All-wave receivers must be able to receive on all bands—check each band for at least one station reception. Receivers with a police band change-over switch should be checked. Tone controls should work, they may not appeal to you, nevertheless they should dull the tone and reduce background hiss. Where a receiver is advertised to have special features, make sure that these features exist and work according to your understanding. Above all see that the control knobs and switches work easily and smoothly. The consumer is quick to notice and dislike mechanical stiffness of controls.

Tone or the fidelity of the receiver can only be checked when the speaker is properly baffled. Unless the make of receiver seems to be a regular "bad actor" this test may be left until the chassis is in the console. Otherwise a bench baffle may be used. A shelf to hold the speaker will be needed. Where smaller speakers are used, a small baffle board with the correct size opening may be used to cover up the larger hole. In testing for fidelity, listen for hum, especially modulation hum (hum heard when the broadcast is tuned in.) The importance of the baffle shows up when testing for hum. The baffle brings out the low notes and consequently the hum. If the baffle is omitted when testing no or little hum will be heard, and when the speaker is placed in the receiver cabinet, the hum will again be prominent.

By this time you are about to complain that testing a receiver prior to installation or acceptance is too long and perhaps too costly. Although it appears to be involved, actually the procedure develops into a routine which takes much less time than you might expect because reliable makes of receivers are delivered in good order. Of course, it is essential to have the facilities and space for this inspection. The more careful your tests are, the less trouble you will have with demonstrations and future complaints. You are assured of a satisfied customer and a booster for your organization.

In absolute fairness we should mention that low priced receivers, midgets and vest pocket receivers cannot be so critically examined. Nevertheless, actual pickups from broadcast stations should be included as a regular routine. You should be fair with regard to defects. Minor defects as misalignment of I.F. stages, failure of the preselector to track with oscillator, broken connections, slipping of the selector dial, break-down of a resistor or condenser should be taken care of at once, returning the defective part to the distributor for replacement. Major defects, like excessive hum, intermittent noise, broken down filter condensers and transformers or similar defects, should be reported to the distributor or manufacturer, if you deal directly with him, for instructions. He may send you the replacement part or request the return of the chassis, sending you a new one. Get permission before you return a receiver, for any reason—that is the way radio business is carried on. Of course, if a given make gives you continued trouble, and you feel that it does your prestige harm or cuts into your profit, stop handling that make or troublesome model, but don't expect 100 per cent perfection—you can't get it.

After the chassis and speaker have been thoroughly tested and found to operate satisfactorily, they should be installed in the cabinet and operation rechecked to observe if any defect has arisen in the assembly. The cabinet is then cleaned and polished to remove marks of unpacking, such as fingerprints, dirt and grease which will accumulate during the process of handling. Dents and scratches should be filled in by the usual process of burning in stick shellac and rubbing down smooth with sand-paper and powdered pumice.

A soft, clean polishing cloth should be available so that finger marks and dust may be removed. There is one secret in making a neat job. Keep the polishing cloth clean. It should frequently be washed out with soap and water, rinsed in clear water, and allowed to dry so that it is always ready for use.

When polishing or rubbing down a surface, make the stroke along the full length of the grain of the wood. Do not rub in circles. After the set has been cleaned from dust and dirt, then a small amount of polishing fluid or wax may be used so as to obtain a high gloss. There are many good preparations and, as these are sold under various names throughout the country, it is not possible to recommend any particular brand because you may not be able to get the kind which would be specified. If you have any doubt as to what brand you should use, then it is well to obtain this information from a first class furniture store in your locality.

Apply the polish to a small section at a time and rub it down to a gloss until all traces of a smeary appearance are removed. The finished surface should be perfectly free of loose wax or liquid.

INSTALLING RECEIVERS IN THE HOME

The customer purchases a definite make and model of receiver because he wants one like the one he heard in someone's home; or because its appearance and performance at the dealer's store appealed to him; or it is recommended to him by a friend, the dealer or advertising. If he is a cautious buyer he will accept a receiver provided it works satisfactorily in his home. Although some radio merchandisers will install a receiver in the home on demonstration, the present tendency of the experienced dealer is to insist on an initial store demonstration. In the latter case the customer has a chance to compare models and makes and reduce his choice to a single receiver.

At the store the demonstration usually can be made under ideal conditions, with perhaps the exception of distance and noise features. By carefully arranging the surroundings, using heavy rugs on the floor and drapes on the walls, the sound from the receivers will be at its best. Where noise is prevalent, shielded antennas and the filtering of the noise producers will help to make the demonstration acceptable. The chances are that an over-zealous merchandiser will try to make the demonstration too good. It may be a matter of opinion, but no store demonstration should be so superior that it cannot be duplicated in the home. The customer expects regular performance to be as good as the demonstration.

The pickup system used at the store should be similar to the one you usually install in a home. At the service bench only regulation pickup systems should be used. It goes without saying that if you sell to a D.C. neighborhood, you should have a D.C. power source.

TRANSPORTATION OF THE SET. After a receiving set has been contracted for, and the time set for delivery arrives, a tested set should be sent to the new owner's location, carefully wrapped in quilted material, formed to fit the console or cabinet and like the covers used by furniture packers and movers. The greatest care should be taken to prevent any scratches, scars, or other unsightly marks.

Everything should be in readiness for a complete installation in the shortest possible time. It is proverbial that when a customer wants a machine he wants it "yesterday," and no time should be lost in giving him complete and satisfactory service at the specified time. In most cases, the machine as it stands on the demonstration floor may be covered at once and delivered immediately to the customer's home. A suitable, well-planned aerial and ground should be ready to connect to the proper binding posts. The line voltage should be measured with a meter and the "high" or "low" line switch thrown to the proper position. depending upon the reading.

Remember, that an installation of a good, well balanced receiver is only as good as the aerial-ground system. Admitting that many modern receivers appear to give good reception with a wire thrown out of the window as an aerial, or with a power socket antenna eliminator, experience has proved that such makeshifts are a source of endless trouble. Many successful merchandisers insist on a new antenna for a new receiver. Even when the customer says that the aerial is of recent erection, the dealer has the customer to agree that a new one should be erected if in the opinion of the servicemen it is not up to their standards.

A regulation antenna having between 50 to 75 feet of aerial wire clear from surrounding objects is usual. For small homes,

COURTESY FULTON BAG & COTTON CO., N. H.

Covering pad for protecting console to be delivered to the customer's home.

cottages, bungalows and small multi-apartment dwellings the usual rubber covered lead-in wire will suffice. In large apartments, where the straight-away portion of the antenna must be placed at some distance from the receiver, or where man-made static is prevalent, the noiseless antenna should be insisted on. All-wave receivers work best with a transposed line lead-in system which should be suggested. Be guided by generally accepted practice, tempered with such experience as you gain in your service work. Avoid so called "temporary" aerials or aerial eliminators, even for demonstrations, as if they were poison, for the first impressions are the ones that last. Such makeshifts do not insure best results. The experienced merchandiser has the prospect who insists on a successful home demonstration prior to signing the purchase contract, agree that an aerial be erected to his standards. In case the receiver is not purchased, the aerial system must be paid for. Such a procedure has the desirable effect of keeping away undesirable prospects.

The time to erect the new aerial system is a debatable matter (there are no hard and fast rules for successful radio selling). Where you are the dealer, serviceman and salesman, the natural thing to do is bring to the home at the agreed time everything necessary to complete the installation; the receiver, the parts for an aerial, printed instructions, tools and service equipment. The job is completed with a single visit.

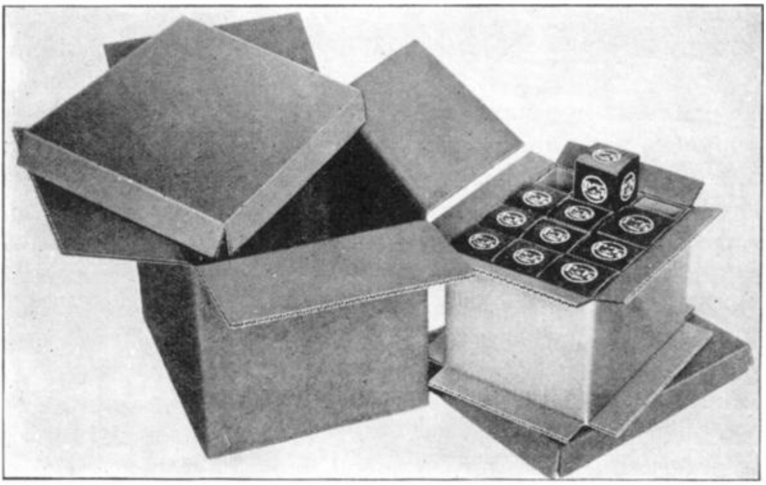
In large organizations where the salesman is the one to give the demonstration or to get the contract finally signed, or in a one man organization where the agreed time for the demonstration is at night, the antenna system should be erected during the day before the receiver is demonstrated. Where the installation and demonstration are not made at the same time, the final connections of the receiver to the pickup system and power socket should be omitted at the installation.

When the aerial and ground is installed, be sure that some one who will decide with you authoritatively as to the position of the receiver will be present. The opinion of the customer and the serviceman may not be alike and you must be able to explain to a responsible person why your position of the receiver is the most desirable. If you are not the one to demonstrate the set or if you plan to return later for this purpose, merely connect the set for a few moments for check, explaining to the customer if he questions the fact that you have disconnected the set that that is your policy or the policy of your company to explain the operation of the receiver at the demonstration. If you do not wish the customer to play the set while you are not there, you can remove the rectifier, the ballast tube or the line fuse.

THE DEMONSTRATION should be carefully planned as it is a part of the selling program. The installation has been made in a ship-shape manner, so nothing can detract from the receiver performance.

You are now ready to give an explanation of the set. Use simple words and language which the average person will understand. Do not try to explain the operation by technical radio terms unless you know that the owner is absolutely familiar with the explanations that you are giving. Very few people know the difference between a transformer and condenser. Therefore, it is useless to employ technical terms unless you know they are understood.

The first thing you should point out is the location of the "Off-On" switch. Explain briefly that the tubes must warm up. Then show the location of the tuning control, mentioning that the purpose of the knob is to allow you to select the stations desired. Explain the meaning of the numbers on the dial. If the set is marked in kilocycles, then show how he may select a particular station by referring to a newspaper or call book which lists the frequencies of all stations. Next show the location of the volume control, explaining that turning the knob will regulate the loud-



COURTESY HINDE & DAUCH PAPER COMPANY

Standard package of tubes, as shipped by the tube manufacturer.

ness of the sound. Explain the tone control if the machine has one. If the set is an all-wave type, explain the use of the range change-over control. Point out the A.V.C. noise suppression or other unique features of the receiver by an actual demonstration. Clearly explain the remote control features if incorporated in the receiver and be sure to explain any peculiarity or limitation of the system.

Tell the owner just why you are doing all this and be sure that you do not overrate the set. It is best to have the owner expect less, and let him find out for himself that the set will do more than expected. He is sure to be more satisfied than if you lead him to expect performance he will not get.

Tell the owner that the best reception can only be expected from nearby or local stations. Distant stations are subject to fading and A.V.C. if a feature of the receiver, only partially corrects this evil. All-wave receivers and short wave reception have their peculiarities. Any other peculiarities should be pointed out before you leave; otherwise you are likely to be called in to fix something that cannot be fixed. This will save you trouble and unnecessary service calls. Matters regarding hum, static, code interference, and heterodyne interference between stations should be fully covered.

You should be familiar with the programs which are on the air at the time. A little study of your local newspaper beforehand will tell you what programs may be expected. If selling is an important part of your business, it should be a duty to study each day the best program to be used in demonstration. The program which you choose should be in accordance with the liking of your customer.

Turn the tuning control, or selector, to the station desired. Use a moderate volume. Loud music or talking is extremely displeasing to most people. Besides, you will want to have a reserve of volume later when you wish to demonstrate this particular feature of the set.

After having tuned in a station with a good program, then leave the controls alone and allow your customer to listen to the set's performance. *Do not change from one program to another*, because this does not allow the customer to become accustomed to the tone quality of the receiver. During this time, ask the prospect a direct question concerning the operation of the set. Put your question so that he will more than likely have to answer "Yes." Your statement may be directed as follows: "I think that the tone of this set is beautiful—don't you?" The prospect will more than likely answer "Yes" to your question. On the other hand, if he has any complaint, then he will be sure to tell you about it. Listen to him carefully and then be sure to make any necessary adjustments at once. Should the prospect be misinformed and expect more than is reasonable, then give a satisfactory explanation so that a full understanding will be had between you and the prospect.

Give the prospect a chance to operate the set by himself. Allow him to make adjustments with the various controls, pointing out to him that the tuning dial should be rotated slowly. This will allow the station to be tuned in at its maximum volume and clarity and at the same time avoid completely passing over some distant station. The tendency for people not experienced with a modern set is to rotate the dials entirely too fast.

Watch his movements carefully, then, after a sufficient length of time, explain how he may improve on the way he operates the set. Do not make blunt statements telling him that he is wrong. Make your explanation, as, "I believe you'll tune it in clearer if you'll do it like this," following it with the necessary information. Under all circumstances be courteous and helpful and do not forget that the simplest type of explanation should be used, without going into any great technical details.

A demonstration in the store need not include all the above details. There will be no need to teach the customer how to handle the controls. Here the demonstration may be limited to simple procedures which point out the sales features of the product and superiority over low priced machines.

FINISHING THE JOB. If you are the demonstrating salesman then the finishing of the job will be the winding up of your sales talk and preferably the final act of having the customer sign the sales contract. Should the prospect insist upon having a little more time to try out the receiver, be sure he is satisfied before you leave. It is well to have a definite understanding that the installation has been made to the liking of the prospect.

The serviceman should, before he leaves, make a final inspection of everything to make sure that he has left the place clean and orderly. Papers, dirt and dust resulting from his work should be disposed of properly, and a final touch with the cleaning and polishing cloth will allow him to leave the prospect with an impression that he has completed a first-class job.

After making a sale, don't dismiss it. Call back on the customer in two to four weeks at least, to see that satisfaction has been rendered.

PREPARING FOR AND HANDLING SERVICE CALLS

Radio receivers become defective, lose their original ability to satisfy. Even when the *components* don't break down, the tubes lose their original pep. Stages, through constant attack by changing room temperature and humidity, get out of alignment. Servicing as a profession is here to stay as long as radio broadcasting, both visual and sound, continues to please, amuse and educate the listening public. As a future serviceman it is your duty to prepare yourself to handle servicing in a businesslike manner.

Receivers may break down during the usual ninety day guarantee period. In spite of the fact that it is a compulsory, free service call, you should give such calls the very best of attention. You will want to retain the set owner as a future service customer and set buyer. Not only will he continue to use your services, but he may influence his friends to buy your receivers and use your repair service.

Here, we will not go into the problem of getting new service clients, but assume that you have a following and desire to serve them to the best of your ability. With every service call give 100 per cent satisfaction. Give more than you contracted for if it does not involve too much expense. If an estimate on a repair job turns out to be too low, do not put in poor material or turn out a hurried job so as to make a profit. Take your loss and from your records and experience learn how to give a better estimate next time.

Service calls will come in by phone, personal visit and occasionally through the mail. The customer knows little about the mechanism of radio and usually does not like to answer a string of questions. If the call is your first contact with the customer you must get the *name*, *address* and, if possible, the *phone number*. The latter may be omitted if you care to look up the listing in the phone book. Next in importance is the *make* and *model* of the receiver. More than likely the *model* will be unknown so the year it was purchased new may give some information, especially if you watch the yearly trend in designs. Of course, if it is an old customer, you need ask no questions provided you keep a card file with a record of information similar to the one on page 23.

Further than this, about all you reasonably can ask a customer is "What seems to be the trouble?" In their own peculiar way, they will tell you that the set is dead, has poor selectivity, has poor sensitivity, distorts, fades, is noisy, cuts off irregularly or regularly, hums, squeals, lost its power—or a blunt statement that it does not work like it formerly did. The customer may volunteer other information, that the set emitted smoke, has a peculiar odor, went dead suddenly, was gradually getting defective. Be sure you get the complaint or be assured that someone will be at home to tell you what may be wrong, simply because you must at least correct the defect which is uppermost in the customer's mind.

If you are fortunate enough to get the make and model of the receiver you can immediately refer to a service circuit diagram, a tube list, a service manual or to a file on troubles peculiar to certain receiver models. If you have carefully noted the complaint you have something tangible to start on. Obviously the problem is greatly simplified if you are servicing a machine with which you have had previous experience. The first time you service an instrument be sure to make a record of all information which will help you in future service calls.

TECHNICAL INFORMATION SERVICES. Expert servicemen can repair defects in all conventional type receivers without the aid of a circuit diagram or service manual of the receiver under repair. This ability comes from a thorough knowledge of the fundamentals of radio, constant reading of articles describ-

NAME ________ DATE ________

ADDRESS ________ PHONE ________

SET MAKER ________ YEAR ________ MODEL NO. ________

SET: AC: DC: BATTERY: AUTO: ELIMINATOR ________ : BATTERIES USED ________

TUBES ________

(ORDER—BACK ROW FIRST, LEFT TO RIGHT—CONTROL KNOBS AND UPPER CHASSIS FACING YOU)

TYPE OF PICKUP SYSTEM ________

________ DATE INSTALLED ________

CHARGES FOR SERVICES AND SALES

JOB NO.	DATE	COMPLAINT	NATURE OF REPAIR OR CHANGE	AMT. CHARGE	DATE PAID	AMT. PAID

M18 PRINTED IN U.S.A.

When customer gets a new receiver make out a new card. File the 4 x 6 inch file card according to last name. These cards may be obtained from your local printer, who will use this form as a guide.

ing new receivers and new circuit innovations and experience obtained from servicing all kinds of machines. Nevertheless, the work is greatly simplified if a circuit diagram is available, especially one where in addition to the symbolic connection of the components: the resistance, capacity and inductive values of the parts are noted on the diagram; and tubes used, normal operating voltages and special adjustments are clearly shown.

Typical service sheets are given with your fundamental course. The Institute maintains a file of circuit diagrams for practically all receivers and will gladly send you a photostat of any one for twenty-five cents, the cost of the photostat. If the photostat is returned there will be no charge. By far the best plan is to collect and file them and from every conceivable source; periodicals, N.R.I. service sheets and service manuals. There are concerns * which can supply you with diagrams of all receivers made and if you subscribe to one of these services, your initial work in collecting information is simplified. The initial outlay for such service manuals may seem a little high, yet where your field or work indicates the possibility of getting a wide variety of machines, it is well worth while.

You will note from experience that a given make and model of receiver continually develops the same troubles, traceable from definite effects; squeals, noise, loss of sensitivity, etc.† It is a good plan to record such experiences on a 3 x 5 inch card and file them according to maker and model number. You will find that such periodicals as *Radio-Craft*, *Radio Today* and *Radio Retailing* make a practice of publishing information on troubles and remedies peculiar to definite receivers. If such information is helpful to you, collect it. Here are two samples:

Atwater Kent—Model L   Oscillations

The positions of the connecting wires in this receiver are quite critical. Oftentimes oscillations will be caused when the local-distance switch is in the local position, due to coupling between the red wire from the switch and the R.F. coils. Merely move the wire away from the vicinity of the coil openings.

* * *

Clarion—Model 320   Intermittent Operation

Examine first I.F. coil for poor connections at point where coil windings connect to the flexible leads. Check 8,000 ohm first detector-oscillator cathode bias resistor for intermittent operation.

---

* Rider's Perpetual Trouble Shooters Manuals and Gernsback's Official Radio Service Manuals covering broadcast and automobile receivers are the accepted standards for reference purpose. Supplements keep the manuals up-to-date.

† With lesson 14 of the fundamental course you received a reference book on the general ills and troubles of receivers. Refer to this book until you are familiar with its contents.

These two types of information, (1) circuit diagrams showing the part values as well as operating information, and (2), a collection of typical troubles and remedies peculiar to definite receivers, are just as much a part of the service man's equipment as his oscillator or soldering iron.

EQUIPMENT AND TOOLS. As you probably already realize, knowledge is paramount and tools and equipment are merely an aid to carrying out the analytic functions of your service experience. Elaborate equipment is not necessary. Simple, neat, efficient tools, properly handled, will answer practically all needs.

A modulated oscillator or service signal generator and a multimeter are the two items that you cannot do without if you plan to service receivers in any quantity. The service signal generator should be preferably battery operated so it can be used on any receiver in any location. Power line operated oscillators are likely to feed the signal back into the receiver through the mutual power line, making it impossible to control the oscillator output. Oscillators which do not have this fault may be used. The oscillator should cover, at least, the range of 115 kc. to 18 megacycles. The less use made of harmonics to cover this range the more desirable the oscillator. An oscillator with A.F. tube modulation is preferable to one using grid leak-condenser modulation. Its output level must be controllable and its frequency fairly stable. For precision work a switch to make the oscillations unmodulated will be found a valuable added feature. A long shielded cable preferably with shielded probe handles will be needed. If one is not provided, it can be easily made. Universal clips, lugs and prong contacts easily affixed to the probe handles will be needed.

The multimeter should contain: an ohmmeter having at least a range of 0 to 1,500,000 ohms; a D.C. and A.C. voltmeter with a maximum range of 0 to 600 volts and at least two lower ranges; and a 0 to 150 D.C. milliampere meter also divided into three ranges. An A.C. milliammeter is not essential but worth having. The A.C. voltmeter may be used as an output meter merely by using a series 1.0 mfd. paper condenser. Often it is incorporated into the multimeter. Red and black probe leads are absolutely necessary.

A system of extending socket connections where voltages between any two electrodes and current to any electrode may be measured is quite valuable. Such systems are referred to as socket analyzers, free point set tester adapters and are an arrangement of 4, 5, 6, 7 and 8 prong socket plugs feeding 4, 5, 6, 7 and 8 prong sockets in the adapter and a means of connecting a multimeter into the system. Such an adapter together with a multimeter is often referred to as a set analyzer.

Tubes may be checked with the equipment just referred to, but only in a receiver where the supply voltages to the tube are normal. Generally it is all that is required on a service job, but at the service bench a so-called counter or bench tube checker is necessary. With them the transconductance of a tube, shorted tubes and open filaments may be checked prior to taking them on a service job.

Typical service equipment will be studied later, particularly its form and use in trouble shooting.

As a serviceman's business increases in number of calls handled and profits earned he will undoubtedly find that both will be increased by investing in a dependable but inexpensive car, very likely purchased with the capital being built up by his service business. Such a move would certainly permit many more calls, save time, and facilitate the handling of sets between bench and home, as well as the carrying of tools and tubes.

The number of tools that a serviceman can carry naturally will be limited. Those most needed are listed below:

Large screw driver
Medium screw driver
Small screw driver for dial and knob set screws
Electrician's line pliers
Diagonal cutting pliers
Long nose pliers
Bent nose pliers
Electrician's jack-knife
Electric soldering iron (75 watt)
Small alcohol blow torch (optional)
3 in 1 oil, mineral oil
Socket wrench set for ¼, 5/16, ⅜, 7/16 and ½ inch hexagonal nuts
Neutralizing and aligning tools
Small hammer
Flashlight
Small mirror with extension handle
Solder, resin core
Friction tape, hook-up wire
Sandpaper
Paint brush, 2 inch
Cheese-cloth and pipe cleaners
Speaker cement

Cloth felt to place chassis on and protect floor or furniture
Burning-in kit, to fill in scratches and dents. Furniture polish

More than likely a set becomes defective because of breakdown of some part. It is not possible to predict what parts or accessories you will need, nor is it possible to carry every conceivable replacement part. From experience and because certain receivers appear to be popular in your locality, you will eventually learn what parts should be carried with you on a service call. The usual parts carried are listed below.

An assortment of tubes (knowing the model number of the set simplifies matters).

A complete antenna kit (replace parts as you use them).

Assortment of metallized and wire wound resistors.

Assortment of mica and paper condensers (mostly paper type).

One each, 2, 4 and 8 mfd. universal mount dry electrolytic condensers.

Assortment of power line (screw in, cartridge) and Little type fuses.

Assortment of screws, nuts, soldering lugs, washers, etc.

Dial cords, knobs and similar common parts.

Even with these parts you cannot handle all service calls, but the fact remains that if special parts are needed, the chassis and speaker will, in all probability, have to be removed to the shop bench where a more complete stock of parts can be kept available. The defective part may be repaired or a new part purchased from the nearest parts jobber or mail order house. Such items as power transformers, audio transformers, speaker cones, special tubes, dial mechanisms, special brackets should usually not be kept even in the service shop as they are not standard. If the demand for a special part appears frequently, it may be wise to keep a spare part in stock. Some servicemen like to keep universal type power transformers in stock. Usually it is best to get an exact replacement as it fits in easily and does not have the appearance of a makeshift. Experience will teach you to do the correct thing. Keep your investment in parts down by stocking only those items that you use regularly. That's good business.

THE SERVICE CALL

A service call should be exactly what the word service implies. It means that you should call at the specified time and in a cheerful mood. Don't forget what we already said about a business-like attitude, fair dealing, dependability, courtesy and neatness and that the customer is right if you value his patronage and the good-will of his friends.

If you do not know what the complaint is, ask "What seems to be the trouble?" If you know what is wrong and a responsible party is present, it would not do any harm to state the trouble so that you may get an affirmative answer. For if there is a difference in opinion you will know at once. The initial steps are to turn the radio on and while the tubes are heating up, inspect the ground, aerial and the tubes to learn if they are being heated. Keep your eyes open for surface defects, no pickup connections, no power supply connections, tubes out of socket, no top cap connection to screen grid type of tubes, speaker cable not plugged in, etc. By this time some indication like a noise, squeal, howl may greet your ears.

If no adverse signs appear, tune in a local or nearby station, testing for distortion, lack of selectivity, tone quality—tune in a distant station in order to estimate the receiver sensitivity, in fact, watch for all those things that will allow you to appraise the operation of the receiver. Should the set fail to tune in a station, yet all tubes appear to have filament power and no surface effects are indicated, then an internal defect is indicated. You may then trace down the defect by the regular procedure described elsewhere in this course.

At this point you will have to decide whether you will take the chassis to the shop or make the repair in the home. If it is a matter of new tubes, realignment, or the replacement of a part that you have with you and which can readily be replaced, it is best to complete the job at once. Be sure you carefully check the receiver after the repair, improving the stage alignment if it is easily done, align tubes, tighten loose parts—in other words, render a complete satisfactory service.

In cases where the broken down part is not in your kit or must be ordered, where the defect is not easily located, where such tricky troubles like hum, intermittent (off and on) reception, distortion, internal noise turns up, it is best to take the chassis and speaker to the work bench. Before you do this, get permission. You may have to give an estimate of the cost and here you will have to be guided by experience on similar cases. Even if you are not questioned about the cost and the job may be unusually high, it is best to have an understanding by stating that the job may cost about so much. Thus future differences in opinion of the service charge are eliminated.

The honest serviceman does not take a chassis to his shop when he conscientiously knows that it can be readily repaired in the home. There are jobs when either procedure may be taken and the only guide then is, how complete the usual revitalization of the set shall be. A better job can be rendered at the work bench. In short, the difference between a home and shop procedure is the time available for house to house visits, elusiveness of the defect, temperament of the customer (some won't let you take a set away, others don't want you to work in their home), replacement parts available and the completeness of the alignment desired.

TEST QUESTIONS

Be sure to number your Answer Sheet 36RH.

Place your Student Number on every Answer Sheet.

Never hold up one set of lessons answers until you have another ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your Course, and the best possible lesson service.

1. What qualities should a Radio-Trician develop, besides expert technical knowledge?
2. When starting to unpack a shipment, it is observed that the shipment is received in poor condition, what steps would you take if you plan to make a claim on the transportation company?
3. Why is a rigid shop inspection and test essential before a receiver is placed on demonstration or installed in the customer's home?
4. In what position would you place the HIGH-LOW line voltage control, if you were in doubt as to line voltage variation?
5. Would you use a so-called temporary antenna or aerial eliminator to demonstrate a receiver?
6. What type of antenna would you recommend when installing a receiver in a large apartment house?
7. Why ask the customer, requesting service, for specific information on what is wrong?
8. Aside from tools, replacement parts and training, what two types of information should a serviceman have on hand?
9. Would you attempt to repair in the home, a receiver that plays, cuts off and plays irregularly? There are no surface defects and the tubes test normal.
10. What simple expedient can you take to prevent a customer from using a receiver until the demonstration.

ADOPTING A SERVICE TECHNIQUE

SET ANALYZER METHOD

37RH-1

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

THE USE OF YOU AND ME

Cecil Rhodes once said: "Don't worry. If there were no difficulties, what would be the use of you and me?" The men who face and conquer difficulties, as Cecil Rhodes faced and conquered, will come as assuredly to superiority and power as wood floats and lead sinks. The greater the difficulties, the greater the opportunity for talent to rise above mediocrity. There is no need to seek difficulties, for in these days, at least, they are thrust upon every business in the country. The man who wins is the man who holds on until he can hold on no longer—and then doesn't give up!

NATIONAL RADIO INSTITUTE

WASHINGTON, D. C.

1941 Edition

A LESSON TEXT OF THE N. R. I. COURSE
WHICH TRAINS YOU TO BECOME A
RADIOTRICIAN & TELETRICIAN
(REGISTERED U. S. PATENT OFFICE) (REGISTERED U. S. PATENT OFFICE)

NCP2M941

Printed in U. S. A.

Adopting a Service Technique

WHAT A SERVICEMAN MAY BE ASKED TO DO

WHEN Mr. Jones, the average set owner, calls Mr. John Q. Serviceman, the chances are that his receiver has stopped altogether, distorts terrifically, is picking up interference or cuts off intermittently. More critical set owners might complain that their receiver has lost its "pep" (ability to pick up distant stations) or has poor tone quality; these customers would ask the serviceman to revitalize the receiver or cure its annoying traits. All these calls involve trouble shooting—expert diagnosis followed by defect isolation, using the technique which you are now preparing to master. Before we start on this extensive subject, let us clear up another type of service rendered by Radio-Tricians.

The sight of an old receiver induces many servicemen to suggest a remodeling job, and a few customers will themselves ask whether or not a certain receiver can be brought up-to-date. Some servicemen refuse to remodel except where a worth while receiver has some basic defect, while others unfortunately grasp the opportunity whenever it presents itself.

Remodeling jobs, except in a few isolated instances, are expensive and unsatisfactory to the customer. Reliable makes of receivers were carefully designed to give a balance between many important factors, such as allowable distortion, power output, selectivity and sensitivity. Tubes and parts were chosen from the best material available at the time of manufacture, and a great deal of attention was given to the circuits used. Unless you have experience and knowledge equal to that of the original designing engineer, it should be obvious that you will upset the balance he built into the receiver when you put in different parts and change tubes.

Unfortunately, the man who practices remodeling measures the success of a change-over only in terms of what he is after. For example, he may want to use all-metal tubes or exchange one tube for another which is cheaper, easier to replace, or more modern; he may want to change over from A.C. to D.C. operation or vice versa; or he may seek to build greater sensitivity, greater selectivity or better tone quality into an older model receiver. Although the major purpose of the change-over is realized, other offsetting effects may eventually create disappointment in the customer's mind. If servicemen were to put remodeled receivers through the tests which are considered essential by any reliable manufacturer, there would be far less remodeling, and those sets which were remodeled would be highly satisfactory. The equipping of a suitable test laboratory for this purpose, however, involves a cash expenditure which is beyond the resources of the average technician.

Remodeling must be rationally considered. You must know what difficulties are going to arise and whether the gains will offset the losses. Above all, determine whether it will be wiser to buy a new receiver, considering the many benefits of a new model to the customer, or cheaper to remodel the old set. The capable Radio-Trician carefully examines the circuit of the receiver in question, then utilizes his knowledge of radio circuits and his experience to lay out the new circuit. After figuring the cost of the change he decides whether the expense involved (allowing himself a fair profit) will be acceptable to the customer. When a change-over in a certain model proves entirely successful, he files the new circuit and the change-over data for future use. Should another receiver of this same model come in for service, he could then suggest the change if he thought it would be appreciated by the customer.

At one time, not so long ago, servicemen who made successful change-overs wrote up the details for publication in various service magazines. Such articles were instructive and gave the practical details needed to improve a particular model, but did not tell of the troubles and pitfalls which were encountered in securing satisfactory operation. Servicemen soon realized that there was more trouble than profit in this kind of work, and change-over articles gradually disappeared from the reliable magazines.

Beginners in servicing should remodel only when they have at hand complete and detailed change-over data for the particular receiver in question. The following suggestions will prove helpful when you are considering the remodeling of a receiver.

WHEN SHALL I REMODEL A RECEIVER?

The most common change-over is that involving the replacement of old type tubes with more modern tubes. This problem divides itself into two parts: *a*, where a change is desired because the old tube is no longer easily obtained; *b*, where tubes are changed to get better operating qualities. Item *a* is sometimes easily handled because many tube manufacturers supply data on tubes which can be interchanged without making any circuit changes. Servicemen can get these tube charts from their tube or radio parts distributors.

Careful consideration should be given to a change of tubes which is made to secure a specific new operating feature, such as changing from ordinary screen grid to variable mu tubes to remove cross-modulation and modulation distortion. Unnecessary changes are foolish and a needless expense to the customer.

When changing to variable mu tubes, determine whether the receiver has C bias volume control; if not, make this change. AVC receivers *may* work better with variable mu tubes if the controlling C bias potential swings sufficiently or is extended by a change in the automatic volume control circuit.

In general, if a change is made to tubes of similar characteristics (24 to 24A, for instance) no circuit change is required. On the other hand, a new socket and changes in wiring will be needed when replacing a 24 tube with the 58, which is quite different; however, in this particular case the original supply voltages can be used.

Audio hum can oftentimes be cut down by changing the first audio tube from a 26 to a 56. Grid leak-condenser detection is likely to give more hum output than a C bias type detector; a change to the latter, on the other hand, may reduce sensitivity and increase selectivity. The loss in sensitivity will not be serious if the customer does not use his set to pick up distant broadcasts.

To change from 26 to 56, 24 to 58, 45 to 47, or 42 to 6F6 merely for the purpose of using later type tubes is foolish; such changes give little improvement in set performance yet involve quite an expense. In many cases the performance is poorer than was obtained with the original tubes. Circuit parts are designed to go with definite tubes.

It may be good business to change old tubes which cannot easily be purchased to types which are more universally sold, even if the circuits must be altered slightly, provided that the receiver in question appeals to the customer for some reason, sentimental or otherwise. In choosing the new tubes select those which have similar operating voltages, to avoid changes in the power pack. Substitute a triode for a triode, choosing new tubes which have approximately the same mutual conductance and amplification. The set owner must be willing to sacrifice some desirable features of his receiver for the sake of using tubes which are more readily obtained.

Changing battery sets using obsolete tubes (01A, 12A, 99, 20) is often considered desirable. The usual change is to 2 volt tubes, which allow use of air cells or of 2 volt storage batteries. Operating voltages are not important when remodeling battery receivers, for the voltages are easily changed externally by using more or fewer batteries. Where the B drain is to be kept low, a class B push-push output stage may be included in the change; of course this means that new and expensive audio transformers must be used, and perhaps a new loudspeaker installed.

Changing receivers from A.C. to D.C. or D.C. to A.C. operation is quite a favorite with many servicemen, but before such a change is carried out, inverters and rotary converters should be considered. An improvement in performance is possible when converting D.C. to A.C., but a loss in performance and customer satisfaction is more than likely to occur when A.C. receivers are converted for D.C. operation. Can the receiver be exchanged? Will a new receiver be cheaper? If the receiver is too good to be discarded, will the customer consider an inverter or motor-generator set? These are important questions to settle. Be fair with the customer.

Old receivers operating from a 110 volt D.C. source use the 01A, 12A and 71A type tubes. In changing over to A.C., use the accepted 6.3 volt filament tubes. The series filament arrangement is altered to a parallel arrangement, and all bias voltages are readjusted to the correct values for the new tubes. A power pack must be built, possibly using the original line filter chokes with new condensers having high working voltages. The original loudspeaker may have to be discarded, as in cases where the field coil originally was in series with the tube filaments and carried a comparatively high current. A 110 volt field is now standard in most D.C. receivers; a loudspeaker with such a field can easily be used in the rewired set by using the field coil as a choke, providing sufficient additional rectified voltage to the filter input to overcome the drop in the field coil. As an alternative, you can change over to a separately excited (not desirable) or permanent magnet type dynamic loudspeaker. Where 6.3 volt tubes were originally used, the change-over is a little simpler, for fewer changes in resistors supplying bias voltages will be needed.

Keep in mind the fact that A.C. operation was not considered by the designer when laying out the parts for the D.C. receiver which you are thinking of rewiring for use on A.C. Hum due to incorrect placement of parts may occur in the rewired set, particularly if the power transformer and filter choke are located anywhere near the detector and A.F. stages. Be sure to twist the filament leads together, as this will lessen hum pick-up.

Converting from A.C. to D.C. means eliminating the power pack, reducing the plate and screen voltages, and possibly changing tubes. Use 6.3 volt heater type tubes throughout, connecting the filaments all in series. Since the plate voltages will be reduced, the bias voltages must be changed correspondingly by using new resistor values. The field coil of the dynamic loudspeaker may be operated from the D.C. power socket; this as a rule means using a series resistor to limit the field current if the voltage originally across the field was less than 100 volts. Similar tubes should always be used; substitute a triode for a triode, a pentode for a pentode, choosing tubes with about the same dynamic mutual conductance (g_m) and amplification (μ) characteristics as the old tubes.

Certain receiver remodeling jobs are really additions. The installation of a tone control or tuning meter is quite permissible for any worth while receiver, provided you understand the operation of the receiver circuit. The current range of the tuning meter should be such that its full-scale reading will be slightly higher than the sum of all the normal plate currents of the tubes whose currents are to be indicated by the meter.

Adding AVC is often considered to reduce fading, but the fact that stations fade is no indication that AVC is required. If the stations cannot be brought back with manual control, no amount of AVC (which reduces the over-all sensitivity of a receiver) will prevent the fading. The real value of AVC lies in its ability to prevent powerful stations from blasting out when the set is tuned past them, although it does tend to lessen fading on the stronger distant stations. The customer who is accustomed to operating a receiver without AVC really has no need for this addition. Put in AVC only if you are willing to sacrifice some sensitivity and build up the audio gain of the receiver; otherwise pass it by.

The definite acceptance of the all-wave superheterodyne receiver as the modern standard has prompted a desire to convert T.R.F. and "super" sets to all-wave "supers." Such changes are best accomplished with an all-wave converter having a built-in and independent power supply; this type of converter is very easily connected to the receiver. Where an additional external unit is objectionable, mount the converter in the receiver cabinet and place the receiver chassis (which requires no adjustments while tuning) in the loudspeaker compartment. (Naturally this is not possible with table model sets.) If the customer insists (despite your recommendation) upon converting the set to a "super," then install a new superheterodyne chassis in his cabinet. This is far cheaper and more satisfactory than trying to rebuild the old set. A good super chassis for a conversion of this type can be obtained from any one of a number of reliable firms; others sell complete kits of parts, which enable you to build "tailor-made" sets to fit into different sizes of cabinets.

Changes intended to increase selectivity, sensitivity, fidelity and power output are debatable matters. Selectivity may be increased at the expense of fidelity and circuit stability; fidelity by sacrificing selectivity and spending money for new parts; power output at the cost of a large power pack and extra parts. In general it is best simply to realign and revitalize a receiver, restoring its original performance, rather than to remodel. Unless you have had previous experience with the same model and the same change-over, you will find every change-over a problem in itself; this is why the subject of remodeling cannot be treated concretely and completely in any book. Never change over a receiver simply to cure a condition caused by a defect in some part. In other words, place the receiver in first-class operating condition before you even consider a change in the circuit.

Important. Always keep a record of *all* changes which you make in a receiver, whether you change only one resistor or rewire the entire circuit. This precaution is of great importance, for it will save a great deal of time should that receiver come back to you again in the future. These changes may appear quite obvious to you at the time, but once forgotten it may take hours of checking against the original circuit diagram to locate the changes which were made.

You will readily agree from the foregoing discussion of receiver remodeling that this type of work is considerably more involved than might appear at first glance. The successful Radio-Trician generally adopts the policy of "hands off" when remodeling is a possibility.

Now that we have taken care of the pitfalls of remodeling, we can proceed to a study of radio servicing techniques in general, taking up one by one the different procedures involved and discussing the advantages and disadvantages of each.

TROUBLE SHOOTING IS AN ART

We will again stress the importance of confirming the trouble which resulted in the customer's complaint, for the minimum expected from the serviceman is the elimination of this defect. The following complaints are usually received.

1. *Set does not play.* This probably means either that one or more tubes are defective, some part in the *signal* or *supply* circuit is defective or open, there is no power, or the pick-up system is defective—in short, a complete breakdown.
2. *Noisy Reception.* The interference will be traceable either to defects inside the receiver (internal), or more probably to an outside (external) source. Internal noise may be due to defective tubes, parts or connections. External noise may be the normal atmospheric noise heard with distant station broadcasts; it may be produced by lightning or by man-made static created by household and industrial equipment. In general, noise exists because there is a poor connection, a partial short, or, as in the case of motors and buzzers, because of excessive sparking at contacts and brushes. A spark or an arc in any circuit which may be inductively coupled to the receiver will create noise.
3. *Annoying Hum.* An internal defect, such as a fault in the power supply or filter system, will create hum disturbances in the receiver. Another cause, rather rare, is pick-up of external hum voltages, as from power lines.
4. *Intermittent Reception.* Although a frequent complaint, this intermittent condition may be difficult to remedy. When the receiver remains inoperative for a time sufficiently long to make tests, the defect is readily isolated; oftentimes, however, the set will cut off for only a few minutes at a time. If touching a definite part or tube terminal restores operation, the defect is usually located in the associated circuit. If operation is restored by flipping a switch or by jarring or touching *any part* in the circuit, the defect will be more difficult to isolate. Everything may be suspected, and often all resistors, tubes, and especially by-pass and coupling condensers must be replaced one by one until the annoying cut-off is eliminated.
5. *Squealing.* To determine whether this is due to external causes, note whether it is present when the receiver is tuned to some broadcast; if the squeal is intermittent it is originating outside the set. A receiver defect causing squealing usually exists when the set is just turned on, is tuned to some definite frequency or through a band of frequencies. If the set is not of the regenerative type a breakdown exists, or in the case of neutrodyne receivers, the adjustments have been disturbed or the tubes changed; with superheterodynes improper alignment may be the cause of a few isolated squeals.

6. *Distortion of Programs.* When voice or music sounds muffled, harsh, raspy and unintelligible, the defect is often traceable to worn-out tubes or to incorrect operating voltages, and particularly to the C bias. In a few cases distortion will be caused by a complete breakdown of some part. We assume here that the set fidelity was originally satisfactory to the customer, and the alignment adjustments of the receiver were not tampered with.
7. *Poor Volume.*
8. *Poor Sensitivity.*
9. *Poor Selectivity.* Volume, sensitivity and selectivity complaints come most frequently from customers who use their receivers for special purposes, such as to pick up music for dancing, and oftentimes from DX fans—those who enjoy listening to distant stations.
10. *Set Is Generally Unsatisfactory.* Here is a complaint which should be handled with extreme care and tact, for the claims may be unreasonable just as often as they are legitimate. Especial care and tact is needed if the complaint occurs after a recent service call. If you decide that the complaint is reasonable, take extra precautions to eliminate the trouble; if it is unreasonable, explain your decision to the customer as tactfully as you can.

Note how these ten basic complaints divide into two broad groups: ***1*, the set is dead; *2*, the set plays unsatisfactorily.**

One of the purposes of the N.R.I. Servicing Course is to prepare you to handle complaints like these speedily and efficiently. You will, as you proceed with this Servicing Course, learn to diagnose and search out the defect for each case in a quick, intelligent manner.

Experience will be a great help. Plan to get first-hand contact with actual jobs. Where a fellow serviceman will allow you to watch him at work, or better yet allow you to help, "learning how" will be a simple matter. You might even take your first jobs, after you have analyzed them, to a serviceman on condition that he will allow you to watch how he attacks the problem.

Study the chart on page *9* (prepared by the editors of the magazine *Radio Today*), which lists the troubles which can be caused by each part in a typical modern superheterodyne receiver, as well as troubles caused by certain external factors. This chart will be especially valuable when you first begin to use *effect-to-cause reasoning,* a servicing technique which is taken up later in this lesson.

Another very good method of gaining actual experience is this: Get an old T.R.F. receiver, preferably of the A.C. type, and restore its operation. Now have a friend create some fault in the set—cut a wire, short a signal circuit, ground some signal circuit lead or insert a poor tube—without telling you what he did. Locating "artificial" faults like this gives just as good experience as working on sets brought in by customers.

After you have become familiar with the effects of various faults, align and revitalize the set a final time, then sell it. Repeat the procedure with a broadcast superheterodyne receiver, and finally tackle an all-wave receiver. Don't expect everything to be easy at the start—servicing is an *art* which you must develop.

It is wrong to plunge immediately into trouble shooting with service testers. A good service technique starts with deliberate thinking and with common sense based on a knowledge of fundamental radio principles and radio design practice, both fortified by experience. We stress again that service testers are only aids in isolating the defect. You will find that as you acquire experience you will depend less and less on testers to isolate defects.

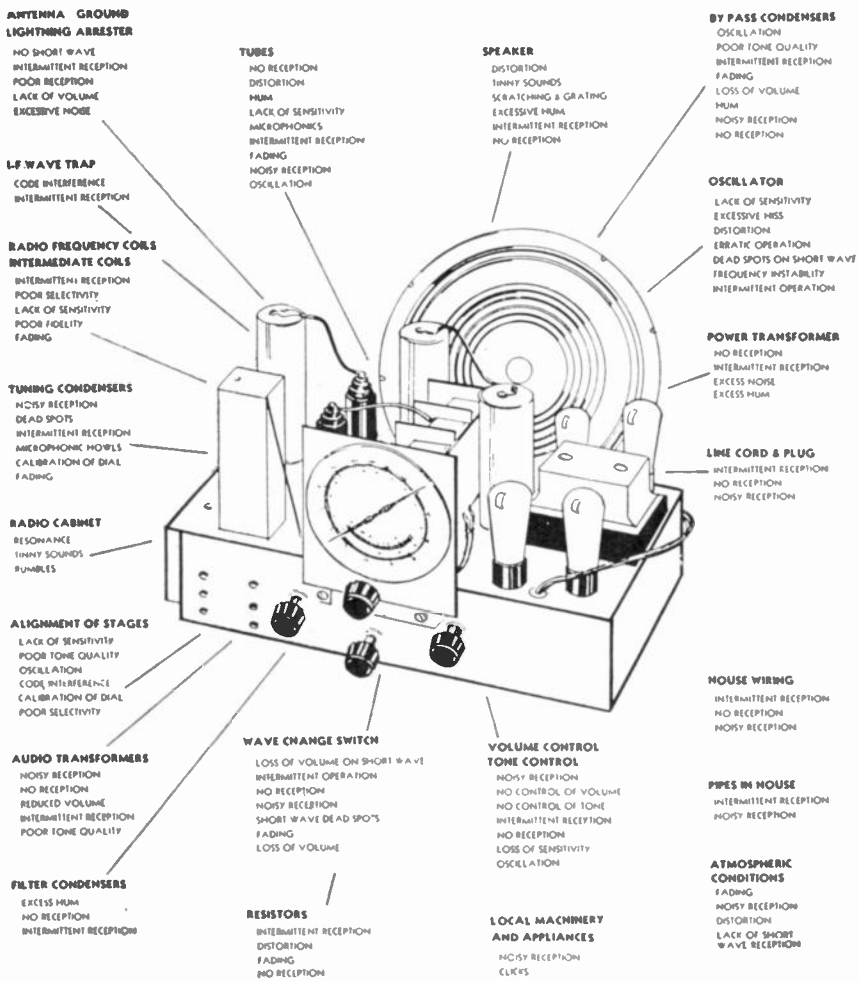
Don't take a set out of its cabinet or try to make part replacements until you are reasonably certain that the defect *is* somewhere below the chassis rather than an externally located trouble which might easily be repaired. In this way you will not abuse the customer's property. Deliberate before you start testing. Perhaps the defect is external or a tube defect, and not in the chassis. Interference and lack of reception may be due to external causes; it is embarrassing to discover this after the chassis has been taken out of the cabinet. Check the power supply source (the fact that tubes and pilot light heat up is often a satisfactory check); inspect the aerial and ground; look for the filament glow in glass tubes while they are heating; feel metal tubes to see if they are warm; carefully examine the external surfaces of the chassis for loose parts, control grid caps not in place, tubes missing or loudspeaker and chassis connecting cables out of place. Look for the "obvious" or as servicemen call them, the "surface defects."

While the tubes are heating up listen for squeals, howls and noises; tune the set to get a general idea of how it operates (in cases where the set plays unsatisfactorily), and listen carefully for symptoms which may indicate the possible cause of the defect. This is *effect-to-cause* reasoning, a very important radio servicing technique; you listen for the effect, then reason "now what could cause this?" Once you recognize an effect you have localized the trouble to a definite section of the receiver, and need no longer bother with other sections. Your ability to make use of effect-to-cause reasoning will naturally improve with experience.

Above all, beginners should avoid useless fussing with receivers in the customer's home—it destroys customer confidence. It is a better plan to remove the chassis to the shop bench when you cannot quickly locate and repair the trouble

If the set does not play at all, then it is obvious that the first step is to make it play even if the restored performance is not acceptable. This is true whether you plan to correct the defect in the customer's home or at the shop work-bench. Use the simplest and quickest procedure possible in locating the defective part or connection, for once the set is made to function it can be restored to normal operation by further servicing.

When you have made certain that the fault is not due to external missing parts, to improper connections, or to tubes which do not heat or



Courtesy "Radio Today."

The parts and conditions identified by bold face type on this chart are the most common trouble-makers in radio sets. Under each part name are the defects which it can cause; note that similar effects can result from defects in several different parts.

are not firmly in their sockets, and after finding that your experience will not allow you to reason the cause from the obvious effects, then only should you start a systematic trouble shooting or defect isolating procedure. The four important defect-isolating methods are: (*1*), *the set analyzer;* (*2*), *point-to-point voltage;* (*3*), *point-to-point resistance;*

and (4), direct stage-by-stage elimination. The first three are called *static methods,* because with them the receiver is not picking up a signal; method *4* is a *dynamic procedure,* because it tests the receiver under actual operating conditions. All four will be taken up in the Course. It is important that you know all four, as in many cases one method is superior to or more effective than the others. Often a combination of methods may be required.

Every serviceman worthy of the title RADIO-TRICIAN will develop his own technique—his favorite method, for servicing is a professional art requiring techniques which are adapted to the make-up and ability of the individual man. Every service job, however, involves these important features:

1. A preliminary investigation, such as we have just described, using effect-to-cause reasoning (except when the receiver is dead).

2. A trouble shooting procedure which will isolate the defect.

3. The correction of the defect or the replacement of the defective part.

4. A check on performance. This will in many cases be followed by a revitalization procedure (to be covered in a later lesson), which means placing the set in physically good condition, seeing that all tubes are good and are carefully selected for the uses to which they are put (aligning tubes), and seeing that the tuning stages are lined up.

Step No. 4 must not be overlooked. Many servicemen think the customer expects them only to correct the complaint for which they were called; on the contrary the average customer hopes his receiver will perform as satisfactorily after being serviced as it did when *new.*

Where the receiver circuits are easily and quickly aligned always do this, to insure greater customer satisfaction. A charge should of course be made for extensive revitalization work, but not without first obtaining the customer's consent.

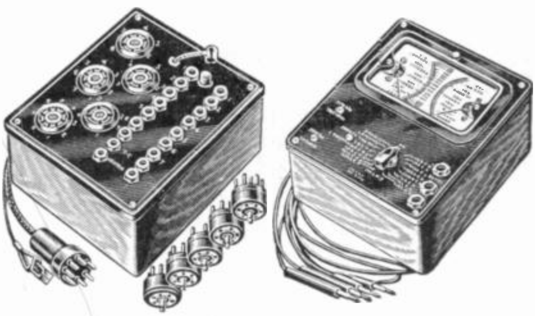
Incidentally, many servicemen offer to their customers at a certain price a special revitalization job, even when the set is apparently in good order. This service includes cleaning the chassis, blowing dust out of the variable condensers, resoldering connections, tightening all parts, oiling moving parts (without affecting moving electrical contacts), testing and aligning tubes, checking operating voltages and aligning the R.F., oscillator and I.F. stages. Quite often sets which have become moist and damp are baked and the coils treated to make them moisture-proof. The pick-up system (antenna, etc.) is checked, repaired or rebuilt as the need indicates and the first tuned circuit adjusted to give the best possible results with the customer's antenna.

It is impossible to recommend or show you a "hard and fast" service technique, for almost every receiver will require a different servicing procedure. On pages *14* and *15* is the outline of a typical technique, including problems encountered and the usual corrective steps. The order of these steps may change in actual practice. It will not always be necessary to go through all the steps, for in a large number of cases the defect will be located before any extensive tests have been run.

Set Analyzer Method

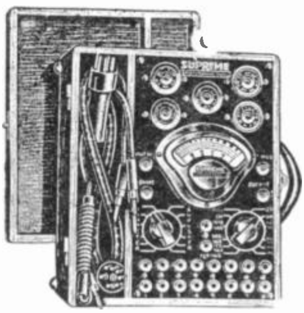
MODERN SET ANALYZERS

WHEN a receiver fails to perform satisfactorily or even fails to play, there is a defect either in the signal circuits or in the supply circuits. Checking the voltages and currents in each vacuum tube stage, then analyzing the supply circuits often helps to isolate the defect. Since in the majority of cases the chassis is mounted in a cabinet, it is helpful



Courtesy Triplett Electrical Instrument Co.

This commercial model free-point analyzer (left), using a circuit diagram similar to that of Fig. *1*, and its companion multimeter (right), identical in size, together make up a modern set analyzer accommodating either metal or glass tubes.



Courtesy Supreme Instruments Co.

In this commercial set analyzer, a free-point socket plug-in and selector system and a multimeter are housed in one case.

to have a simple and effective device which will permit rapid current and voltage readings in any tube stage while the receiver is in its cabinet. This need has been filled by the so-called *set analyzer*, better named the "socket adapter analyzer."

The conventional set analyzer consists of three essential parts: (*1*), a receiver socket plug-in system with a cable extension connecting to sockets in the analyzer, thus extending the tube socket leads of the receiver to the analyzer, where the voltages and currents may be more readily checked; (*2*), a multimeter, generally consisting of a multi-range A.C.-D.C. voltmeter, milliammeter and ohmmeter; (*3*), some method of connecting the multimeter at the analyzer tube sockets for convenient current, voltage and resistance readings. In a number of analyzers a control grid voltage shift is provided, using the milliammeter of the multimeter to indicate the plate current. Thus the mutual conductance of the tubes may be estimated. All set analyzers are so designed that the meters may be used individually for external needs. Set analyzers are available in two forms, one where multimeter and socket adapter are in the same case, and the other where these two units are in separate but similar cases.

A few words regarding the meters. The basic meter is generally a D'Arsonval type moving coil microammeter having a current range of from 50 to 500 microamperes. This instrument measures A.C. by using a copper oxide rectifier, the elements of which are arranged in a full-wave bridge circuit. For general use the basic A.C. and D.C. micro-ammeters are resistance-loaded so that with the necessary multipliers both the A.C. and D.C. voltmeters have a sensitivity of either 1,000 or 2,000 ohms per volt. Shunts are used with the basic meters to extend their ranges for current measurements. The A.C. and D.C. voltmeters usually have a maximum range of 600 to 1,000 volts, conveniently sub-divided into lower maximum ranges. The maximum current range is usually 150 milliamperes, although a number of analyzer meters have been built to read up to 600 milliamperes. Only a few multimeters provide for A.C. current measurements. An ohmmeter with a maximum range of 1½ megohms is generally provided. When we speak of maximum ranges we must not forget that the ammeter, voltmeter and ohmmeter ranges are subdivided so that low values may be more accurately read. This requires a large number of multipliers, shunts and resistors.

We do not ever recommend building a multimeter unless from a carefully planned kit. Commercial multimeters are cheaper than home-made affairs, especially when the cost of giving the home-made cabinet and controls a professional appearance is considered.

The simplest and perhaps most effective socket plug-in and selector system is illustrated in Fig. *1* and may be readily built by the average man who is handy with tools and a soldering iron. Of course, the device should be built as a separate unit which will fit into a case housing it and the multimeter. All parts needed are clearly marked and may be purchased from radio supply houses. Note that there is an eight prong plug with a top cap connector (*TC*). Each prong of the plug connects to a lead in the cable and the top cap has its own lead, making nine in all. A set of six adapters allows the plug to be inserted into either the eight prong octal, large and small seven prong, six prong, five prong or four prong sockets. The tube in the radio receiver (or other device being tested) is placed in the proper socket in the analyzer and the analyzer plug, with its proper adapter, is inserted in the vacant socket in the receiver. If the tube under test has a top cap, the *TC* lead in the analyzer should be attached to it and the top cap lead in the receiver pushed over the cap which is attached to the plug. When these preliminary steps are carried out, each lead in the cable will pass first through one of the circuit-opening twin jacks before going to a tube electrode. This arrangement, which exists regardless of the type of tube under test, permits convenient measurement of tube voltages and currents.

Even though all four-prong tubes are not alike as regards connections between prongs and electrodes, we know that all four-prong tube

Typical Service Technique

You will be able to follow the servicing procedures given here in far less time than it takes to read these two pages, once you have finished this Servicing Course. Each item listed here is explained in detail in this and later Lessons.

Confirmation of Complaint

Ask customer to describe receiver fault. Verify statements by turning on receiver power switch, listening for tube warming-up noises and for indications of defects.

Inspection for Surface Defects

1: Check for surface defects
Aerial and ground system intact
Obvious chassis defects; loose parts, burned out tubes, broken tube top cap cable and other cable and lead connections, odors indicating broken down parts

2: Check power supply to receiver if no tubes light. If only one or two tubes do not light, check these tubes; if tubes test O.K., look for defects in associated parts

3: If receiver continually burns out tubes, check line voltage

4: Try tuning in one or more broadcasts

No Sound from Loudspeaker

Check power pack output voltage of receiver.

Defective Stage Isolation

Static Method: Circuit Disturbance Test

1: Shock detector (second)
2: Shock A.F. tubes. Check loudspeaker if no click is heard
3: Shock I.F. or R.F. tubes
4: Shock mixer tube
5: Shock oscillator
6: Shock pre-selector tubes. If okay *1* will give squeal or thud, *5* should give a strong double click or thud; all others should give normal double output thuds if okay. No output indication indicates defective stage

Dynamic Method: Stage-by-Stage Elimination

1: Connect signal generator (S.G.) to detector input and output meter to voice coil or power tube plate. (Phone break-in may be needed as output may be weak)
2: Failure to get output, advance output indicator stage by stage to detector plate. Signal indicates passing through defective stage. Check loudspeaker if necessary
3: Tune signal generator to I.F. and advance it to input of mixer. In case of T.R.F. sets tune signal generator and set to same frequency
4: With supers set S.G. to frequency of preselector and connect to mixer input. Output indicates good oscillator
5: Advance S.G. through preselector stages
6: After isolating defective stage, check by connecting S.G. to input and output of stage

Defective Part Isolation

1: Check tube in stage, replacing if necessary
2: Remove chassis from cabinet to check continuity of circuit and parts in stage
3: Replace defective part or make required correction in connections

Sound from Loudspeaker

1: Apply effect-to-cause reasoning
2: If effect-to-cause reasoning fails to locate trouble, choose that one of the following procedures which applies to the case at hand

Poor Quality

(good volume)

1: Check and replace poor tubes
2: Check loudspeaker
off center voice coil or armature
weak cone—poor paper
lack of good baffle
no field current, poor magnets
3: Isolate defective stage
4: Check operating voltages in defective stage—incorrect C bias
5: Insufficient volume control, distorts on high levels
6: Stages peaked, cuts side bands, realign R.F. system

Good Quality

Not Selective

1: Check tubes
2: Check operating voltages of R.F. and detector tubes
3: Coils damp—bake
4: Check R.F. and I.F. alignment
5: High resistance in signal circuits
6: Aerial too long—poor ground
7: Broad to local—use wave trap

Selective, Low Volume

1: Check tubes
2: Check A.F. stages
3: Alignment of R.F. system
4: Check operating voltages
5: Aerial too short
6: Weak field or no magnetization in speaker
7: Open in signal circuit—signals bypassed—stage isolation test

Interference

Make internal - external test to determine general source of interference

External

1: Noise due to high noise level—cannot be corrected—try tone control
2: Try noiseless antenna—new aerial location if needed—filter supply
3: Isolate defective device—install filter
4: Heterodyne—explain to customer
5: Regenerative or oscillating receiver—See neighbor

Internal

1: Check chassis for loose parts, bad tube or poor connection
2: Isolate stage
3: Squeal—trace defect or reneutralize receiver
4: Hum—isolate defect by hum elimination procedure
5: Test for modulation distortion

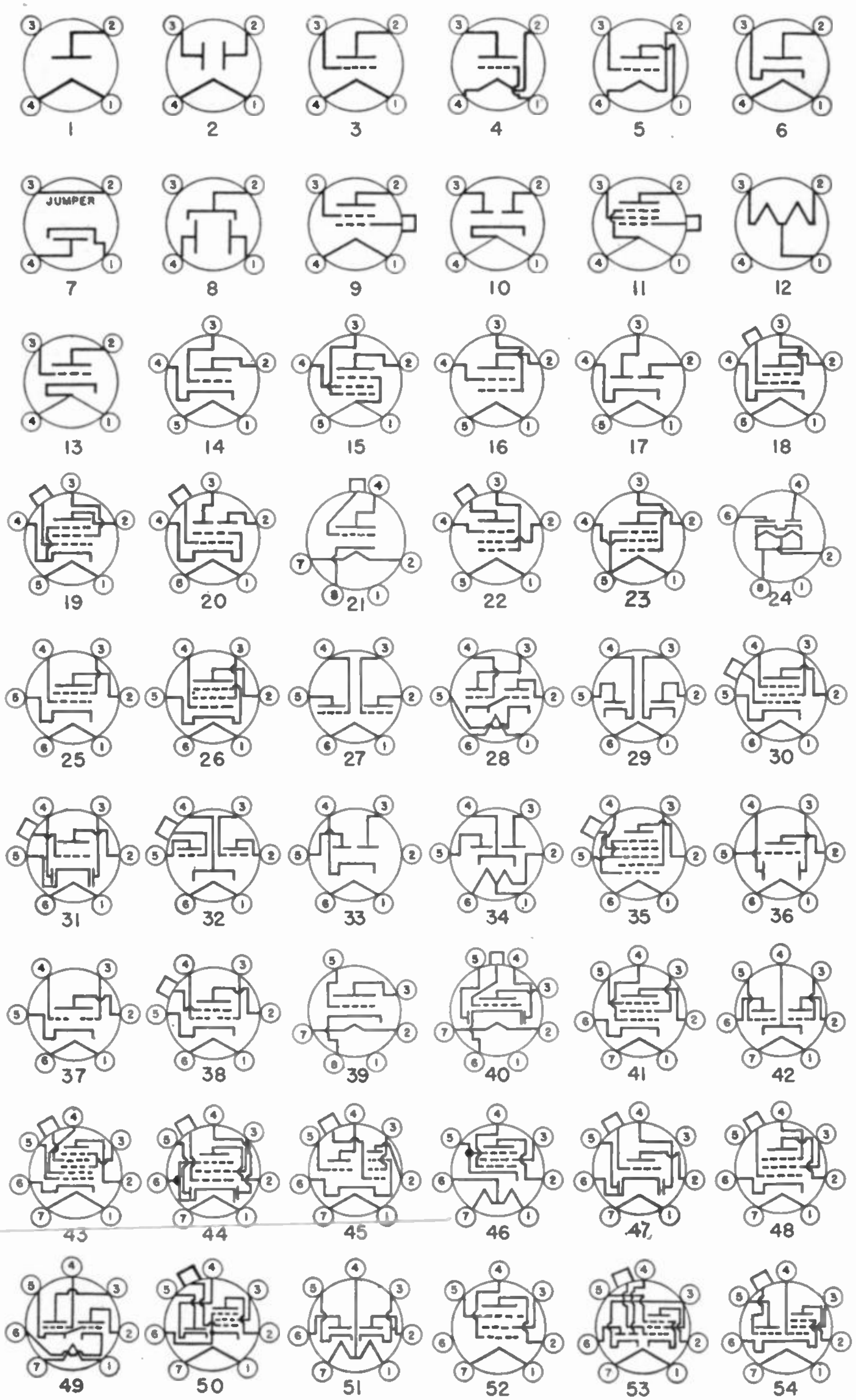
Intermittent Reception

1: Have customer identify condition
2: Effect to cause diagnosis
3: Check filaments of heater type tubes open when hot—(off-on effect)
4: Check for thermostatic joints
5: Isolate stage (during period set is "off")
6: Check all condensers and resistors in suspected stage (preferably by substitution); examine and test coils

Check Performance and Revitalize Receiver

1: Check all tubes (if not previously done) and check performance of set
2: Clean chassis—clean variable condenser plates
3: Resolder poor or questionable connections—tighten chassis parts
4: Drive out moisture—moisture proof coils, etc.
5: Align tubes—S.G. and output meter
6: Align I.F. or T.R.F. stages
7: Make preselector and oscillator track
8: Repair or erect a new aerial system
9: Adjust antenna coupler tuning condenser trimmer or segments to make receiver input track with rest of set—in the home with final antenna

TOP VIEWS OF SOCKETS



bases are alike; the same holds true for five, six, seven (both types) and eight-prong (octal) tubes. Corresponding prongs may be a cathode in one tube and a screen grid in another. To simplify matters the R.M.A. (Radio Manufacturers' Association) has numbered the tube prongs, setting up a standard which disregards the structure of the tube. The sockets in Fig. *1* have this R.M.A. numbering as it would appear if you were looking at the *top* of the socket. If you were to view Fig. *1* from

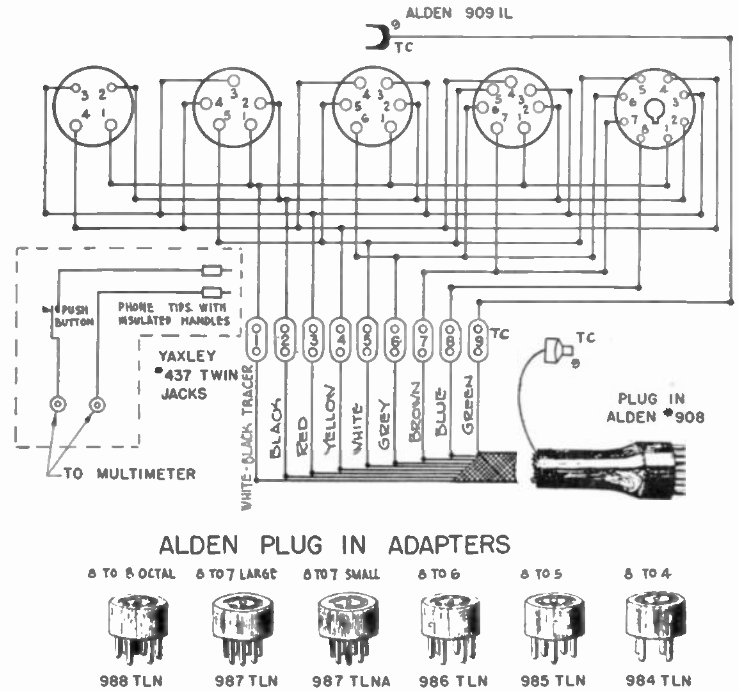


FIG. 1. Circuit diagram of free-point socket analyzer as it should be connected when using Alden parts. With this unit and a multimeter you can make any voltage, current, or resistance test between the elements of any tube in a receiver. To lessen the possibility of damaging the meter because of improper connections, some servicemen prefer to use the push button arrangement shown above (enclosed in dotted lines). The multimeter probes are permanently plugged into the pair of jacks below the push button, and the phone tips are plugged into the twin jacks. The button must always be pressed to obtain a reading on the multimeter.

the back of the page (by holding the reversed page up to a light) or place the drawing in front of a mirror, the prong numbers would correspond to sockets viewed from the bottom. This fact is worth knowing when voltage and resistance measurements are being made directly from the underside of the chassis, without using the adapter. With a little practice you will be able to reverse the diagrams mentally.

All tubes which will fit the eight-prong socket are called octal tubes, but not all octal tubes have eight prongs. For example, pins *2*, *5* and *7* may be missing in a tube, yet this would not interfere with the insertion

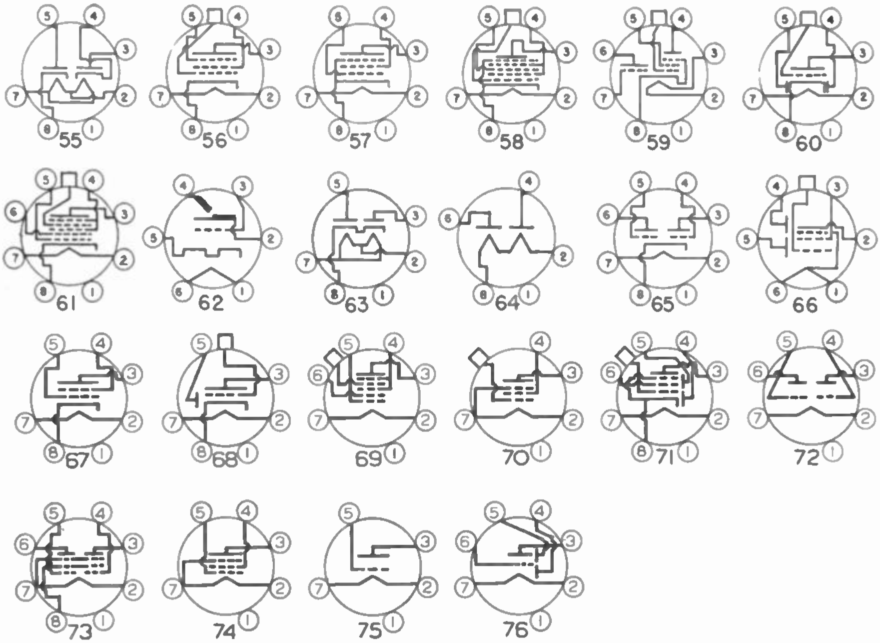


FIG. 2 (above and on opposite page). This chart contains the schematic diagrams and socket terminal connections *as viewed from the tops of the sockets* for the tubes listed in Fig. *3*. Aligning key for octal tubes is always between pins *1* and *8;* pin *1* is generally the metal envelope.

Tube	Base	Tube	Base	Tube	Base	Tube	Base	Tube	Base	Tube	Base	Tube	Base	Tube	Base
00	3	2B6	49	6E5	62	6Y5	33	25Z6	55	49	16	78	30	402–403	3
00A	3	2B7	44	6E6	42	6Y5V	33	26	3	50	3	79	32	450	3
01	3	2B7S	44	6E7	48	6Z3	6	27	14	HZ50	6	80	2	482A	3
01A	3	G2–G2S	17	6F5	21	6Z4–84	17	K27	14	51	18	80M	2	482B	3
01AA	3	2Z2–G84	1	6F5G	21	6Z5–12Z5	34	27HM	14	51S	18	81	1	483	3
01B	3	G4–G4S	17	6F5MG	21	10	3	27S	14	52	16	81M	1	484	14
1	6	KR5	15	6F6	57	WD11	5	A28	3	53	42	82	2	485	14
KR1	6	5W4	64	6F6G	57	WX12	3	KR28	17	55	31	83	2	585	3
RA1	3	5Y3	24	6F6MG	57	12A	3	29	37	55S	31	83V	10	586	3
RE1	2	5Z3	2	6F7	45	12A5	46	30	3	56	14	84	17	840	22
RE2	1	5Z4	24	6F7S	45	12A7	50	A30	3	56A	14	G–84	1	P861	17
S01	3	5Z4MG	24	6G5	62	12Z3	6	31	3	56AS	14	85	31	864	3
S02	3	6A3	3	6H6	55	12Z5	51	KR31	6	56S	14	85AS	31	950	15
1A4	9	6A4–LA	15	6H6G	55	12Z5–6Z5	34	32	9	57	30	85S	31	951	9
1A6	35	6A6	42	6H6MG	55	14	18	A32	3	57A	30	88	2	985	17
1B4–951	9	6A7	43	6J7	56	14Z3	6	33	23	57AS	30	89	30	986	2
1B5–25S	31	6A7S	43	6J7G	56	15	19	34	11	57S	30	90	37	AD	6
1C6	35	6A8	61	6J7MG	56	17	14	35–51	18	58	30	92	37	AF	2
1C7G	69	6A8G	61	6K7	56	18	26	35S–51S	18	58A	30	95	26	AG	2
1D5G	70	6A8MG	61	6K7G	56	19	27	36–36A	18	58AS	30	9(	6	AX	3
1D7G	69	6B5	28	6K7MG	56	20	3	37–37A	14	58S	30	KR98	17	B	4
1E5G	70	6B6	40	6L5G	39	KR20	37	38–38A	19	59	41	V99	4	BA	8
1E7G	73	6B7	44	6L6	67	22	9	39/44	19	59B	52	X99	3	BH	8
1F4	23	6B7S	44	6L7	58	A22	3	39A/44A	19	64–64A	18	181	3	BR	7
1F5G	74	6B8	71	6L7G	58	AC22	18	40	3	65–65A	18	182A	3	D–1/2	1
1F6	66	6C5	39	6L7MG	58	KR22	37	A40	3	67–67A	14	182B	3	D1	2
1H4G	75	6C5G	39	6N5	62	K24	18	41	26	68–68A	18	183	3	DE1	14
1H6G	76	6C5MG	39	6N7	65	24A	18	42	26	69	37	213	2	E	3
1J6G	72	6C6	30	6P7	59	24S	18	43	26	70	37	216	1	G	3
1V	6	6C7	47	6Q6G	68	25–25S	36	44	19	71	3	257	15	GA	15
2A3	3	6D5	39	6Q7	60	KR25	26	45	3	71A	3	264	3	H	3
2A3H	13	6D5G	39	6Q7MG	40	25A6	57	45A	3	71B	31	291	20	LA	15
2A5	26	6D5MG	39	6R7	60	25A6MG	57	46	16	75	31	293	20	PZ	15
2A6	31	6D6	30	6S7G	56	25Y5	29	47	15	75S	31	295	20	PZH	26
2A7	43	6D7	48	6X5	63	25Z3	6	48	25	76	14	401	3	Wunder-	
2A7S	43	6D8G	61	6X5MG	63	25Z5	29	A48	3	77	30	401A	3	lich A	37

FIG. 3. Chart of radio tube numbers. Look up the tube first on this chart, note the number, then refer to the diagram in Fig. *2* which has *that number,* in order to determine the socket connections and the arrangement of electrodes inside the tube.

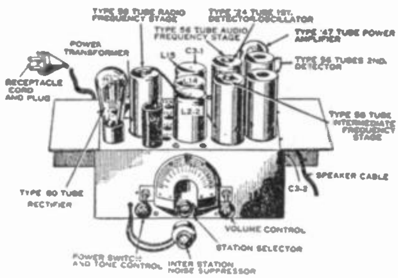
of the tube in an octal socket. All pins in 5, 6, 7 and 8 prong octal tubes are numbered just as if the missing pins (prongs) existed. Thus pins *2* and *5*, if used, would always appear in the same position with respect to the aligning slot. In rare cases the eight-prong adapter plug will not fit into a socket intended for an octal tube. This is because the unused holes in the socket were not drilled out by the manufacturer. Octal prong-reduction adapters could be secured but in general their limited use does not warrant the expense; most servicemen either drill out the missing holes so the eight-prong adapter will fit or replace the socket with a standard octal socket.

Figure *2*, together with the table in Fig. *3*, gives you the schematic diagram and base prong connections for each of the most common radio receiving tubes. The pins in each case are numbered according to R.M.A. standards, as viewed from the tops of the sockets. These diagrams are therefore ideal for use with an analyzer, where you are always looking at the tops of the tube sockets. For simplicity each schematic diagram has been assigned an arbitrary number. The tubes in Fig. *3* are arranged in a numerical order; simply locate the tube you want in the table, note its number, and look up the diagram having that same number. For example, if you wanted to know the connections for a 58 tube, you would locate it in Fig. *3* first. There you learn that it has the number *30*, which is the last diagram to the right in the fifth row of Fig. *2*.

For general service work it is worth remembering that as a rule pins *1* and *4* for a four prong tube, *1* and *5* for a five prong tube, *1* and *6* for a six prong tube, and *1* and *7* for a seven prong tube are the heater or filament terminals. Invariably *2* is the plate connection; *4* for a five prong tube, *5* for a six prong tube, and *6* for a seven prong tube are the cathode connections, provided the electron emitter is indirectly heated. Generally *TC*, the top cap, is the control grid for all tubes. With octal tubes in general pin *1* is the shield, pin *2* a heater, pin *3* a plate, pin *7* a heater and pin *8* a cathode. There are a few deviations from this rule, however, so always refer to Figs. *2* and *3* when in doubt.

Referring to Fig. *1*, observe that the twin jacks numbered *1*, *2*, *3*, *4*, *5*, *6*, *7* and *8* connect to the corresponding holes in the tester sockets, and connect through the cable and the proper adapter to the corresponding socket holes in the receiver. When a milliammeter is inserted into the two holes of a twin jack by means of probe leads, current will be measured. The twin tip mechanism opens the circuit at both jacks, thus connecting the meter in series with that jack lead. When a voltmeter is connected between any *two* twin jacks the voltage between two electrodes may be measured. When the filament of a tube is being tested, a voltmeter (either A.C. or D.C. type, depending upon the nature of the filament voltage) should be connected between the proper jacks—for example, *1* and *4* in practically all four prong tubes. Filament *currents* are seldom measured, for the fact that the filament voltage is correct, supplemented by the knowledge that the tube lights or becomes hot, is a

Sparton Model 14 Super-Heterodyne



-a-

C2-1 Antenna Equalizing Condenser
C2-2 R. F. Stage Equalizing Condenser
C2-3 1st Detector Equalizing Condenser
C2-4 Oscillator Equalizing Condenser
C3-1 I. F. Input Stage Adjustable Condenser
C3-2 I. F. Output Stage Adjustable Condenser
L1 1st Tuning Coil
L2 Second Tuning Coil
L14 R. F. Transformer
L15 I. F. Transformer

VOLTAGE ANALYSIS

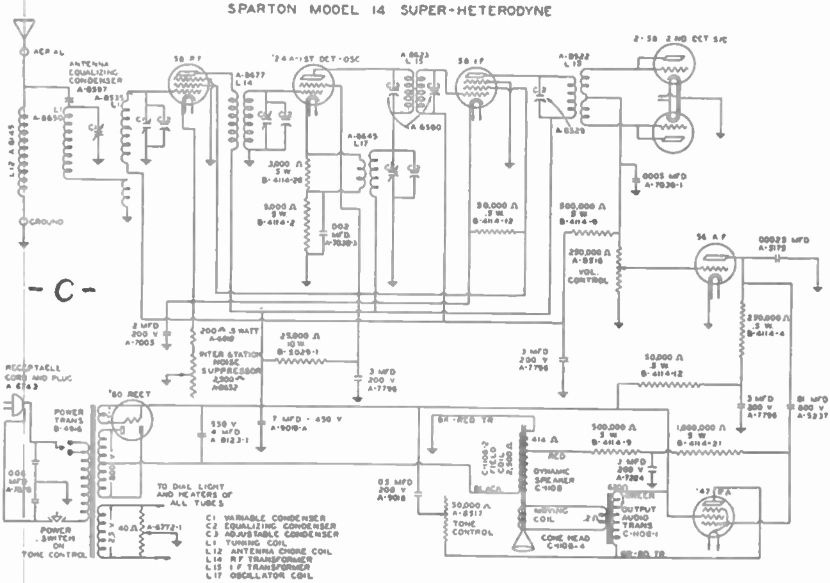
Line Voltage 115—Position of Voltage Compensator 100-115—Position of Volume Control Full

Tube	Location	Heater or Filament	Plate	Control Grid —	Screen Grid +	Plate Current M. A.
58	R. F. Stage	2.2—2.5	218—242	2—4	95—105	5.8—7.0
'24	1st Det.-Osc.	2.2—2.5	218—242	——	95—105	0.7—2.0
58	I. F. Stage	2.2—2.5	218—242	2—4	95—105	5.5—7.0
56	2nd Det.-AVC	2.2—2.5	*	*	——	*
56	2nd Det.-AVC	2.2—2.5	*	*	——	*
56	A. F. Stage	2.2—2.5	30—40	Zero	——	0.5—0.7
'47	Power Stage	2.2—2.5	203—225	†18—20	218—242	20—24
'80	Rectifier	4.5—5.0	315—345	——	——	19—23 per Plate

* Present only when signal is applied
† Measured from tap on field coil to ground.

-b-

SPARTON MODEL 14 SUPER-HETERODYNE



-c-

FIG. 4. Typical service data issued by a receiver manufacturer.

sufficient practical test of the filament supply. If a rectifier tube is being tested a D.C. voltmeter may be connected between the cathode and a plate, checking for a reasonable D.C. drop. All this will come with practice, as you follow the information in Figs. *1*, *2* and *3* while being guided by your knowledge of radio circuits.

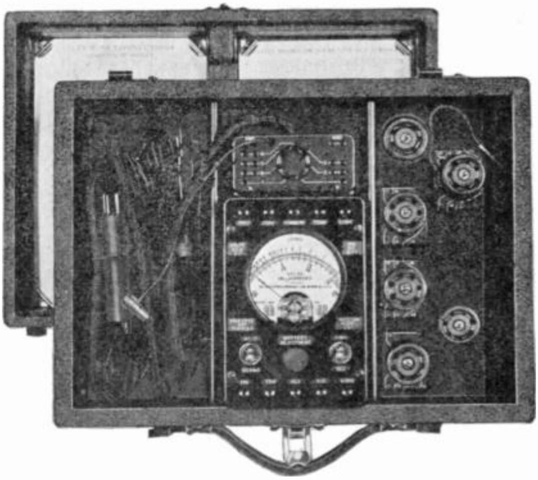
We should mention that the resistance between any two electrodes may be measured by using an ohmmeter in place of a voltmeter. The set *must* be turned off when resistance measurements are made; the tube can be left in the analyzer socket or removed, as you prefer. In all measurements the ohmmeter should be adjusted to a range which gives a meter deflection near the middle of the scale, where the greatest accuracy is obtained.

HOW TO USE THE SET ANALYZER

In discussing the set analyzer trouble shooting procedure, it will be helpful to have a typical receiver in mind. For trouble-shooting by the set analyzer method, some manufacturers supply a service information sheet like that in Fig. *4*, which includes: *a*, a chassis layout; *b*, a normal voltage and current analysis chart; *c*, a schematic circuit diagram with the important circuit constants. Essentially the same data is given in professional service manuals. The voltage-current chart is always given for a definite A.C. line voltage, with the line compensator (if one is built in) set to a definite position. The chart gives the tubes, use, voltage on the heater, plate, control grid or C bias, screen grid and other electrodes, and in some cases the important electrode currents (in Fig. *4* the plate current) for each tube. Observe that not all values can be given, nor is it desirable to give some of the operating values. For example, plate and C bias voltages on combination AVC-detector tubes exist only when the set is tuned to an R.F. signal, and depend upon the strength of the signal. As all set analyzer readings are static values (set not tuned to a signal), these voltages are omitted. A dash (—) in the chart indicates that the voltage is non-existent or of no consequence. In testing high C bias detectors some manufacturers feel that it is best to measure the *static* plate current; the static value in this case (plate current for 24 tube in *b* of Fig. *4*) is .7 ma., while with a strong signal the plate current may rise to 8 ma. Other hyphenated values (2-4) mean that any value between these two limits is to be considered normal.

When making a voltage-current analysis, an electrode current can only be measured by inserting a milliammeter in series with that electrode. Checking filament voltages offers no difficulty, as there is only one way of measuring them—across the two filament terminals of the tube socket. Other electrode voltages may be confusing; unless otherwise specified in the voltage chart, they should be measured between the cathode (at the socket) or negative filament terminal (D.C. operated filaments) and the electrode under investigation. In testing sets having A.C. filament tubes the polarity of the filament terminals is immaterial.

Let us see how we would measure the operating voltages and currents in the receiver illustrated, using the selective analyzer shown in Fig. *1*. First we will test the R.F. preselector stage. Remove the 58 tube from the R.F. socket, put it into the six prong socket of the analyzer and attach to the tube the *TC* cap connector. Attach the eight to six prong reduction adapter to the cable plug, then insert the combination into the empty socket in the chassis. Connect the top cap lead on the chassis to the top cap of the plug. Turn on the set, allow the tubes to heat, and you are ready to measure the static operating values for the



Courtesy Weston Electrical Instrument Corp.

The Weston Model 698 Selective Set Servicer, shown here, contains a multimeter and a socket adapter set. The tester plug, with its 4-foot cable, is wired to a small 7-prong tube socket block (above meter housing) on which are mounted pin jacks. The adapters in the right-hand compartment are for 4, 5, 6, large 7, and octal tubes. Probe leads (in the left-hand compartment) are used to make connections between the multimeter and the jacks on the tube socket block.

first R.F. tube. Insert the probe leads into the multimeter, but not into the selective analyzer until you are certain of what you are going to measure.

Let us first measure the filament voltage. Referring to the manufacturer's chart (*b* in Fig. *4*), we note that it should be between 2.2 and 2.5 volts A.C. Set the multimeter to a low A.C. voltage range, 0 to 5 if available and not over 0 to 15 volts. Referring to Figs. *2* and *3*, we observe that prongs *1* and *6* connect to the filament. Plug the probes into jacks *1* and *6* of the selective analyzer and read the meter. Remove the probe leads from the selective analyzer. To measure the plate voltage set the multimeter at a D.C. range of about 300 or more* volts; after referring again to Fig. *2* to locate the plate and cathode prongs, plug the probes into jacks *2* and *5* (either hole on a jack may be used for voltage tests). As jack *2* (in the plate lead) is at a positive potential with respect to jack *5*, be sure that the + probe is inserted into jack *2* (the *red* probe, usually considered +, is plugged into the + terminal of the multimeter jack). Read the meter.

---

* If in doubt as to the correct voltage, use a higher range first for safety.

With the *black* probe in jack *5*, the cathode and reference point for voltage measurements, move the + probe to jack *3*. This measures the screen grid voltage. (From a knowledge of R.F. *pentode* tubes we know that the top cap is the control grid, pin *3* is the screen grid, and pin *4* is the suppressor grid.) Changing the positive probe to jack *9* gives the C bias voltage, but you will observe that the meter needle reads backward. By reversing the probe leads to jacks *5* and *9* the meter will read upscale. Measuring these three voltages actually takes far less time than it does to tell how. To measure the plate current, which we know should be between 5.5 and 7.0 milliamperes, insert the probes into both *2* jacks and read the current.

In a set analyzer of this type it is wise to remove the probes from the jacks before making any changes in the multimeter setting. If you go from a voltage to a current reading without taking out the test probes you may burn out the meter. If the multimeter has a push-button which must be pressed to secure a meter reading, the precaution mentioned may be omitted. You can easily build into the analyzer a safety circuit like that shown inside the dotted lines of Fig. *1*.

In measuring the operating values at the 47 tube socket, jacks *1* and *5* give the filament voltage, *2* and *5* the plate voltage, *2* and *2* the plate current, and *4* and *5* the screen voltage. You will think that jacks Nos. *3* and *5* should give the C bias voltage, but measurements would show a very low value, and you would assume that there was a defect. The plate voltage and current might nevertheless be normal, facts which contradict the existence of an improper C bias. Always check the circuit diagram; in this case C bias is obtained from a tap in the loudspeaker field. Note that chart *b* (Fig. *4*) cautions you to measure C bias from this tap to ground. Of course, this is what you would do, but a study of the diagram tells you why. Between the control grid and the tap are two high value resistors, one a signal decoupling filter resistor. Connecting the meter between terminals *3* and *5* is sufficient to cause a large voltage drop in these resistors, thus reducing the voltage reading.

We shall not go into the procedure necessary for the other sockets. All that you need in order to check the remaining sockets is a knowledge of tubes, a willingness to refer to pin layout diagrams, the voltage chart and the circuit diagram. Whenever you obtain an incorrect reading refer to the diagram and try to imagine what, in that particular tube socket circuit, could cause an abnormal voltage or current. That is the secret of set analyzer trouble shooting.

Always measure voltages before currents. If the plate of a tube is shorted to either the cathode or a grid, the plate voltage would be very low and the plate current high. Measuring the plate voltage first places you on guard for excessive plate current, which might burn out your milliammeter.

Not all charts indicate extreme limits for measured values; on many voltage analysis charts only a single average value is given. Do not expect your measurements to check exactly with the values given; variations of 15 per cent above or below normal in electrode currents and voltages, and variations of up to 5 per cent above and 15 per cent below normal filament voltage are allowable. Charts like *b* in Fig. *4* are obtained by the manufacturer with a voltmeter of normal sensitivity, this in general being 1,000 ohms per volt unless otherwise specified. If you use a meter of higher sensitivity your readings will be higher; if you use a meter with lower sensitivity your readings will be lower. Again you must be familiar with the properties of your multimeter.

GENERAL SERVICING TECHNIQUE

Searching out the source of trouble does not begin with the set analyzer—even though many make this mistake.* As you already know, there are a number of important steps which should be carried out before voltages and currents in the receiver are measured; these steps are given in the *Typical Service Technique Chart* on pages *14* and *15*. Referring to this chart, notice that after the customer's complaint has been verified and an inspection made for surface defects, the technique divides into two broad groups, depending upon whether or not sounds are heard from the loudspeaker.

At this point we will consider receivers which operate improperly. As the chart points out, effect-to-cause reasoning is all-important. Failing to reason out the cause of the trouble, you can either follow the step-by-step procedure which applies to the complaint or check all tube voltages and currents with an analyzer, as you prefer.

Checking Voltages.—If the receiver is of the battery or eliminator operated type, check the main supply voltages. If the set is of the A.C. type, having a built-in power pack, first check the D.C. output voltages of the power pack. A high range D.C. voltmeter (0 to 600 volts) connected between the filament or cathode of the rectifier tube and ground should give a large reading, which in general should be greater than the sum of the highest plate voltage and the highest C bias. If an unreasonable reading is obtained, check the plate-to-plate voltage of the rectifier tube with a high range A.C. voltmeter, thus checking the A.C. supply to the rectifier. Now check with a D.C. voltmeter the cathode-to-plate voltage for each rectifier section (both plates in the case of full-wave rectifiers). A reasonably large voltage drop should be obtained for vacuum types, and about a 25 volt drop for mercury vapor rectifiers. A large difference in the two cathode-to-plate voltage readings for a full-wave rectifier may be the cause of hum.

Check the plate voltage, screen grid voltage, control grid voltage (and other electrode voltages if present), as well as the plate currents of the power tubes, intermediate A.F. tubes if used, second detector, intermediate frequency tubes, mixer-first detector tube, oscillator and preselector tubes in the order given. If any of the tubes have a variable

* Servicemen who are not trained in the latest methods often start a job by testing all tubes with a tube checker, then checking voltages and currents in each vacuum tube stage, hoping perhaps that a power supply defect will show up.

grid bias type of volume control, be sure it is set for *maximum* plate current, the accepted position for the values given in most voltage charts.* Be on the alert for conditions where current and voltage do not exist at static operation.

TUBE TESTING WITH A SOCKET ANALYZER

While analyzing a tube circuit it is wise to check the tube by using either a tube checker or the following alternate grid shift test procedure. Insert a 4.5 volt battery in series with the control grid, with polarity such that the plate current is increased. The ratio of the plate current change in milliamperes to the grid voltage shift (4.5 volts) multiplied by 1,000 is the approximate mutual conductance of the tube in micromhos. Check the value obtained against the mutual conductance listed for that tube on a tube chart; with experience you will be able to tell whether the tube is good simply by noting the amount of plate current shift. For example, the static plate current for the 47 tube in Fig. *4* is 24 ma., when the plate voltage is 225 volts and the negative grid bias 20 volts. A 4.5 volt bias voltage is inserted into the circuit by plugging the battery leads into jack No. *3* of the socket adapter in Fig. *1*. This makes the new bias 20 — 4.5 or 15.5 volts; with this value the plate current (measured by inserting meter probes into jacks No. *2*) becomes 34 milliamperes. The mutual conductance is figured from the formula:†

$$G_m = \frac{\text{change in plate current}}{\text{change in grid voltage}} \times 1{,}000 = \frac{34 - 24}{4.5} \times 1{,}000$$

$$G_m = \frac{10{,}000}{4.5} = 2{,}200 \text{ micromhos (approximately).}$$

From a tube table we find that the average G_m for a 47 tube operated at a plate voltage of 250 volts is 2,500 micromhos—so this tube is good. As a general rule the mutual conductance should not be more than 25% below the tube manufacturer's rating. If you constantly use a 4.5 volt battery, you will soon learn without reference to tube charts whether the plate current change for any tube is adequate. A simple formula for approximating the G_m of a tube (when the grid is shifted 4.5 volts) is:

$$G_m = 220 \text{ times the change (in ma.) of plate current.}$$

If you carry a supply of good tubes in your repair kit you can simplify the tube test by checking and comparing the plate current shifts of the good and questionable tubes. This is the best method if you want to keep down calculations.

---

* Some manufacturers give a second set of plate current readings for minimum voltage control position. This is a check on the operation of the volume control.

† This will not give the true G_m of the tube if a high resistance load exists in the plate circuit. In this case comparing the plate shift with that of a good tube will settle the question.

CIRCUIT DISTURBANCE TEST

When a receiver emits no sound whatsoever, it is obviously quite difficult to determine what the internal defect may be by an effect-to-cause reasoning process. Examine all the external parts and connections for possible surface defects. Determine whether all tubes heat up, thus roughly checking for a defective tube or no supply to the tube. When a set does not play, the *first step* in restoring its performance is to *find the defective stage;* next you analyze the defective stage and its tube, then correct the defect, and finally revitalize the receiver. A large number of servicemen start with socket analysis, but the expert starts with what we call the "circuit disturbance test," a procedure which quickly isolates the defective stage. The circuit disturbance test is:

1. Touch with your finger the grid of the detector (second detector in supers) or pull out the detector tube (in order to *shock* * the circuit). An output squeal, a thud or a click indicates a normal detector-A.F. system. This scheme is feasible only with grid-control type detectors. Where a diode detector is used, pull out the tube *ahead of* the detector. If an output click is heard, we may safely assume that all subsequent stages (A.F. stages) are O.K. If no click is heard, pull out the A.F. tube following the detector. A click here isolates the trouble in either the detector or the previous stage. (In universal or D.C. socket power receivers, where filaments are in series and are sometimes shunted by resistors, it is inadvisable to pull out tubes when making a circuit disturbance test. Remove the chassis from the cabinet and touch the control grid terminals of each stage in turn.)

2. Failure to get an output indication in step No. 1 indicates a defect in the detector-A.F. system. Therefore, pull out the audio and power tubes in turn, starting with those nearest the detector, and listen for the characteristic "O.K." click. In going from *no click* to *a click,* you pass through the defective stage or tube. No click in the last A.F. stage indicates a loudspeaker or power supply defect.

3. Assuming that the detector-A.F. system is in order, shock the last I.F. tube circuit and other I.F. tube circuits in order until you reach the first detector. In T.R.F. receivers shock the R.F. tube circuits, working back from the detector to the receiver input. As you pass from *a click* to *no click* you pass through the defective stage or tube, for now you are working backward. Where the stages employ a tube whose control grid connection is made to a cap on top of the tube, it is more convenient and more desirable to touch the cap or remove and reconnect the top cap connection, rather than pull out the tube. Two clicks will be heard, one

* Of course you know by now that a tube stage may be "shocked" either by touching the control grid with your finger (the more convenient method), or by pulling the tube out of the socket, then replacing it.

when the grid is touched and the other when your finger is removed.

4. To test the receiver oscillator or combination oscillator-detector, touch the control grid of the oscillator with a finger; two strong clicks, one when the cap is touched and one when the finger is removed, indicate a normally operating oscillator. Pulling out the oscillator tube is not a conclusive test.
5. Shock the preselector tube circuits, going from the mixer to the receiver input. In the preselector-oscillator circuits it is merely necessary to touch the stators of the variable condenser gang, for these are connected to the tube grids.

Many servicemen measure the voltage between the common return to all circuits (usually the chassis) and the filament or cathode of the rectifier tube before applying the circuit disturbance test, to verify the existence of a main D.C. supply. Others use the circuit disturbance test first, and if no click is heard when the power tube is removed, measure the plate-to-chassis voltage of the tube, using a socket plug-in system. Failing to get a voltage reading they then check the main supply voltage.

Always return a tube to its socket after a test. It must be remembered that pulling a tube out of an A.F. stage employing transformers or plate chokes is liable to break down the insulation of the transformer or choke. Pulling out a power tube may overload the power pack condensers sufficiently to break them down. Nevertheless, servicemen have done this for years without many breakdowns; when these do occur they may generally be ascribed to the fact that the part was going bad and would soon have broken down in normal operation.

INTERPRETING SET ANALYZER READINGS

By means of the circuit disturbance test you have roughly identified the defective stage. The circuit disturbance test is not fool-proof, but its results can very easily be verified with the aid of a modulated signal generator. (The use of the signal generator for defective stage isolation is taken up in another lesson.) Once you have isolated the defective stage, a set analyzer allows you to make a tube and circuit analysis of that stage in order to isolate the defect itself. Here are a few important general suggestions for interpreting set analyzer readings.

1. If a control grid-cathode voltage is not obtained, check the cathode-common grid return (chassis) voltage. If voltage is then obtained there is an open in the grid input circuit (coil, resistor or connection). Always refer to the circuit diagram for some indication of what would cause zero grid-cathode reading.
2. No plate-cathode voltage. Check voltage between the chassis and the B+ end of the plate coil or resistor. A voltage reading here indicates an open in the plate load or C bias resistor. Check the continuity of the C bias resistor. If O.K., an open is indicated in the plate load.

3. If no plate voltage is obtained on several tubes and from the diagram these tubes have a common supply terminal connection or common C bias resistor, check that part.
4. Normal plate voltage but high plate current. Check control grid-cathode voltage and cathode-ground voltage. The latter may be high and the former very low or non-existent, probably indicating no C bias connection to grid. A low cathode-ground voltage probably indicates a shorted C bias condenser or a change in the value of the C bias resistor.
5. All voltages low. If you have already checked the main D.C. supply, the trouble is likely to be in the power pack chokes, in the voltage divider or in the filter condensers. (You will learn how to check these when you study the point-to-point voltage trouble shooting method.)
6. If the defect is traced to a diode detector or AVC stage, the usual procedure is to test for continuity and resistance of the associated circuit parts (point-to-point procedure). Always check the continuity of AVC circuits to the input of the controlled tubes.
7. Cathode-ground voltage normal, control grid-cathode voltage low. In resistance-coupled stages this condition is normal. However, a leaky condenser between the grid and the plate of the previous tube (a defective coupling condenser) will result in a large plate current and a positive control grid-cathode voltage. Check coupling condensers after everything else fails to show why a resistance-coupled stage is inactive—shunt another good condenser across the one suspected of being open.

Set analyzers are limited in their use, and will not detect certain faults. We have already mentioned the need for circuit continuity tests in diode detector and AVC sections of the receiver. Where the plate voltage is shunt fed (fortunately not widely used in receivers except in those having resistance-capacity coupling), a defect in the coupling or grid input circuit may exist while voltages and currents may still be O.K. That is, a set analyzer will not detect an open in the coupling condenser of a resistance-capacity coupled stage. The set analyzer tests all stages at static conditions, and consequently there is no definite indication that the receiver will work satisfactorily when a signal is tuned in. A circuit disturbance test will here isolate the stage, and the coupling condenser may then be checked by substitution.

If you tune in a station with the set adapter plugged in, so as to see what circuit changes take place, the chances are that when the adapter is plugged into the R.F. and I.F. stages the signal will be by-passed through the cable instead of feeding into the next stage, and no reception will be obtained. However, it is often possible to check the A.F. system under dynamic conditions.

In spite of the shortcomings of the set analyzer it is a very valuable and often a very necessary test device. This you will be able to determine for yourself after you have learned and used all methods of servicing.

The one important fact which you should always bear in mind is that a complete service technique should start with a confirmation of the complaint. Next you trace through several important steps, the first being the inspection for possible surface defects. The effect-to-cause analysis is then used (where the receiver operates unsatisfactorily); use a complete set analyzer check only if you cannot reason out the cause or locate it by simple checks. If the set is dead you must proceed with a circuit disturbance test, pulling tubes or touching grids and noting the output indications, such as a thud, squeal or click coming from the loudspeaker, or use some other procedure to isolate the defective stage. When the defective stage has been located, the next logical step is the isolation of the defective part or the defective connection. Either the part is repaired or replaced, or the connection is made perfect. Finally, if the best possible service is to be rendered, a revitalization procedure will be essential.

By using this systematic analysis the need for recognizing or tracing every connection in the receiver is eliminated, and you have to study only a small section of the circuit. In modern receivers having all the way from ten to twenty tubes and even more, this is obviously a decided advantage.

Learning the proper order is so important that the steps taken are worth stressing again, especially now that each step has been studied in detail. They are listed here in their correct order:

1. Confirmation of the complaint.
2. Inspection for surface defects.
3. Effect-to-cause analysis (or circuit disturbance test if set is dead).
4. Defective stage analysis.
5. Repair or replacement of defective part.
6. Check on performance, followed by revitalization.

We will consider, before we close our study of servicing, the detection of and the remedial steps for curing troubles in loudspeakers and in tubes, as well as internal and external receiver noise, hum, fading and intermittent reception, lack of selectivity, sensitivity and fidelity. This study will make effect-to-cause reasoning a more valuable procedure to you for isolating radio receiver troubles. A detailed study of unique troubles always makes such troubles easy to recognize, easy to locate and easy to correct. But first we must learn the other trouble shooting methods.

TEST QUESTIONS

Be sure to number your Answer Sheet with the *number* appearing on the front cover underneath the title of this text.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your Course, and you will receive the best possible lesson service.

1. Name the ten common service complaints.

2. Would you expect to secure better performance from a receiver by changing it from A.C. operation to D.C. operation?

3. Arrange in the proper order the following six steps in servicing a dead receiver: Check on performance, followed by revitalization; circuit disturbance test; inspection for surface defects; repair or replacement of defective part; defective stage analysis; confirmation of complaint.

4. Which two pins in an octal (8-prong) tube are generally the heater terminals?

5. Is it necessary to measure filament current if the tube is warm and the filament voltage is known to be correct?

6. What information should a radio set manufacturer supply for trouble shooting by the set analyzer method?

7. What output indications are your guide in making the circuit disturbance test?

8. What is the primary purpose of the circuit disturbance test?

9. Will set analyzer voltage and current readings tell you if the plate-grid coupling condenser in a resistance-capacity amplifier stage is open?

10. In testing the antenna choke L_{12}, first tuning coil L_1, and its associated condenser C_1 in the circuit indicated by Fig. *4c*, would you use an ohmmeter or a set analyzer?

The Correct Professional Attitude - Installing and Servicing Radios. No. 36 RH

1. A serviceman should develop a Business-like attitude, Dependability, a sense of Fair Dealing, Courtesy and Neatness.

2. Ask the transportation company to send a representative (claim agent), and in his presence finish unpacking the shipment. Valid claims, will thus be approved at once.

3. It insures perfect performance and prevents future embarrassment and comebacks.

4. High position.

5. NO. First impressions are the lasting ones. Temporary or antenna substitutes do not insure best results

6. A noiseless type antenna.

7. You must at least correct the defect uppermost in the customer's mind. You have something tangible to start on.

8. For general service work a Radiotrician finds (1) Circuit diagrams showing the value of important parts as well as operating information and (2) a collection of typical troubles and remedies peculiar to definite receivers, valuable information.

9. No. Defects causing intermittent reception are hard to locate. Such jobs are best repaired at the work bench.

10. Remove the rectifier tube, ballast tube or line fuse.

Adopting a Service Technique - Set Analyzer Method. No. 37 RH-1

1. Set does not play, noisy reception, annoying hum, intermittent reception, squealing, distortion, poor volume, poor selectivity, poor sensitivity, set is generally unsatisfactory.

2. No.

3. (1), confirmation of complaint; (2), inspection for surface defects; (3), circuit disturbance test; (4), defective stage analysis; (5), repair or replacement of defective part; (6), check on performance, followed by revitalization.

4. Pins 2 and 7.

5. No.

6. A chassis layout, voltage and current analysis chart and a complete schematic circuit diagram.

7. A thud, squeal or click coming from the loudspeaker.

8. To isolate the defective stage quickly.

9. No.

10. Use an ohmmeter.

HOW TO TROUBLE SHOOT
by the
POINT TO POINT VOLTAGE
and
RESISTANCE METHODS

38RH-1

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

DISCOVERERS STILL!

Our principal asset in radio is still the unknown, the uncharted ocean of science which no man owns, and over which each radio engineer who sails—a ten thousandth edition of Christopher Columbus—may sail a discoverer still.

OWEN D. YOUNG.

NATIONAL RADIO INSTITUTE

WASHINGTON, D. C.

1941 Edition

A LESSON TEXT OF THE N. R. I. COURSE WHICH TRAINS YOU TO BECOME A RADIOTRICIAN & TELETRICIAN
(REGISTERED U. S. PATENT OFFICE) (REGISTERED U. S. PATENT OFFICE)

NCP2M741 Printed in U. S. A.

Point to Point Voltage Method

THEORY OF TECHNIQUE

It is surprising how much trouble shooting you can do with a multimeter and particularly a D.C. multirange voltmeter. You will recall in studying the set analyzer procedure that a D.C. voltmeter is used to measure electrode potentials; a D.C. milliammeter to measure electrode currents, usually the plate current; and an A.C. voltmeter to measure filament and power transformer voltages. A study of radio receiver circuits shows that in practically every vacuum tube amplifying stage there is some part which conducts the plate current. As this part will have an appreciable resistance, the voltage drop across it will be a measure of the plate current. As a rule the voltage drop across the C bias resistor will suffice. A complete check should include a plate voltage measurement. Clearly a multirange D.C. and A.C. voltmeter tester or a multimeter is sufficient to check the power supply network in a receiver.

From what we already know about servicing a receiver, the service technician should quickly be able to determine if a defect is internal or external to the chassis. *Only when an internal defect is indicated*, should the chassis be removed from the cabinet or console. An open chassis presents the most ideal condition for isolating trouble. If the repair must be made in the home, a thick cloth or felt pad can be layed across the top of the console or on a table and the chassis placed on it. The speaker should remain connected to the chassis. Now you can work on the chassis without fear of scratching or damaging the console or table. Every part of the radio is either in view or easy to get at and the need for a set analyzer switching system is eliminated.

By placing the chassis on end if it will remain that way by itself or placing it in that position by means of supports, it is possible to check the receiver while tuned to a broadcast, make any of the dynamic tests or make any alignment adjustment. It is convenient to measure the voltage across any part, or if the set is turned off measure the resistance of any part in the power supply or signal networks. In fact a plug-in analysis system would be a hindrance to quick trouble shooting.

With the negative (black) probe of the multirange voltmeter on the chassis or common return, the other or positive (red) probe may quickly be placed on any tube electrode and the supply to that electrode checked. The plate-chassis voltage is the most important and starting with the power output stage and advancing to the receiver input, all plate supplies are quickly checked. The voltage measured will usually be the sum of the plate and C bias voltages. After you measure a plate-chassis voltage, place the + probe on the cathode or —F tube terminal, that is, measure the C bias. In a self-biased tube circuit, if the plate-chassis and the cathode-chassis voltages are found normal—correct plate current is indicated.

Failure to read a plate-chassis or a C bias voltage isolates a defective stage, and that stage must be tested more critically. Any part in the stage that allows the passage of a direct current can be tested immediately, by placing a voltmeter across the part in question. Suppose, as shown in Fig. 1, a plate circuit contains the primary of an audio transformer and a resistance-capacitance filter and suppose no plate-chassis voltage was obtained. With the — probe on the chassis connect the + probe on the +B common supply terminal. If a normal reading is obtained, advance the + probe to the transformer-resistor connection. No reading indicates a defective resistor or resistor connection provided the terminal, the plate of the tube or the primary is not shorted to the chassis. If a reading is obtained, an open in the primary of the transformer is indicated. The important feature of the point to point voltage procedure is that, in addition to measuring the operating voltages, we automatically test the circuit continuity. By placing the voltmeter probes on the grid and plate terminals, continuity in the grid input circuit may be checked. We will shortly go into all this in greater detail.

Another interesting feature of the point to point voltage analysis is that the voltages may be measured with the set turned on and tuned to a broadcast. Thus circuits may be probed which operate only when the set is tuned to receive a carrier signal. A voltmeter with a high sensitivity (equal or greater than 1000 ohms per volt) will not materially affect operating conditions except when probing on the control grid. If you had a vacuum tube voltmeter or a high resistance thermo-couple voltmeter, with a condenser in series with one of the probes, it would be possible to check the R.F. input and output of R.F. stages advancing from the receiver input to the input of the last detector—a dynamic test. A copper oxide rectifier voltmeter could be used for dynamic tests in the audio system.

Very few set makers give the voltages across the various parts of the circuit. As electrode voltages and currents and the resistance of the parts are given, we may still use this method, if we are on the lookout for possible confusing effects. For example, in the detector circuit shown in Fig. 1, the manufacturer indicates in a chart that the plate current is .2 ma. Therefore the voltage across the transformer primary R_p should be 500 × .2 ÷ 1,000 equals .1 volt; across R it should be 75,000 × .2 ÷ 1,000 equals 15 volts; and across R_g it should be 30,000 × .2 ÷ 1,000 equals 6 volts. Suppose you measure these voltages with a 1,000 ohm per volt meter on the 0 to 15 volt range. You would read a value of .1 volts across R_p. In reading the voltage across R you would find it to be less than 15 volts. In this case we have a voltmeter whose resistance of 15,000 ohms is shunted across the 75,000 ohm resistor or a total of 12,500 ohms.* Assuming that

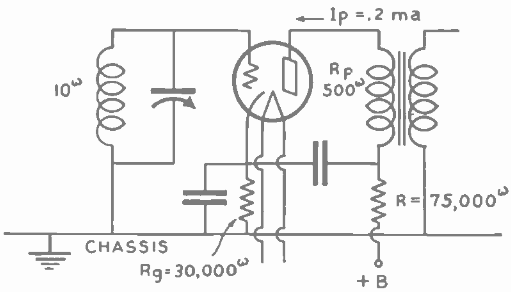


FIG. 1

the plate current does not change materially with the voltmeter in shunt, the voltage read will be 12,500 × .2 ÷ 1,000 equal to 2.5 volts. By the same reasoning we would assume that the voltage read across R_g would be 2 volts. Actually it would be higher, as reducing the C bias would increase the plate current. More than likely the voltage-current chart furnished by the set maker would give the correct C bias voltage reading using a 1,000 ohm per volt meter. If you use a low resistance voltmeter, the low resistance of the meter in shunt, will seriously lower the reading.

The point we are bringing out is that, although the true voltages across circuit parts are not read, with a little thought it is possible to realize whether continuity exists and whether a reasonable drop is obtained. If for any reason the exact voltage must be checked, an ohmmeter would give the exact part resist-

* Shunt combination $= \frac{75{,}000 \times 15{,}000}{75{,}000 + 15{,}000} = 12{,}500$ ohms

ance, a series milliammeter the current, and the product of these two values divided by 1,000 will yield the desired voltage difference. If the manufacturer should give a point to point voltage chart, then the problem is greatly simplified.

The point to point voltage trouble shooting technique is extensively used by experts when the chassis is brought to the shop service work bench, and under these conditions we recommend it to you. Some servicemen object to using this method in the customer's house, in that it gives the customer the wrong aspect in servicing. They claim that professional looking equipment impresses the set owner. The correct attitude to take is to use that technique which will find the source of trouble as quickly as possible.

Some receivers are so well shielded that it would be inconvenient and perhaps impractical to open up the chassis so all the connections lay in full view. The wiring in midget and universal receivers is sometimes so poorly laid out that it is impossible to locate or get at the sockets. In such cases, one of the other methods, particularly the set analyzer procedure, may well be followed.

ESSENTIAL STEPS

Every technique starts with the confirmation of the complaint. Then

1. The receiver, the pickup system and the power socket line are carefully examined for surface defects.

2. If the set plays, but unsatisfactorily, then the output sounds or the interference should be carefully noted to ascertain whether the effects observed indicate what the cause may be.

3. Tubes should be checked, using either a portable tube checker or the service signal generator-output meter comparison method. In this technique the tube check is the more desirable device.

4. If the set does not play, the "circuit disturbance" test should be carefully carried through. As you have traced the defect to a definite stage and have eliminated the tubes as a source of trouble, you have definitely shown that the defect is internal. Then you may remove the chassis from the cabinet and check the point to point voltages in the defective stage.

5. Failing to isolate the defective stage by the circuit disturbance test, the next step is to check the entire chassis by means of the point to point voltage procedure. Starting with the high

voltage secondary of the power transformer, the voltages through the power pack are checked to the main D.C. supply. After this start with the power output stage and advancing to the receiver input, check the operating voltages at each tube and the intermediate circuit part voltage drops. Defects are thus isolated.

POINT TO POINT VOLTAGE TESTS IN A T.R.F. RECEIVER

In order to illustrate the necessary steps in checking a receiver we will use the simple T.R.F. receiver shown in Fig. 2. For the sake of completeness we will assume that the circuit disturbance test did not isolate the defective stage.

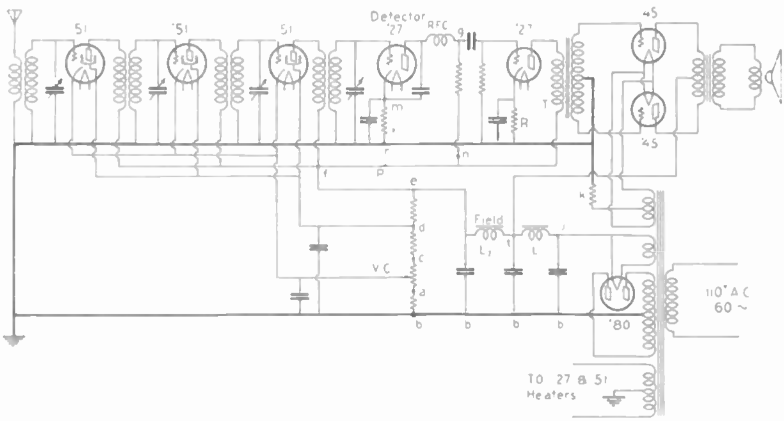


Fig. 2

In this simple circuit there are three variable mu R.F. amplifier tubes with four tuned R.F. circuits. The detector is of the C bias type, and is resistance-capacitance coupled to the first audio tube. The latter is coupled in the usual manner to a push-pull stage consisting of two '45 tubes. The power pack consists of two filter sections; the condensers may be of the paper or of the electrolytic type. The choke coil in the second section of the filter is the field coil of the dynamic speaker.

All audio tubes and the detector tube are self-biased, that is, their bias voltages are obtained in the form of voltage drops in resistors placed in the path of the plate currents. Thus, the plate current of the first A.F. tube passes through the resistor *R* and the voltage drop created in this resistor furnishes the bias for this tube. In a similar manner the resistor *X* furnishes the detector bias, and the resistor *K* the bias for the push-pull tubes. The current through resistance *V.C.* to *b* is partially the voltage divider bleeder current and partially the plate and screen grid current of all three '51 tubes. The volume is controlled by varying the C bias potential, the minimum value being obtained by placing *V.C.* at *a*.

In making a routine point to point voltage test, you must be careful in setting the volume control. In this particular receiver, the volume control is the potentiometer whose terminals are *a* and *c*. When the slider is at the upper end, at *c*, the currents flowing in the plate circuits of the R.F. tubes will be small and the bleeder current will mainly determine the C bias voltage. The grid bias under this condition will be the greatest. On the other hand, when the potentiometer slider is moved to the point *a*, the current in the plate circuits of the tubes is greatest, and under this condition, the bleeder, plate, and screen current flowing through the biasing resistor *a-b* determines the C bias. The total grid bias variation will be from about 3 volts to about 50 volts.

The important fact to remember is that whenever the circuit voltages may be disturbed by some manual control, always set this control to get normal or maximum tube operation. In this case, set *V.C.* at *a*, so the plate current of the tubes it controls are at maximum, normal value.

Let us now take up voltage measurements in the power pack. First we would check (using a high range A.C. voltmeter) the high voltage secondary A.C. potential. Measure the A.C. voltage between one plate of the full wave rectifier and the center of the secondary. Repeat for the other plate. These two voltages should agree with the manufacturer's values and be approximately equal. The next thing that interests us is the D.C. voltage the rectifier tube is delivering to the filter circuit. This can be easily measured by connecting the high range D.C. voltmeter between the two points *j* and *b* in Fig. 2. In making these measurements, however, it must be remembered that we are measuring the average value of the D.C. voltage, *not the peak value*. We shall discuss this matter later on.

Next there is the voltage drop in the choke coil L_1. This can be measured in two ways: we can place the voltmeter directly across the terminals of L_1, as between *j and t*. But if it is not convenient to get at L_1, we may measure the voltage between *t* and *b;* then subtracting this from the voltage between *j* and *b* we have the drop across L_1. Conversely, knowing the drop across L_1, this can be subtracted from the voltage across *j-b* to determine that across *t-b*.

In a similar manner, we can investigate the voltage conditions in the next filter section, obtaining the voltage across *e-b* and that across L_2.

As we have said, the voltages across the filter condensers measured by means of D.C. voltmeters are average voltages. It is often desirable to know what the peak voltages are across the condensers. This is especially important nowadays when electrolytic condensers are used extensively. The safe peak voltages applied to these condensers must not be exceeded, otherwise the leakage current through the electrolytic condenser will become unusually high, heat the condenser and cause it to break down. In the case of wet electrolytics you will probably hear a *sizzling* noise, indicating intermittent breakdown and healing of the dielectric film in the condenser. In semi-dry and dry types this effect is not observed and you must resort to common sense or to more precise methods of measuring the peak applied voltages. We should add that the electrolytics in the filter input are more often subjected to excessive peak voltages.

If a milliammeter with a shorting switch across it is placed in series with the condenser and the leakage current measured (opening the shorting switch) after the initial excessive current flow has passed, it should be less than 2 milliamperes for an eight mfd. condenser in good condition. If more flows when using a new 600 volt peak electrolytic condenser, the condenser will eventually break down. Peak voltage in excess of 600 volts should not occur in a properly designed receiver, so the only precaution you may take after installing a new condenser is to run the primary of the power transformer on the high voltage tap or insert a line resistor.

It is interesting to know how peak voltages may be measured. The simplest and most economical way of measuring these peak voltages is with a vacuum tube voltmeter used in the "slide back" manner. The circuit is shown in Fig. 3. The tube may be a '37, its input connected to a potential divider. The ratio of the potential divider may be made anything desired, but a ratio of about 40 to 1 will be satisfactory for most work. That is, we may make the lower part equal to say 4,000 ohms; the total resistance would then be 160,000 ohms, which would make the upper part equal to 160,000 − 4,000 or 156,000 ohms. Then, if any voltage is applied across the terminals *AB*, only 1/40 of this will be acting on the tube.

First, with the terminal *AB* disconnected, the potentiometer *P* is adjusted until the plate current of the tube just becomes zero. This is noted on the plate current meter *M*, which may have a range of 0–5 ma., or less.

Next, connect the terminals *AB* to the points where we wish to measure the voltage, as at points *j* and *b* of Fig. 2. Connect *A* to the positive terminal, at *j*. The plate current of the tube will rise—may even exceed the maximum reading of the meter. Now readjust the potentiometer *P* until the plate current is again zero.

In each case where the plate current was made zero, read the D.C. voltmeter *V*. The difference between the two readings is the value of the peak voltage applied to the grid and cathode of the tube. The voltage across the terminals *AB*—that is, the voltage we are measuring—is, of course, 40 times this value.

The B battery in Fig. 3 may be a 22.5 volt block; the grid voltmeter *V* may have range of zero to 20 volts. The C battery may also be a 22.5 volt block.

The resistance of the potential divider, *AB*, should be as high as it is possible to obtain accurately measured resistances; at least it should be much higher than the net resistance connected to the power supply apparatus, as at *eb* in Fig. 2.

Returning now to our point-to-point analysis of the circuit shown in Fig. 2. We have determined whether the filter voltages are normal except the voltages at the divider. We should find in placing a voltmeter across *b* and *d* that it should read the normal R.F. screen voltage plus the normal or lowest R.F. C bias voltage. The voltage across *b* and *V.C.* should be less than 50 volts. If no potential difference is measured in both cases, question the voltage divider by-pass condensers.

Now we should turn our attention to the audio output stage. With the negative voltmeter probe on the chassis, we place the plus probe on the plate of one and then on the other '45 tube. The voltages measured should be very nearly equal. Because the resistance of the input of the push-pull transformer is very low, placing the + probe on the center tap of the primary should show only a slight increase in voltage and the value should be the same as read at *b–t*. Should no voltage at one plate be obtained and a reading obtained at the center tap, there should be no doubt that that half of the primary feeding the no-voltage plate is open, or at least the connection has opened up. With the − probe on the chassis and the + probe on the center tap of the filament winding feeding the '45 tubes, you will measure the C bias of the '45 tubes. As resistor *K* is always small in ohmic value compared to the resistance of the voltmeter, the true bias value will be obtained. If measured as normal, we know that the plate currents of the '45 tubes are essentially correct, as we have already checked the plate voltage as normal.

The next stage tested is the first audio. With the − voltmeter probe on the chassis and the + probe on the plate of this '27 tube, we measure the normal plate voltage plus the C bias voltage. Failure to get a reading apparently indicates an open transformer primary or primary connection; or a plate to chassis or primary to secondary short. If we measured the voltage across *b–e* as normal, we may assume that there is no short in this plate

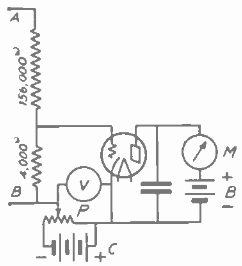


Fig. 3

circuit nor is there a primary to secondary transformer short. One exception may be that common connection *f* is open. By placing the + probe at the plates of the other voltage amplifier tubes, we may quickly ascertain if the connection at *f* is defective. Voltages between the chassis and the other plates definitely indicate an open primary. Placing the + probe on the cathode, the C bias voltage is obtained. As resistor *R* is rather low in ohmic value, the true C bias voltage is obtained. No voltage indicates a shorted C bias condenser or no plate current. We may check for plate current* at once by measuring the drop across the primary of the transformer. With the + probe on the plate of the first audio, switch the − probe to the grid. A reading even if much less than normal plate voltage establishes the fact that the grid input resistor is intact. Now, if we shift the + probe to

* This test is merely to indicate that plate current exists, not that it is normal.

the chassis, the — probe remaining on the grid, and if we get a down scale reading we know that the coupling condenser of the resistance-capacitance coupler is leaky or the audio amplifier tube is gassy. Try a new tube. A large down scale reading (reverse probes) means a shorted coupling condenser.

The detector stage offers a few chances of going wrong, if we are not careful. Again we place the — probe of the voltmeter on the chassis and the + probe on the plate. The reading obtained should be less than the main supply voltage (that between *b–e*), less by the drop in resistor *g–n*. If the manufacturer gives the plate-cathode voltage (using a normal sensitive voltmeter) you have a definite value for comparison. Next place the + probe on *m*. This should be equal to the C bias value given by the manufacturer. Remember that you are not reading the true detector C bias unless you use a 20,000 ohm per volt sensitive voltmeter—a device rarely found in a service shop. Resistor *X* may have a value of from 30,000 to 50,000 ohms. If you want to know the exact C bias, measure the plate m.a. current and the ohmic value of the C bias resistor. The product of both divided by 1,000 is the normal operating value. There would not be any real need for such a procedure, for you may as well be guided by the value given by manufacturers or by your sense of what is or is not correct.

Should you get no detector tube plate-chassis voltage, place the + probe at *g* and then at *n* to determine if an open exists in the choke or resistor. Placing the + probe on the plate and the — probe on the grid indicates a grid input feed, if a normal chassis-plate voltage is obtained. Should you read a high C bias and a low chassis-plate voltage you may be reasonably sure that the detector R.F. by-pass condenser is shorted.

Testing the R.F. stages in the receiver shown in Fig. 2 should offer no difficulty. With the — probe on the chassis place the + probe on the various plates and screen grids. As substantially no drop in voltage exists in the primaries of the R.F. transformers the plate voltages read should equal that obtained between *b* and *e* and the screen voltages that obtained at *b* and *d*. All screen grid-chassis and all plate-chassis voltages should be equal in value. With the + probe on the cathode vary the potentiometer V.C. The voltmeter reading should go up in value as you turn *V.C.* towards *C*. This checks the operation of the volume control.

There are only a few more tests. With an A.C. voltmeter check the filament voltages to each tube. If the tubes light or heat and the voltages measured are normal, we may assume that the filaments are not overloaded.

Place one of the voltmeter leads on the receiver ANT post and the other on some + connection in the chassis. A voltage reading establishes continuity through the primary of the antenna coil. In some receivers the chassis is not connected to an external ground, although the low end of the primary in the antenna coil is externally grounded. In such circuits a voltmeter alone will not check the primary of the antenna coupler. As most multimeters are built with an ohmmeter we should have no difficulty in checking a complete antenna-chassis connection. If you are making this point to point resistance test in the house—measure the antenna-ground resistance, disconnecting it from the receiver. It should be infinitely large.

We have checked the entire chassis by the point to point voltage trouble shooting method. However, a complete service job would first follow the steps of: confirming the complaint, hunting for surface defects, applying the effect to cause reasoning, and trying to isolate the defective stage by the circuit disturbance test. Failing to locate the defective stage, and now reasonably sure that the defect is internal, we would remove the chassis from the cabinet or console and apply point to point voltage tests starting in the power supply and ending in the R. F. sections. Having found the defect and made the correction, a revitalization procedure would place the machine in ideal operating condition. Actually there would be no need for a complete check of this sort unless the circuit disturbance test failed to isolate the defective stage. Let us review the circuit disturbance test procedure for this machine, assuming that the chassis is in the cabinet.

Pulling out and replacing the detector tube should give rise to an output thud from the speaker if the detector and audio system is in order. Failing to get an output thud, remove first one then the other '45 tube. Again output thuds indicate normal circuit conditions. Failing to get a thud in both cases, check the main supply voltage, chassis–80 tube filament supply winding or chassis to connection of the speaker field choke. If measured as normal, check the output transformer and voice coil connections. Assuming that the output stages checked normal, pull out the first audio tube. An output thud at this point where one was not obtained by pulling out the detector, definitely isolates the trouble in the detector-first audio coupling circuits.

If the detector-audio system checks normal, remove the control grid cap from the last R.F. tube and reconnect. An output indication shows that everything to that point is normal. As you advance this test to the input and go from a signal to no signal, you pass through the defective stage. Once the defective stage has been isolated the circuit may be checked by the point to point voltage method, applying the same reasoning as to what may be wrong as was just explained.

Although the circuit shown in Fig. 2 is rather simple, and more involved circuits will be met, the same principle and ideas are used. It is essential to know how the circuit works from a study of the diagram and this is based entirely on your acquired knowledge of radio theory and receiver design. Above all in checking a chassis from the bottom, your guide in determining the electrodes will be a tube chart showing what electrodes are connected to pins 1, 2, 3, 4, 5, 6, 7 and T_c.

A number of servicemen employ what may be considered as a point to point voltage test, except voltmeters are not used. To check for a chassis-plate voltage, they would short *momentarily* the plate to the chassis with a screw-driver. To test for filament voltage, they use a pilot lamp indicator or momentarily short the filament. A spark indicates the presence of a voltage.

Sooner or later you will discover these tricks so we have mentioned this procedure as a warning not to follow it. The circuit disturbance test places as severe a shock on the receiver as one should dare apply. The simplest of service testers will include a D.C. voltmeter, so there need be no excuse for not having one to use.

POINT TO POINT RESISTANCE METHOD

Theory of Method. From a purely constructional viewpoint, a radio receiver is made up of coils, condensers, resistors, tubes; the necessary brackets and sockets to hold these various parts in place; and wires to connect these parts into a working circuit. We can test tubes in a tube checker and thereby eliminate them as sources of trouble. Resistors may be checked by measuring their ohmic value. Condensers may be leaky or shorted and an ohmmeter check will, in most cases, suffice to establish their serviceability. A positive check on condensers is obtained by measuring their capacity. In some cases the fact that they will hold a charge will be enough of a check. Coils and transformers may be checked by measuring the inductance of the various coils. From a more practical viewpoint, every coil in good condition will have a definite ohmic resistance. An ohmic check should suffice. If a continuity check is made on the circuits we can readily establish the fact that the connections are as intended, provided we have a circuit diagram of the receiver to guide us.

This sort of reasoning has led to the point to point resistance measurement, and is quickly applied when the circuit diagram submitted by the set maker gives the resistance values of every coil and resistor. Fortunately this practice is now a universal feature of modern service diagrams, although when a few values are omitted an approximate assumed value may be used. In general you will find in tracing the circuit of any amplifying stage of a radio receiver, that there will be a continuous circuit between any two electrodes of the tube, the resistance of which will be determined by the ohmic resistance of the components connected between these two electrodes. For example, in Fig. 1, shown below, an ohmmeter connected between the grid and cathode

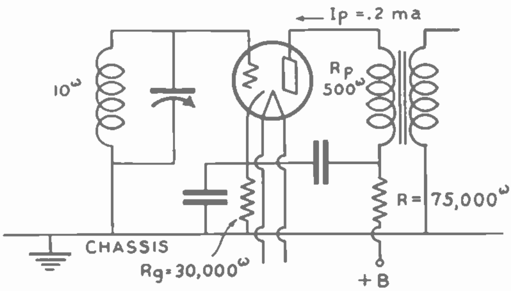


Fig. 1

terminals of the socket (tube removed) should read 10 + 30,000 or 30,010 ohms. By placing one probe of the ohmmeter on the chassis and the other alternately on the grid, cathode and plate we should read 10ω, 30,000ω and 500 + 75,000 + the resistance of the devices connected between chassis and $+B$. In the latter two cases correct ohmic readings indicate that the condensers are not shorted. By opening one condenser connection a charging or capacity test will establish the fact that condenser is internally open or is intact.

A grid to cathode ohmmeter test only establishes the fact that the grid bias resistor is in normal condition and that a chassis to grid connection exists. Let us see why this is so. The best service ohmmeter will yield a reading which is accurate to 2 per cent in its low ranges and 10 per cent in its high ranges.

What do we mean by this? If we measure a part as 100 ohms we are only informed that it is about 100 ohms. Actually it may be 2 per cent above or below the value read or, in this case, between 98 and 102 ohms. Similarly, a reading of 100,000 ohms using the high range of an ohmmeter, merely indicates that the true resistance is from 90,000$^{\omega}$ (10 per cent below) to 110,000$^{\omega}$ (10 per cent above).

All this points to the fact that the ohmmeter range and the resistance network measured should be carefully considered. First the ohmmeter range selected should give a low or up to mid-scale deflection, the region in which the ohmmeter readings are most precise. For example, a typical ohmmeter reads 0 to 1,500 ohms and 0 to 150,000 ohms with accuracy although higher values may be measured in each range. The readings are "bunched" on the upper ohmmeter scale deflections and therefore only approximating values are measured. Suppose you were measuring a part known to be about 10,000 ohms, common sense would tell you to use the higher range, even though this value may be read on the lower range.

Turning to the reading of the resistance between grid and cathode of Fig. 1, which we know should be 30,010 ohms. Assuming that the ohmmeter range used yields 2 per cent precision readings. From what was said, we know that a reading of 29,400 to 30,600 ohms must be accepted as the best obtainable. At once we realize that the grid input coil can be completely shorted and still be in the accepted range. So a grid to cathode check merely indicates continuity. In fact, *when several high resistance parts are in series with one or more low resistance parts, an ohmmeter reading could only tell us that the circuit had continuity—was not open.*

How can we tell that the grid coil is not shorted? Apply the ohmmeter so that the input coil resistance will predominate. In this case measure the resistance between the grid and chassis.

The secrets of successful point to point resistance trouble shooting are: selecting a suitable ohmmeter range and measuring the resistance between points which yield useful information.

Apparatus Required. The basic testing devices needed will at least include, 1, a portable tube checker and 2, a multirange ohmmeter with a range of at least 1 to 1,500,000 ohms. As we develop and modify this trouble shooting method we will find that a multirange A.C. and D.C. voltmeter will be quite helpful. An A.C. voltmeter will help establish the fact that power is supplied to the power transformers, that the high and low A.C. power output voltages are at rated value. A D.C. voltmeter is of immense value in establishing the fact that the power pack is delivering rated voltage. In testing battery operated receivers it is an essential device. A well designed and precise multimeter will serve all three needs.

Some servicemen insist that a capacity meter is required to check the condition of filter and by-pass condensers. Yet it should be obvious that if a condenser is not shorted or leaky, easily determined with an ohmmeter, that the capacitor in question is either intact or open. A charging test—placing a voltage across the condenser alone, and then shorting the terminal yielding a spark—should suffice. If the receiver originally operated, even though unsatisfactorily, and it is felt that the trouble is due to an open in some definite condenser, placing a duplicate con-

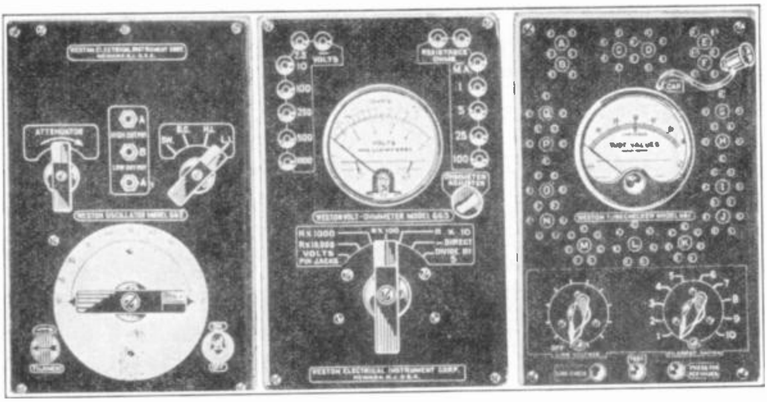


FIG. 4

denser in shunt should restore normal operation or improve reception, if an open condenser is the fault. Essentially a capacity tester is a luxury and not a necessity.

A service oscillator, although not strictly required for a point to point resistance trouble shooting technique, will be required for aligning tubes, aligning I.F. and T.R.F. stages, to make the preselector and oscillator of superheterodynes track, all a part of the process of revitalization. Summing it all up, a portable tube checker, a multimeter and an oscillator are essential equipment. Typical commercial devices which may be assembled in a single carrying case are shown in Fig. 4.

Testing Technique. Assuming that you are fully aware of the nature of the complaint and the complaint does not suggest a special check, the logical order in applying the point to point resistance method starts with:

1. A critical examination of the chassis, antenna-ground system, power supply for obvious surface defects—and continues with

2. Predetermination of the cause from analyzing the apparent effects.

3. If the set is totally inactive and you observe that all tubes light, check each tube in a tube checker. If a tube does not light, test that tube first. If found defective, replace with a new one and try tuning in a station. If the set is still inactive, test remainder of tubes in tube checker.

We now may proceed in two ways. One scheme would be to isolate the defective stage by the circuit disturbance test, and then test the stage by a point to point resistance procedure. The other way and the one usually suggested by some experts is to first remove all tubes from the receiver as this method eliminates the need of having them for testing purposes, and—

4. Test the A.C. voltage supplied to the plate or plates of the rectifier tube.

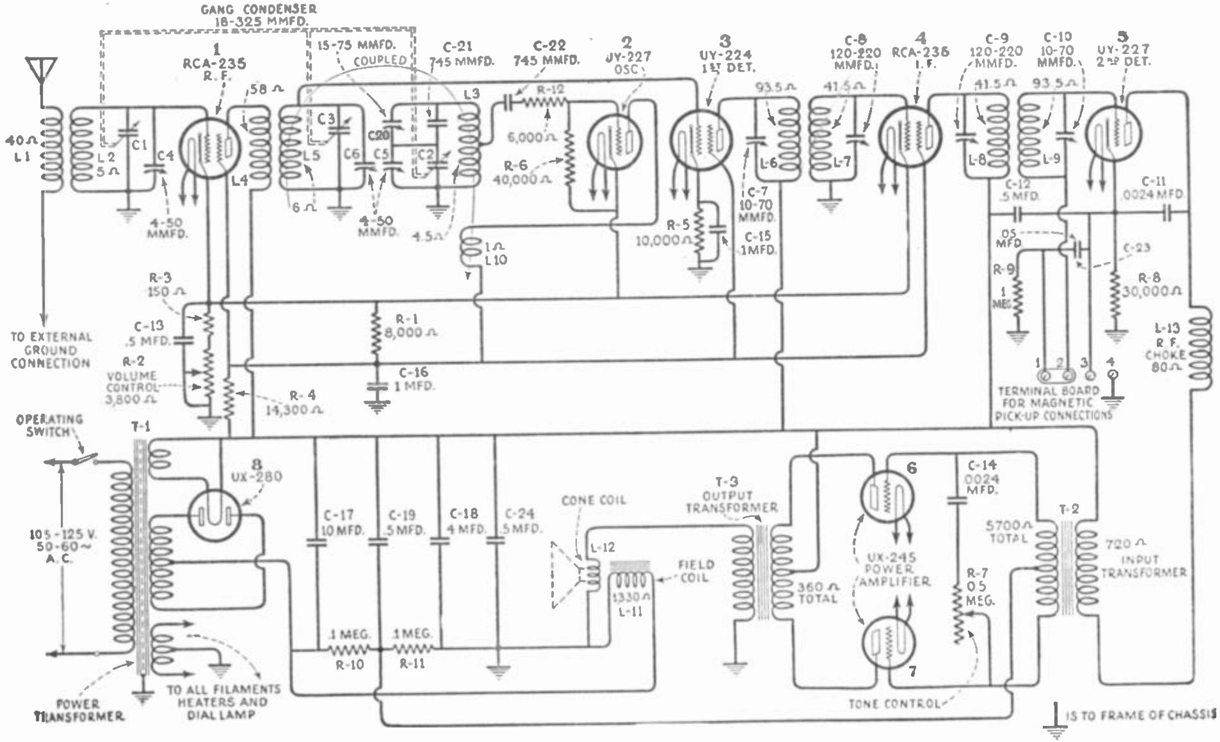
5. Measure the resistance of the aerial-ground network.

6. Check the continuity and resistance of the secondary of the output transformer, the resistance of the voice coil in dynamic speaker, and the speaker A.F. excitation coils in magnetic units. Tests 5 and 6 are the two circuits that cannot be checked from the sockets and are eliminated first as sources of trouble.

7. Starting with the tube socket nearest the receiver input, measure the resistance between the chassis and the tube electrodes. Depending on the nature of the receiver circuit, more valuable information may often be obtained by measuring resistance from some electrode of the tube whose circuits are under test to the filament of the rectifier tube or perhaps to some electrode of another tube in the receiver. It is worth stressing that *the two most used reference points are the chassis* and the cathode (or filament) of the rectifier tube.*

---

* In universal (A.C.—D.C.) power operated receivers the chassis is not a common terminal point, but the negative power supply line is the —B or common reference terminal. The prong on the power plug that *does not* trace to the plate of the rectifier tube is the most convenient point of contact.



Schematic Wiring Diagram

FIG. 5. Note: Terminals *1* and *2* are connected.

Where one tube is controlled by another, some electrode of the controlled tube will be electrically connected to the controlling tube. The connecting circuit should be checked. For example, in an A.V.C. receiver the control grid of the R.F. or I.F. amplifier tube traces to the negative terminal of the plate load of the A.V.C. tube. This network should be tested by checking between the controlled and controlling tubes.

Where condensers are in the networks under test, they may be tested for opens or capacity.

Which of the two procedures you follow is entirely up to you, although it appears from practice that if the defective stage can be isolated at once by the circuit disturbance test, considerable time may be saved.

Typical Point to Point Resistance Analysis. Figure 5 shows a simple superheterodyne receiver diagram exactly as presented by the manufacturer in his service manual. Fortunately the ohmic resistance of most of the parts are given. In illustrating the point to point technique as applied to this receiver we will check the entire receiver. Actually in practice the procedure would not be as lengthy as we would indicate by the following discussion, for the defect would probably be isolated before a complete diagnosis was made.

We will assume that steps 1, 2 and 3 of the previous section have been made and all indications are that the defect is internal. Remove all tubes from their sockets. The next step is to follow the complete point to point resistance procedure which will be to remove the chassis from the cabinet, for quick trouble shooting is best accomplished with an open chassis. Remove all the tubes which we know by test are in normal operating condition.

In the following discussion we will first consider the measurements that can be made if the chassis is not removed from the cabinet and then mention the additional checks possible if the chassis is open. One of the features of a point to point resistance test is that a considerable amount of checking can be made from the top of the chassis (chassis in cabinet).

Turn the *operating switch* on, and with a high range A.C. voltmeter, check the voltage between the two rectifier plate socket pin grips or terminals. Next check the voltage between one plate and the chassis and the other plate and the chassis. The two last readings should be very nearly equal. If in step No. 3, explained in the previous section, you found that all tubes lighted, there would be no need of checking the low A.C. voltage secondary windings. If some tubes did not light, but the tube was checked to be O.K., then test the A.C. voltage at those sockets. After power measurements have been made, turn power switch off before making resistance tests.

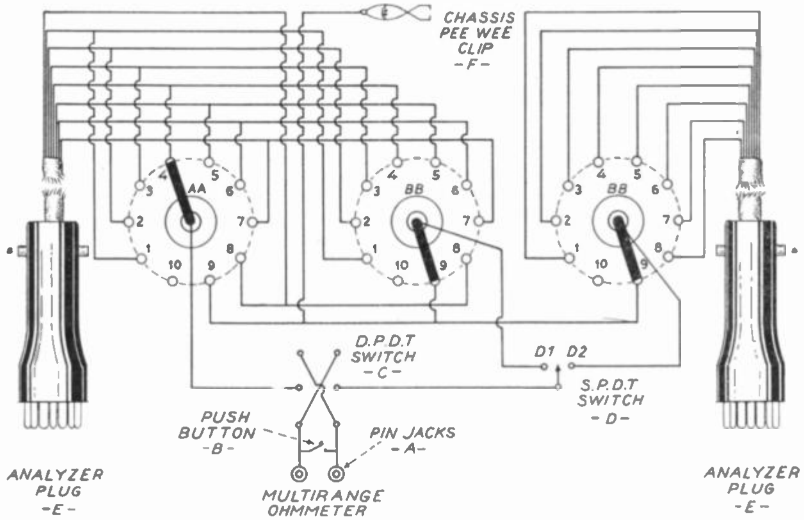


Fig. 6

A—Insulated tip jacks, 2 needed; B—Pearl pushbutton, 1 needed.
C—Double pole, double throw toggle switch, 1 needed.
D—Single pole, double throw toggle switch, 1 needed.
AA—Yaxley No. 1610 single gang 10 point switch with 1 to 10 etched dial plate, 1 needed.
BB—Yaxley No. 1620 two gang 10 point switch with 1 to 10 etched dial plate, 1 needed.
E—Naald No. 907 WLCA 7 prong plug with cable, 2 needed.

E_1—Naald 977 DSA large seven prong socket adapter, 2 needed.
E_2—Naald 976 DSNA six prong socket adapter, 2 needed.
E_3—Naald 975 DSNA five prong socket adapter, 2 needed.
E_4—Naald 974 DSNA four prong socket adapter, 2 needed.
E_5—Naald 978 MSA eight prong socket adapter, 2 needed.
} Not shown in Fig. 6

In determining which socket terminals are *F*, *H*, *K*, *G*, G_s, G_{su}, G_o *P*, etc., it will be essential that you be familiar with the R.M.A. socket numerical notation and be guided by the chart of tube types and electrode location. This is given elsewhere in the Course. Circuit diagrams such as Fig. 5 do not give this information. We will assume that you will be able to identify the socket pin holes, or the socket connections whether you probe from the top or the bottom of the chassis.

Note that coil L_1 has no connection to a socket. Possible trouble at this point must be eliminated at once. Connect the ohmmeter to the ANT and GND post of the receiver. It should read about 40 ohms. Observe that there is no connection to the chassis. So check continuity between ANT terminal and chassis. The ohmmeter should read infinite resistance.

We turn our attention to the output circuit and particularly the voice coil and the secondary of the output transformer. The circuit diagram informs us that it cannot be checked from a tube socket. Inspection of the chassis tells us that the speaker has its own terminal strip.* Test can be made here if we can identify the terminals. Can this be done without opening up the chassis? From the diagram, we know that only one terminal connects directly to the chassis. This we identify at once. Between this terminal and one of the two remaining terminals we should measure about 1,330 ohms and it happens that that terminal is the one with the double lead. The other terminal must be the connection from the voice coil which leads to the secondary of the output transformer.

As we just mentioned a resistance test between the chassis and the double lead terminal should give an ohmmeter reading of about 1,330 ohms and we assume that the field is intact. (Actually the field is shunted by the two .1 meg. resistors in series. Clearly a .2 meg. resistor in shunt with a 1,330 ohm resistor should not materially lower the resistance of the combination.) With one probe on the chassis and the other on the last of the three terminals, we should read a value determined by the resistance of the voice coil shunted by the secondary of T-3. The values are not given so we must be guided by experience. We would know that the voice coil would have an ohmic resistance of about 10 ohms—the secondary would be less. Therefore, the reading obtained should be quite a bit lower than 10 ohms and at least above 1 ohm. All we may check for is a total short.

Now start with the first R.F. tube—numbered *1* in this diagram. When the chassis is in the cabinet we are limited to chassis and socket terminal probing because leads from most parts are below the chassis. With one ohmmeter probe on the chassis, the other is placed on the grid terminal (socket pin hole). If we get a reading of 5 ohms, we know that C_1 and its trimmer

* In most receivers the speaker cable, whether it uses a terminal strip or a plug-in socket connection, may be disconnected from the chassis and the voice coil on the output transformer and the field coil tested. These details are not shown in a circuit diagram, such as Fig. 5.

C_4 are not shorted and coil L_2 is not open. Of course, we do not know that the connections of C_1 and C_4 to the circuit are broken. If the chassis were out of the cabinet and in full view, we could check such possibilities. A physical inspection should from a practical point of view suffice.

In testing the cathode-chassis resistance we work through R_3 and the volume control R_2. Assuming that condenser C_{13} is not shorted, we should obtain a reading of 150 + 3,800 equal to 3,950 ohms when the volume control is at its minimum setting, and 150 ohms for a maximum setting. With chassis out of the cabinet C_{13} may be temporarily unsoldered from resistor R_3 and checked with a capacity meter or charged with a 45 volt battery block. Upon shorting the condenser a spark indicates a good condenser. It should be realized that a short in condenser C_{16} would throw resistor R_1 in shunt with R_3 and R_2. The effect would be more marked when R_2 is at minimum volume position. In this event we would have 8,000 ohms in shunt with 3,950 ohms, a total of 2,644 ohms.* Therefore, a shorted C_{16} condenser is quickly identified.

In practical servicing open and shorted condensers would be isolated in the *effect* to cause analysis. Obviously, if C_{13} were shorted, then when originally trying out the receiver you would get no volume control action. A shorted C_{16} would cause the set to be dead. A point to point resistance test would quickly identify shorted condensers. On the other hand should C_{13} be open, the set may regenerate, giving rise to a squeal or distortion; an open C_{13} may cause degeneration† evident by low volume. In sets of the same make and design the result would always be the same for a given defect, therefore, your experience, the experience of other servicemen or a chart of experience compiled by the manufacturer are of great help. By the same reasoning an open C_{16} condenser may create regeneration. The important fact that is being brought out, is that it would not be practical in making a complete resistance diagnosis to open each and every condenser, as the networks are checked, to determine whether the condensers are normal. Shorts will show up in the resistance tests, opens can be best identified by the effect to cause reasoning. If the symptoms point to an open in a certain condenser, shunting it with a good condenser should restore operation if the con-

* $R_{shunt} = \frac{8.000 \times 3.950}{8.000 + 3.950} = 2,644$

† Where the input is fed with a signal from some stage further along due to absence of a by-pass so the signal fed is out of phase—essentially neutralizing.

denser in question happens to be open. A number of schemes have been suggested to test condensers even when shunted by other devices. Their operation is questionable in all cases and is really not essential. Our attention will from now on be centered on shorted condensers.

With one probe of the ohmmeter on the chassis and the other on the screen grid, of tube No. 1, we work through R_1, R_2 and R_3. If R_2 is at maximum volume setting, the resistance would be determined by $R_1 + R_3$, a total of 8,150 ohms. This checks R_1; R_4 remains to be tested. By placing the ohmmeter probe which originally was on the chassis, on the filament prong hole of the rectifier tube a resistance of 14,300 ohms should be measured.

The plate-chassis resistance of tube No. 1 comes next. As C_{13} and C_{16} have been proved to be in normal condition, the ohmmeter measures the resistance of L_4, R_4, R_1, R_3 and R_2 in series a total of 26,308 ohms or 22,508 depending on the position of R_2. This measurement would fail to check L_4, which is tested by measuring between the plate of No. 1 tube and the filament of the rectifier tube and should be 58 ohms. In actual practice the last test alone would be made.

By referring to Fig. 5 you will observe that in checking the plate-chassis resistance of all tubes except tubes 2 and 8 that condensers C_{18} and C_{24} are in shunt. C_{18} happens to be an electrolytic condenser and we would know this by chassis inspection. Furthermore, the ohmmeter is battery operated and should the $-$ lead of the ohmmeter connect to the anode of the electrolytic condenser a current will flow, resulting in a low shunt resistance, causing the ohmmeter reading to gradually decrease. One should be careful to test with the $+$ ohmmeter probe on the anode of the condenser. You may then get a reading which gradually increases in value. The maximum value is the important one. If you connect the $-$ ohmmeter probe to the condenser anode you will get a low resistance reading, often decreasing in value. *You have connected the ohmmeter incorrectly;* reverse the probe connections. Values obtained will depend on the voltage of the batteries in the ohmmeter. The effect is very prominent in wet electrolytic condensers.*

* Sets that use wet electrolytic condensers and have been idle for some time before being put into use may result in a burned out rectifier tube unless the condensers are first formed. It is wise to test their resistance and if low form them first by an externally applied D.C. e.m.f. The forming process may take 2 or 3 hours. Be sure that the condenser if of the wet type has electrolyte.

The path from the plates of the same tubes trace through C_{17}, another electrolytic condenser. As both electrolytics may be in shunt with some network it would be a wise step to test them early in the resistance diagnosis. At the same time let us check the rectifier circuits and the voltage divider system.

We have already checked the power transformer by actual voltage measurements. C_{18} and C_{24} are checked by placing the + ohmmeter probe on the filament of tube No. 8 and the — probe on the chassis. A good electrolytic should show a resistance reading equal to $R_1 + R_2 + R_3 + R_4$. A short may indicate a defective C_{18} or C_{24} condenser, so the chassis must be taken out of the cabinet and each condenser checked separately after unsoldering the connections. Now open the field coil by removing the connections to the double lead terminal, leaving the two leads connected to each other. On checking between one rectifier plate and the chassis, a reading of .2 megohms indicates that R_{10} and R_{11} are intact. Checking from filament to plate of rectifier tube checks electrolytic condenser C_{17}.* Finally a check between filament of the rectifier to grid of tube No. 6 or No. 7, tests condenser C_{19}. A reading of 2,850 ohms (half of secondary of T_2) indicates a shorted condenser. To test the main voltage divider network, place the ohmmeter probes on the filament of tube No. 8 and the chassis. Vary R_2. The resistance should vary from 26,250 ohms ($R_1 + R_2 + R_3 + R_4$) to 22,450 ohms ($R_1 + R_3 + R_4$).

We turn now to tubes Nos. 2, 3, 4, 5, 6 and 7. To simplify matters we will now tabulate the values that should be found in checking the point to point resistances. G_n is chassis, K-cathode, G-grid, P-plate, G_s-screen grid and *F-filament*. Unless otherwise specified R_2 will be set so its value is 3,800 ohms.

Tube No. 2, Oscillator:

$G_n - K$	3,950ω	$R_3 + R_2$
$G_n - G$	43,950	$R_6 + R_3 + R_2$
$G_n - P$	now of no consequence, so check	
P to G_s of Tube No. 3	1ω	L_{10}

Observe that parts C_{20}, C_5, C_{21}, C_2, L_3, C_{22} and R_{12} form a network which connects electrically between the chassis and the grid of tube No. 2. Condenser C_{22} prevents a point to point re-

* After the electrolytic condensers have been checked it would be a wise plan to temporarily disconnect them from the circuit. Leakage and charging effects are eliminated. This may always be done where the chassis is removed from the cabinet.

sistance check. The network may only be checked with chassis out of cabinet. The steps taken are obvious. Tube No. 3, First Detector:

G_n-K	10,000ω	R_6
G_n-G	6ω	L_6
G_n-G_s	11,950ω	$R_1+R_3+R_2$
P−F tube No. 8	93.5ω	L_6

Tube No. 4, I. F. Amplifier:

G_n-K	3,950ω	R_3+R_2
G_n-G	41.5ω	L_7
G_n-G_s	11,950ω	$R_1+R_2+R_3$
P−F tube No. 8	41.5ω	L_8

Tube No. 5, Second Detector. Note that terminals 1 and 2 are connected.

G_n-K	30,000ω	R_8
G_n-G	1,000,000ω	R_9, (L_9 negligible)
G−Term. No. 1	93.5ω	L_9
P−F tube No. 8	800ω	$L_{13}+T-2$ primary

Tubes No. 6 and No. 7, push-pull output

G_6-G_7	5,700ω	Secondary T_2
P_6-P_7	360ω	Primary T_3
P_6-F_6	180ω	values need not be exactly equal
P_7-F_8	180ω	

Note that R_7 cannot be checked unless chassis is taken out of cabinet. Even this is not needed, for unless C_{14} is shorted it will not stop operation and the ability to make tone adjustments may be checked, once the set is made operative.

Practical Hints and Precautions. Note how rapid the check can be if the information is tabulated. Manufacturers do not make it a practice to give this information in tabulated form. The serviceman should consider it sufficient if all parts are noted with resistance and capacity values. Fortunately the trend is in that direction.

Should you find the point to point resistance method ideal for your needs, it would be a good plan to prepare a table of point to point resistance for the receivers you are constantly repairing.

Where no resistance information is given for some of the parts, the approximate resistances given in the following table* may be used as a guide.

R. F. transformers—Primary (untuned)	.5 to 15 ohms
R. F. transformers—Primary (self tuned)	20 to 100 ohms
R. F. transformers—Secondary	.5 to 5 ohms
Oscillator coils —Tuned Circuit	.5 to 5 ohms
I. F. transformers —Primary or Secondary	25 to 200 ohms
A. F. transformers—Primary	500 to 3000 ohms
A. F. transformers—Secondary	1100 to 8000 ohms
Power output transformers—Primary	300 to 1000 ohms
Power output transformers—Secondary	.2 to 10 ohms
Power supply transformers—Plate Secondary	200 to 600 ohms

* Compiled by John F. Rider.

Power supply transformers—Primary	1 to 5 ohms
Power pack filter chokes	150 to 800 ohms
Speaker field used as filter choke	800 to 2500 ohms
R. F. chokes	10 to 150 ohms
A. F. chokes	10 to 1000 ohms

We have shown that a chassis can be checked by the point to point resistance method, even while in the cabinet. This is valuable as there are cases where the customer insists on knowing the cost of the service job before allowing the chassis to be removed. This method of trouble shooting helps to confirm the location of the defect and to a great degree of accuracy tell what actually is wrong. Where there is no barrier in removing the chassis, do so immediately after you are certain that it is an internal defect, because it is then easier to test each and every part or network.

Much time can be saved if the circuit disturbance test is made first. Then the point to point resistance test may be initially directed to the suspected defective stage.

A free point socket analyzer is a helpful device when the chassis is in the cabinet, and it is difficult to get at the sockets and still it is necessary to test point to point resistances. This device is limited in its use, as analysis is limited to one socket at a time. It is essentially a help in checking continuity.

A plug-in and selective switching system may easily be made with parts that can be purchased from a large wholesale mail order radio supply house. A suitable system should permit measuring the resistance between any two terminals of the same tube circuit, between any socket terminal and the chassis, and between any terminal of one socket and any terminal of another socket. Figure 6 is the schematic of a simple but extremely flexible point to point resistance tester. All parts are clearly identified and explained in the caption. Structural details are not given. This selective analyzing system should be built into a carrying case together with the ohmmeter.

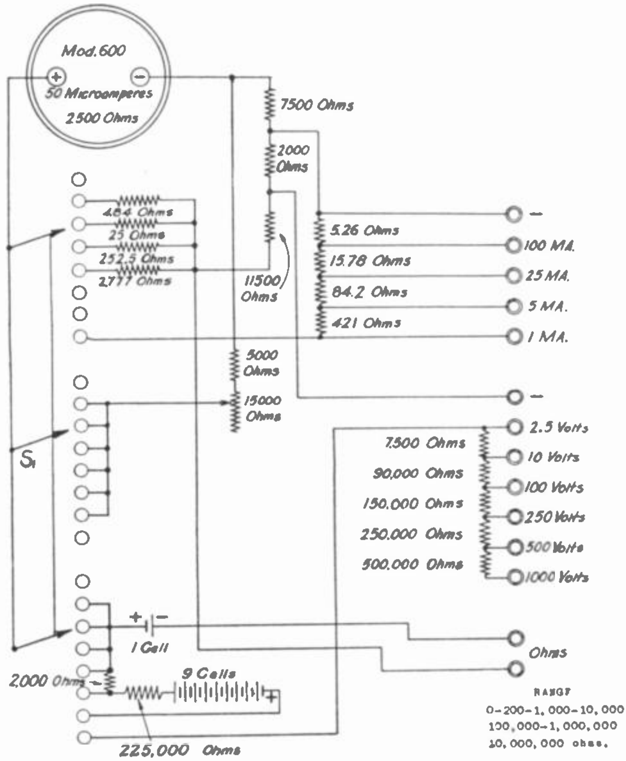
The finished device will have two 1 to 10 selector switch controls. Note that the two right hand selector switches are combined into a double deck affair. Two analyzer plugs and two sets of adaptors (prong reduction and extension) are needed. Selector switch *AA* is the free or moving point, whereas selector switch *BB* selects the reference point. When switch *D* is placed on D_1 then the reference point is some socket terminal of the tube under test; when switch *D* is placed on D_2 then the reference point is any terminal (including chassis) of the tube socket in which the associated plug-in and adapter are inserted. All tube pins, adapter and plug-in pins are numbered according to the latest R.M.A. and Weston standards. The wires 1, 2, 3, 4, etc., from the adapter connect to switch points 1, 2, 3, 4, etc., of the selector switches. In that way a tube table listing what tube elements are connected to pins 1, 2, 3, 4, etc., greatly simplifies actual analysis when a circuit diagram is used as a guide. If you plan to service by the point to point resistance method using this adapter, it will be quite helpful to mark the pin numbers on the service diagram.

The multirange ohmmeter probes are plugged into jacks *A*, the pee wee clip *F* is connected to the chassis. Push button *B* is used in adjusting the ohmmeter, particularly when each range of the ohmmeter must be adjusted. While testing, the push button may be depressed to check the ohmmeter adjustment. The double pole toggle switch *C* changes the ohmmeter polarity.

We should realize that a point to point resistance trouble shooting procedure is extremely valuable in a number of special circuits, as Loftin-White and other direct coupled amplifiers, A.V.C. receivers, and muted A.F. stages. Invariably these circuits are best analyzed with the chassis open and in full view. Because very high resistances are used, voltage readings are apt to be confusing due to the use of voltmeters with limited sensitivity. This is not inherent in the ohmmeter method of resistance checking.

You must remember that the resistance values given in a service diagram are only average and subject to variation. Coil resistances are reliable to 2 per cent, resistor values reliable up to 10 per cent. When parts are connected in series or parallel, the errors are accumulative. In series connections the largest resistor governs the total error, in parallel arrangements the smallest resistor governs the error.

Carbon resistors will change in resistance value as they warm up. As the resistor unit, whether it be of the solid or insulator carbon coated type, has a granular structure the current through the resistance will have a marked effect on the resistance. As the current increases it will take paths which were previously of too great a resistance and the resistance will decrease. The current will be determined by the applied voltage. Strictly speaking, the resistance of a carbon resistor should be measured by a special circuit in which the applied voltage is the one normally applied in the receiver. After operated for some time, the voltage and current is noted and the resistance computed by Ohm's Law. Practically no serviceman need go to such an involved process, as a rough measurement of resistance by means of an ohmmeter will suffice. Radio set designers will only use carbon resistors where exact resistance values are unimportant. Therefore, in checking carbon resistors in any network try to select terminals for point to point measurements that isolate them and be less critical of the values measured. Wire and metallized resistors may well be checked to 5 per cent tolerance, although the



Circuit diagram of a Weston D.C. Volt-Ohmmeter made from an available kit of parts. S_1 is a three deck 8 point selector switch. Weston No. 663 Volt-Ohmmeter Kit.

circuit they are used in will have to be considered. C bias resistors should check closer than resistors in resistance-capacitance filters.

Quite often it will be found that the simplest network where terminals are accessible will consist of resistors, coils and condensers in combination. Where condensers block out the D.C. current from the ohmmeter, a true check of the isolated resistor can only be obtained by getting into the chassis and unsoldering connections. This is only recommended if the effect to cause analysis fails. In resistor and coil combinations, the total resistance may be computed. If the chassis is out of the cabinet and unsoldering connections is no obstacle, then you may measure the resistance of the individual parts in the complex network. Perhaps the unsoldering of one joint will simplify the whole test procedure. We showed how disconnecting L_{11} in Fig. 5 helped considerably.

John F. Rider, who has done considerable to develop the point to point resistance to its present practical stage, offers the following helpful general statements regarding basic radio receiving circuits.

1. There seldom is a direct connection (zero resistance) between the plate and screen grid terminals of a screen grid type tube.

2. There seldom is a direct connection between the cathode and screen grid terminals of the same tube.

3. There seldom is a direct connection between the plate and cathode of the same tube. Note in using triodes as diodes the plate is directly connected to the cathode.

4. There seldom is a direct connection between the plate of a tube and the grid of the following tube. Exception: direct coupled (Loftin-White) amplifiers.

5. There seldom is a direct connection between the cathode of a tube and the control grid of the following tube. Exception: triple twin tubes.

6. There seldom is a direct connection between the control grid and plate of the same tube.

7. There seldom is a direct connection between the electron emitter and the anodes of rectifier tubes.

8. There seldom is a direct connection between the control grid, screen grid, secondary grids, or plate with the chassis or ground.

TEST QUESTIONS

Be sure to number your Answer Sheet with the number appearing on the front cover underneath the title of this text.

Place your Student Number on every Answer Sheet.

1. While testing on a service call, when should you remove the chassis from the cabinet to make a point to point voltage analysis?

2. In a point to point voltage test in any self-biased tube stage, what two voltages indicate normal or correct plate current?

3. Which, will a low resistance voltmeter connected to the cathode and chassis of the detector tube in a circuit like Fig. 1 read: the correct bias voltage; a value above normal; or, a value below normal?

4. What does an output thud from the speaker indicate when you pull out and return to the receiver the detector tube?

5. List, in the proper order, all the following servicing steps **(give numbers only)** in a point to point voltage procedure. *1*, applying the effect to cause reasoning; *2*, hunting for surface defects; *3*, a revitalization procedure; *4*, a point to point voltage check of R.F. sections; *5*, a point to point voltage check of the power supply; *6*, circuit disturbance test; *7*, removal of chassis from cabinet.

6. What are the secrets of successful point to point resistance trouble shooting?

7. When measuring the point to point resistances in a receiver, what are the two most used reference points?

8. When connecting an ohmmeter to an electrolytic condenser, what would you suspect as wrong when the ohmmeter continually reads lower in value?

9. What would an *ohmmeter reading* tell you if the circuit checked contains several very high and low resistance parts in series?

10. In a point to point resistance test would you expect to read zero resistance (a direct connection) when checking between the plate and cathode tube terminals of the same tube?

Voltage and Resistance Methods. No. 38 RH-1

1. When an internal defect is indicated.

2. Correct values of plate-chassis (plate voltage) and cathode-chassis (C bias) voltages.

3. A value below normal.

4. The detector and audio system is in working order.

5. 2, 1, 6, 7, 5, 4, 3.

6. Selecting a suitable ohmmeter range, and measuring the resistance between two points that yield useful information.

7. The chassis and the cathode (or filament) of the rectifier tube.

8. Ohmmeter connected incorrectly, reversed probe connections.

9. That continuity merely existed in the circuit.

10. Seldom.

DIRECT STAGE BY STAGE ELIMINATION METHOD OF TROUBLE SHOOTING

REVITALIZING RECEIVERS

39RH

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

IF—

If you can dream—and not make dreams your master;
  If you can think—and not make thoughts your aim;
If you can meet with Triumph and Disaster
  And treat these two impostors just the same; . . .
If you can fill the unforgiving minute
  With sixty seconds' worth of distance run,
Yours is the Earth and everything that's in it,
  And—which is more—you'll be a Man, my son!

RUDYARD KIPLING.

NATIONAL RADIO INSTITUTE

WASHINGTON, D. C.

1942 Edition

A LESSON TEXT OF THE N. R. I. COURSE
WHICH TRAINS YOU TO BECOME A
RADIOTRICIAN & TELETRICIAN
(REGISTERED U. S. PATENT OFFICE) (REGISTERED U. S. PATENT OFFICE)

NCP2M242

Printed in U. S. A.

Direct Stage by Stage Elimination Method of Trouble Shooting

PRINCIPLES OF THE TECHNIQUE

A circuit disturbance test is extremely valuable in isolating the defective section of an inoperative receiver. From our previous study of its use we know that as a procedure it is not foolproof, nor does it give us all the information we desire. Some manufacturers even caution against removing a tube while the set is operating, as the shock may be too great.

A logical procedure in isolating the defective stage should embody a test employing locally generated radio signals. In testing a T.R.F. receiver, tuned to a local station, it is possible to connect the aerial lead to the plate of the tube * preceding the detector and if you get an audible output you know that the detector-audio system is operative. If no signals are heard, a phone used as an output indicator may be connected to the output of the successive A.F. stages beginning at the detector, which tells us at which audio stages signals are obtained. In going from a signal to no signal, the defective A.F. stage is isolated. By advancing the antenna connection to the plates of the R.F. tubes and in a direction towards the receiver input, a change from a signal to no signal isolates the defective R.F. stage. Evaluating the intensity of the audio signal permits you to determine if the stages are actually contributing their share of signal amplification.

For T.R.F. receivers such a technique is far superior to a circuit disturbance test, if strong local signals are available. The scheme fails to work with superheterodynes which are slowly replacing all tuned radio frequency types. To extend the technique to superheterodyne receivers we require a generator of R.F. and I.F. signals, provided by a variable frequency modulated service oscillator. From a service viewpoint, let us see how a T.R.F. and a superheterodyne receiver differ.

A simple T.R.F. receiver embodies a series of T.R.F. amplifiers feeding a detector which in turn feeds an A.F. amplifier, all in cascade. A superheterodyne receiver consists of a T.R.F. amplifier and a local oscillator feeding a mixer-demodulator tube which in turn supplies a modulated I.F. signal to an I.F. ampli-

* A 0.1 megohm resistor in series with the aerial lead will enable you to connect directly to the grid of any R. F. tube, without detuning the stage.

fier. From this section the operation is similar to a T.R.F. receiver. If a modulated generator (service oscillator) is connected to the output or input of any stage in the receiver preceding the detector (second detector in a super) and the signal generator is tuned to the frequency of the stage, an output signal indicates active stages following this point, providing the application of the signal generator does not affect or destroy the operation of the stage to which it is attached. Whenever a tube is normally fed with two different signals, such as a mixer tube of a super, both signals must be supplied to obtain a complete check of operation.

The output indicator may be the loudspeaker, an output meter connected to the voice coil of dynamic speakers or to the signal excitation coils of magnetic units, an output meter connected to the plate-to-plate, or plate-to-chassis of the output tubes, or a phone inserted in series with the plate of any A.F. amplifier or in shunt with the plate load of an A.F. amplifier. Often both visual and aural indications are desirable at the same time. The insertion of an output indicator should not destroy set operation, nor should the supply voltages damage the output indicator. As we study the use of typical equipment and circuits, these precautions will be shown.

Using an A.F. signal generator, it is possible to check the A.F. stages by feeding an A.F. signal to the input of the power output stage or the input of any of the A.F. amplifying stages. In proceeding in a direction away from the speaker, if you pass from a signal to no signal the defective section is isolated. A variable voltage toy transformer giving 2 to 30 volts output and connected to the A.C. power socket would serve our needs. A test A.F. signal source is only required when testing radio amplifiers and when the amplifier is not associated with a radio tuner-detector.

If a modulated R.F. signal is fed to the input of the detector of a radio receiver, and the detector functions, an audio signal will be obtained at its output. Thus an A.F. generator may be dispensed with and the signal generator used to test the R.F. section may be used to test the A.F. section.

The technique will be slightly different. Connect the R.F. signal generator to the detector input. If no output is aurally or visually observed, question the detector and test it first by connecting a phone across the detector load (a series .5 mfd. condenser will be required to block the plate current out of the phones). Then advance the phone indicator to the output of the following A.F. stages. In passing from a signal to no signal the defective stages are isolated. This test is an improvement on the A.F. signal generator method as it reduces the equipment required, and checks detection.

The direct stage by stage method of defective stage isolation which we will shortly consider in detail is a good deal easier and requires far less time than it at first appears. Always have the circuit diagram available for reference, as there may be some question as to how to connect the output indicator and the signal generator and exactly what results should be expected. You must have complete information on the construction of your tester, if you wish to prevent damage to either the receiver or the tester.

EQUIPMENT REQUIRED

In considering the equipment required to trouble shoot in the direct stage by stage elimination manner; we should consider the accessories and devices needed to facilitate rapid diagnosis, the equipment for internal stage analysis, and receiver revitalization.

SIGNAL GENERATOR. A service oscillator which we shall call a signal generator is an indispensable device. For ordinary set testing it must have a frequency range of 110 to 1600 kilocycles, for this range includes all regular broadcast signals and frequencies employed in the I.F. sections of superheterodynes. For quick work the signal generator should not depend too much on harmonics to get these frequencies. Usually the harmonics of an oscillator are weaker than the fundamental. In working with weak or inactive receivers a strong signal will be required. Where the signal is merely applied to the receiver input, for purposes of alignment, the seventh harmonic of a grid leak-condenser modulated oscillator will suffice even if the pick-up coil is coupled to the tuned circuit of the oscillator.

A fundamental range of 110 to 270 kc. and the resultant second harmonic of 220 to 540 will handle practically all I.F. frequency needs. A fundamental range of 540 to 1600 kc. will serve admirably for testing T.R.F. receivers and the preselector sections of superheterodyne receivers. Normally the harmonics of the 540 to 1600 range will permit you to test short wave receivers up to 10 megacycles. Where all wave receivers are to be checked, the signal generator should deliver a maximum frequency of 25 megacycles (25,000 kc.). As the signal generator will usually be applied at the set input, harmonics of a lower generated frequency will usually suffice.

You should be able to control the output of the signal generator to a very low minimum. To do this requires a positive control attenuator and an extremely well shielded device. Every signal generator will have two output posts, one usually the ground of the signal generator, the other the high or active R.F. terminal. The ground of the signal generator is generally connected to the ground or chassis of the receiver. The other terminal may be connected to the ANT post of the receiver or in the stage analysis procedure to the plates or grids of the various tubes. Unless the output circuit of the signal generator has a series condenser (usually about .002 mfd.) the plate supply will be shorted in a plate-chassis connection. If your service oscillator does not have this condenser, connect one into the output circuit, making sure that the condenser is within the signal generator shield.

An unmodulated oscillator is an extremely valuable device and the usual grid leak-grid condenser modulated oscillator may easily be changed to give both an unmodulated and modulated output. The grid condenser (C_g) and the grid resistor (R_g) may be connected in a service oscillator as shown by Figs. 1a and 1b. Figure 1b is the desired connection for our needs, so change to it, if necessary, following the additions shown in Fig. 1c. The original resistor R_g is shunted by a toggle switch S_w, the handle of which is insulated from and has no connection to the switch—as usually made. In series with R_g is a resistor R about 20,000 ohms. The value of R should be as large as possible without introducing audible modulation, and when in series with R_g should not lower the modulation pitch too much. With S_w closed unmodulated signals are produced; with S_w open modulated signals are obtained.

When thrown to the unmodulated position the signal generator may be accurately calibrated by beating its signal with a broadcast carrier signal. A signal from a grid leak-grid condenser oscillator if mixed with a broadcast and fed to a receiver will usually not produce a beat (squeal) output; an unmodulated signal will. As the carrier frequencies of most high class broadcast stations are radiated correctly to 50 cycles of the assigned value, it is possible to calibrate to a high degree of precision. The usual procedure is to connect the signal generator to a broadcast receiver and with both active, tune the signal generator to the approximate fundamental as given by the calibration and tune the receiver to some station in the broadcast band operating on a frequency which is a harmonic of the oscillator or equal to its fundamental frequency. A squeal will be heard. Now if you tune the signal generator to the silent zone (zero beat) between the two squeals usually heard, the signal generator is exactly tuned to the desired frequency.

To get exact broadcast frequencies tune both the receiver and the generator which we assume has a fundamental 540 to 1600 kc. range, to a broadcast of the desired frequency. To calibrate the I.F. signal generator range, tune the signal generator to the I.F. frequency desired and the receiver to a broadcast which is in the 540 to 1600 range and which is some harmonic value of the I.F. desired.* As stations in the U. S. A. broadcast on frequencies which are a multiple of 10, that is, 640, 700, 910, only

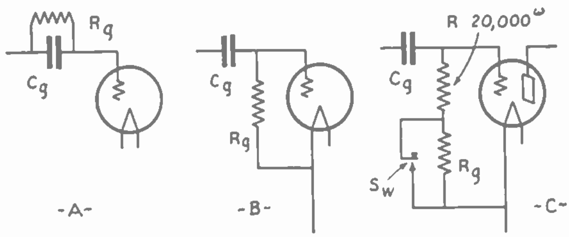


FIG. 1

those I.F. frequencies whose harmonics are multiples of 10 may be checked. For example, the harmonics of 175 kc. are 350, 525, 700, 875, 1050, etc. A frequency of 350 kc. is below the broadcast band, broadcast signal frequencies of 525 and 875 do not exist, so frequencies of 700 and 1050 should be used and 700 preferably as this harmonic of a signal generator set to 175 kc. will be the stronger of the two. For your convenience we are now listing the most common I.F. frequencies and the exact broadcast frequencies which will give a beat signal.

---

* To check an all-wave oscillator which needs recalibration you need an all-wave receiver and a simple 100 kc. unmodulated oscillator like the one explained in the home experimental outfits. The latter is set by beating with some broadcast station (600, 700, etc.). Connect the 100 kc. generator and all-wave generator to the all-wave receiver, all working. Set the all-wave oscillator and receiver to any frequency which is a whole number times 100. Adjust the all-wave oscillator and receiver for zero beat. The reading of the receiver dial tells you approximately what the oscillator frequency is, but the exact value is the nearest whole number times 100.

I.F.	Receiver Set to	I.F.	Receiver Set to
110	550, 660	262.5	1050
115	690, 920	265	1060
125	750	445	890
130	650, 780	450	900, 1350
140	560, 700	455	910
170	680, 850	460	920, 1380
172.5	690	465	930
175	700, 1050	470	940, 1410
177.5	710	485	970
178	890	490	980, 1470
180	720, 900	500	1000, 1500
250	750, 1000	535	1070
260	780, 1040		

There are no frequencies in the broadcast band that will exactly beat with the harmonics of such frequencies as 171, 181.5, 456, 472.5, 482, 517.7, etc., often used in I.F. stages. In such cases the position of the signal generator tuning dial may only be approximated.

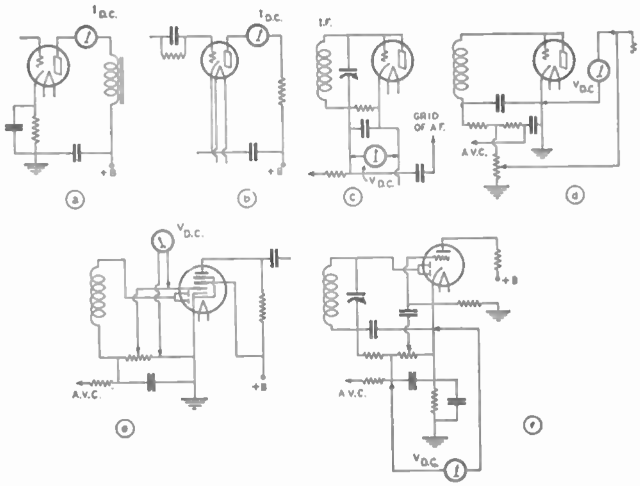


FIG. 2

If you check a calibration on the unmodulated position and switch to the modulated position, the frequency of the oscillator will change, although insufficient to affect the use to which a modulated oscillator may be put. For exact frequency stage alignment the unmodulated signal generator may be used, by employing as the output indicator a milliammeter in the plate circuit of the detector. In C bias detection, Fig. 2a, the milliammeter will originally read a low value and increase as more R.F. voltage is fed to the detector input; in a grid leak-grid condenser detector, Fig. 2b, the meter will originally show a high plate current which will decrease in value as the input to the detector is increased.

Diode detectors require special attention. A 1,000 ohm per volt or better sensitivity D.C. voltmeter placed in shunt with the diode load, should show increased deflection as the R.F. voltage applied to the diode is increased. Not always is it possible to make the connection without getting into the chassis. Figures 2d and 2e show typical connections where external chassis connections are possible; Figures 2c and 2f require internal chassis connection unless in Fig. 2c you get at the trimmer of the I.F. coil externally.

Signal generators employing a separate audio oscillator to modulate the R.F. oscillator will beat with an incoming signal, making it possible to calibrate while modulated. This simplifies the test and calibration procedure.

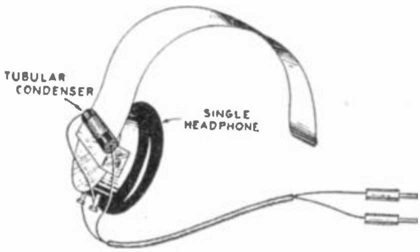


FIG. 3

MULTIMETER. The multimeter described for use with the set analyzer, point to point voltage and point to point resistance methods of trouble shooting will be needed. In addition an output indicator will be required. An A.C. copper oxide rectifier voltmeter may be used, employing a .5 to 1.0 mfd. paper condenser in series. To repeat, the multimeter should incorporate at least:

a: 0 to 600 volt D.C. voltmeter with suitable lower ranges; minimum sensitivity, 1,000 ohms per volt.
b: 0 to 600 volt A.C. voltmeter with suitable lower ranges; minimum sensitivity, 1,000 ohms per volt.
c: 0 to 600 volt A.C. output meter with suitable lower ranges.
d: 0 to 150 ma. D.C. current meter, lowest range 0 to 1.5 ma.
e: 0 to 1.5 meg ohmmeter, with suitable lower ranges.

PHONE OUTPUT INDICATOR. In checking the A.F. system, especially when no aural or visual output indication is obtained, it will be found that on advancing the output meter to the detector and A.F. amplifier stages that the signal level will be too low to actuate the meter. For this reason every serviceman should have a more sensitive output indicator than a rectifier type voltmeter. Such an output device is a 1,000 ohm phone, connected between the plate and chassis. A D.C. current will flow through the phone and probably demagnetize it, which is easily prevented by inserting a series .5 mfd. paper condenser. A phone with a flat strip head band with a long phone cord will be needed. Use a tubular condenser, taped to the headband and connected in series with the phone circuit. Insulated handles on the pin tips should be used to prevent shocks. See Fig. 3.

ACCESSORIES. Almost as important as the signal generator and multimeter, are the accessories which permit you to connect them to the receiver being tested. As you develop experience in servicing you will probably add to the ones suggested

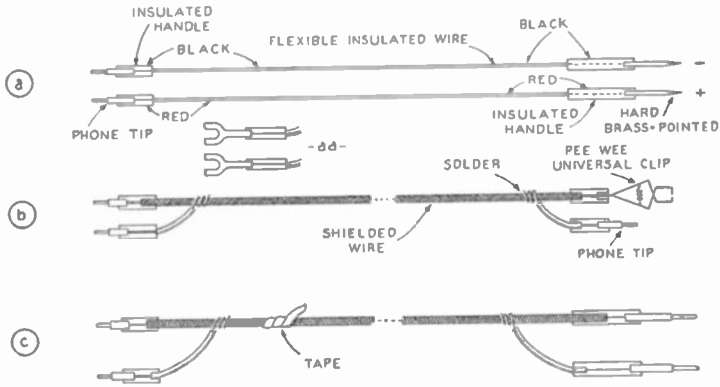


Fig. 4

here. A number of these devices will be supplied with the signal generator and the multimeter.

A *pair of probing leads* are indispensable and invariably are furnished with the multimeter. One end of each lead connects to the multimeter, while the probe handles are grasped by your fingers much like a pencil, a probe in each hand. In this way you may measure quickly any desired factor in the receiver merely by adjusting the multimeter to the proper section and range, and applying the probe points to any two terminals or connections in the receiver. The probe points are hard and sharp so rosin coatings on joints, corrosion or even insulation may be pierced to the conducting body.

Although there are many makes of probe leads, they are essentially alike and like that shown in Fig. 4a. The usual length is 4 to 6 feet measured from tip to tip. Probing ends must be well insulated, so there is no chance for a disagreeable shock. The other end may use regular phone tip plugs with a small insulation handle, if the output connections of the multimeter are the usual phone tip jacks. Where binding posts are used at the multimeter, the connecting ends are made with lugs as shown by Fig. 4aa. Both handles and insulation covering of one lead are finished in *black*, and the other in *red*. By convention and use the *black* lead is usually connected to the — terminals of the meter and part or network under test; while the *red* lead is connected to + or positive potential of the multimeter and device measured. In this way the meter will invariably read up-scale.

The output of the signal generator must be fed to the receiver with the least amount of radiation from the connecting leads. To do this a shielded cable is required. The one shown

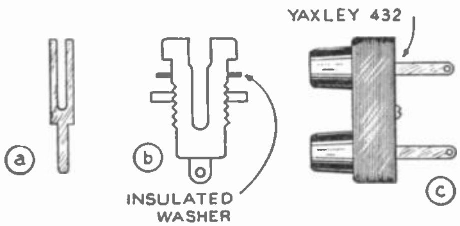


FIG. 5

Made in a variety of forms; Insulated tip jacks are made in black and red. Yaxley Mfg. Co., Indianapolis, makes a complete line.

in Fig. 4b is probably the one you will receive with the signal generator or service oscillator, and is primarily designed for stage alignment, neutralizing and tube alignment. Naturally the ends designed to connect to the signal generator will have phone tips or lugs, depending on the oscillator construction. At the other end you will find a "pee wee" universal clip used to connect to the control grid of screen type tubes or to the chassis, while the other lead has a phone tip so it may be connected to GND receiver binding post or to the prong of any tube in the socket by means of suitable adapters.

In the stage by stage elimination trouble shooting procedure, quick temporary connections are important, and for this purpose a shielded probing cable will be required. If one is not supplied with your signal generator, make one as shown by Fig. 4c. Don't destroy your other shielded cable as it is more conveniently used in the tests mentioned before. About 5 feet of flexible shielded wire will be needed (shielded antenna, lead-in will do). Insulated phone tips should be connected to one end, while probe points are attached at the other end. The probe ends should not have tapering points, merely a phone tip with a long shank, the ends being pointed. This last feature permits you to insert either the probe or connecting ends into phone tip jacks. The shielding should be covered with tape—3/8 inch surgical tape, which you can purchase in any drug store, will be suitable. Cover the tape with elastic varnish. In probing with the shielded cable, the shielding may accidentally connect to undesirable parts of the chassis shorting the receiver—insulation over the shield prevents such accidents.

It is a good idea to standardize connecting terminals and there is no better basic connector than the common phone tip and phone tip jack, both easily and cheaply purchased. In Fig. 5: *a* is

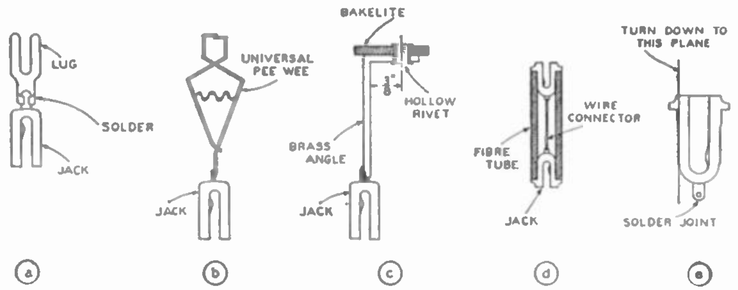


FIG. 6

the phone tip or plug, *b* the phone tip jack, which may be insulated from metal panels by the insulated washer; and *c* is a double or twin tip jack so constructed that the two leads from a meter inserted into both pin jacks connects the meter in series with the circuit in which the twin jack is connected. If your testers and tester panels use binding posts or "Fahnstock" clips you cannot go wrong by switching to this type of connection—it is quick and positive.

Probe leads shown in Fig. 4a and the shielded cable shown in Fig. 4c should be made standard. With a few special connectors and adapters which we will now show, connections to a chassis in its cabinet may be conveniently made. By using standard cables and probes, direct connections may be made to the jacks. For bolt, chassis and wire connections, a universal pee-wee clip may be adapted. For clamp connections lug adapters may be used. A tube prong adapter is necessary. Often it is desired to extend probing leads so a coupling connection is needed. All four types of adapters are shown in Fig. 6: *a* the lug, *b* the universal pee-wee, and *c* the prong and *d* the coupling connection adapters. A turned down plain type jack, Fig. 6e, is soldered to the lug, pee-wee clip and prong connector. At least two of each will be required.

Although the prong connector adapters may be used to make measurements at any tube prong, a recent universal socket

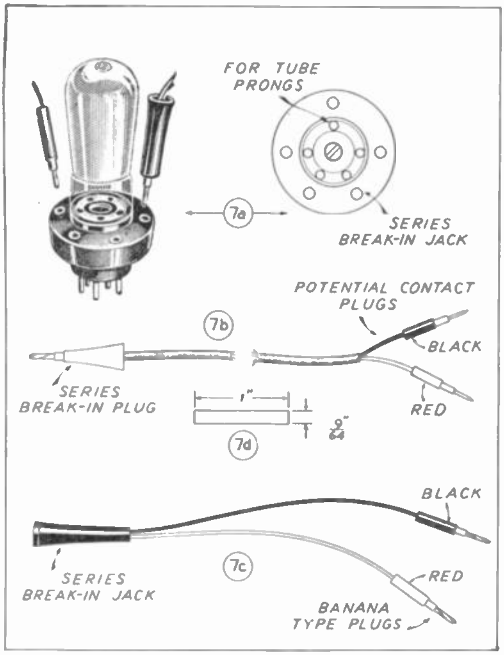


Fig. 7. Universal Testing Adapters and Extensions made by Alden Products Company, Brockton, Mass.

Item 7a available as follows: 4 prong (type No. 944UT); 5 prong (type No. 955UT); 6 prong (type No. 966UT); 7 prong large (type No. 977UT); 7 prong small (type No. 977UTA); and 8 prong (type No. 988UT).

Item 7b NaAld type 9DL cable.

Item 7c, order type No. 9DLJ dual connector cord.

Item 7d; make out of bakelite rod, sand paper for smooth tight fit, or use NaAld type No. 112D plug.

adapter developed at the recommendation of the N.R.I. Instruction Staff permits rapid point to point signal generator connections or voltage measurements at any tube socket with the tube active and with the least divergence from dynamic conditions. At the same time, current in any electrode may be measured by inserting a series break-in plug into a series break-in jack. Figure 7a shows a typical universal testing adapter (general and top view) and is made for a standard 4, 5, 6, small and large 7, and 8 prong base tubes.

To use this universal adapter remove the tube (advisable to turn set power off) insert the universal adapter in the set and the tube in the adapter socket; turn set power on.

By inserting the series break-in plug of the extension shown in Fig. 7b, into any adapter jack and connecting the multimeter to the two potential contact plugs, current to that electrode may be measured. By combining parts 7b and 7c shown in Fig. 7 you obtain a potential or point to point resistance probe lead. Inserting the two banana type plugs into any two jacks of the adapter and the other two ends to the multimeter, potential or resistance measurements may be made. For neutralizing purposes the insulation pin shown in Fig. 7d may be inserted into

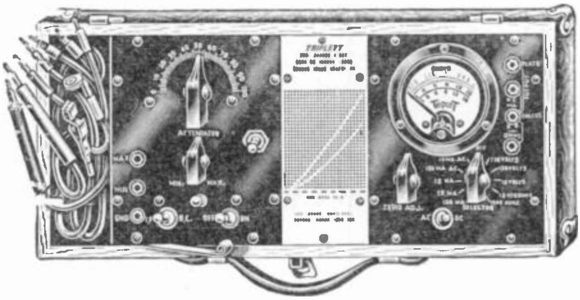


FIG. 8

Triplett No. 1177 Perpetual Tester follows very closely the specifications in this text, as the result of the makers' willingness to accept N. R. I. suggestions. Probe leads and probing cables follows the text. Two prong contacts and pee-wee universal clips are provided, which attach to cable and probe lead ends. Model No. 1175 covers the all-wave band.

the filament jack of the adapter. The break-in plug with extension will be valuable in the direct stage by stage elimination method, especially when the signal generator is to be inserted in series with some tube electrode circuit and where tube emission and emission control are to be measured.

In using adapters, probe leads and cables it is important that you know which socket terminals are the P, G, G_{su}, K, etc. A table of information following R.M.A. or Weston standards should be your guide. For convenience, the universal adapter shown in Fig. 7a is engraved according to R.M.A. standards.

TYPICAL APPARATUS. Sufficient information has been given to help you choose what commercial apparatus you wish to use in your service work. Figure 8 is a typical tester. The apparatus shown is by no means the only device applicable to the N.R.I. developed stage by stage elimination method of trouble shooting.

GENERAL TECHNIQUE

We should stress the fact that the "stage by stage elimination method" is a scientific method of isolating the defective stage by eliminating one by one the stages that operate dynamically and in a satisfactory manner. Once the defective stage is located, the point to point voltage method, set analyzer and point to point resistance plug-in adapters may be used to trace down in the isolated defective stage the exact cause for set failure. The universal socket adapter will eliminate the need of expensive, elaborate and cumbersome analyzer adapters.

After you master this technique you will realize that it is a weaving together of the best points of all methods. This system of trouble shooting is no different from the other three, for you always start with:

1. Visual inspection of the antenna-ground system; power socket connection to see that the power cord is plugged in; see that all tubes, chassis parts, tube top connections, speaker plug-in connectors are in place. and as the set is turned on see that all tubes heat up*—surface defects.
2. Be on the lookout for odors indicating burned out or overloaded parts. Try tuning in a broadcast and listen to the speaker output. Try to reason out from the squeals, howls, distortion, rattles, etc., heard what the cause of the defect may be—effect to cause reasoning.
3. If the set does not tune in a broadcast or the procedures indicated in items *1* and *2* do not lead you to the cause, you may then proceed to the stage by stage elimination method. You already know by visual inspection of the tube filaments that the A.C. power is being supplied and the main power transformer is functioning in this section. In applying the stage analysis we should first eliminate possible defective audio stages.
4. Connect the output meter to the output stage. Connect the signal generator to the input of the detector (2nd detector in supers). Tune the signal generator to the resonant frequency of the input circuit so the shorting effect on the signal generator will be at a minimum. An audible output indicates an active A.F. system, a visual output indication but no audible output indication indicates a defect in the speaker or its input section following the output tubes. If no aural or visual output indication is obtained, check the supply to the power tube. Insert a milliammeter into the plate circuit, using the universal socket adapter.
5. If you find that power is supplied to the output tubes we may assume that the A.F. system or detector is at fault. Insert a universal adapter into the detector socket, making signal generator connections to the

* Where metal tubes are found, you will have to feel the tube to learn if it is heating up. An illuminated pilot light indicates power is being fed to the receiver.

adapter jacks. Connect the phone indicator to the plate-cathode jacks of the adapter. (Always refer to a circuit diagram. Double and single diodes, Wunderlich detector tubes, etc., offer special problems.) An output indication indicates normal demodulating action. Failure to get this aural indication indicates an improper testing connection, (check connection with diagram); a defective tube or lack of supply; or a shorted input. By connecting a milliammeter in the plate lead and shorting the bias voltage, the change in plate current indicates emission control (g_m). The plate current reading indicates normal plate supply. With the tube out of the socket, set turned off, measure the input resistance, thus eliminating an input short. The three important tests once the defective R.F., oscillator, detector, or A.F. stage is located are: *1*, plate current or emission test; *2*, emission control test; and *3*, input resistance check.

6. Assuming that the detector checks active, advance the phone output indicator to the intermediate A.F. amplifier, using the correct universal socket adapter. As indicated by item 5, you may check for voltage supply, tube emission control and a shorted input circuit. Continue the same test procedure input to the input of the output stage. In checking the detector-A.F. system you pass from a signal to no signal output. By virtue of the universal adapter construction you may check indications at the input or output of a tube.

   Having proved that the detector-A.F. system checks active, we turn our attention to a stage by stage elimination check in the R.F. system. Two cases present themselves, namely, the T.R.F. (fixed R.F., tuned R.F. or a combination of both); and the superheterodyne.

7a: *T.R.F. Case:* Set the signal generator to some convenient broadcast frequency (1,000 kilocycles). Connect the signal generator, using the universal socket adapter, to the input of the tube preceding the detector. Tune the receiver to the frequency of the signal generator. If this stage is in normal operating condition you will get an output indication and a value above that obtained when feeding a modulated signal to the detector input. If necessary, reduce the signal generator output and proceed in the same manner through the various T.R.F. stages until you reach the receiver input. The defective stage will be identified when you pass from *a signal* to *no signal* output. Having located the faulty stage, feed the signal to the plate-chassis of the tube under test to prove that the trouble is not in the output coupling. If a signal is heard, check: input resistance for possible short, plate current and tube emission control as explained. It is worth remembering that: *when a signal generator is not at hand, the aerial lead wire may be used switching it from the plate of one tube to the next. The set should be tuned to a powerful local station.*

7b: *Superheterodyne Case:* Adjust the signal generator to the I.F. frequency and connect to the input of the I.F. tube ahead of the second detector, which we now know is active. Tune the oscillator for maximum output, assuming that the first I.F. stage preceding the detector is active. Advance the signal generator towards the input of the first detector, still left at I.F. frequency. If these stages are in normal operating condition, increased output should be evident. If a defect exists you will pass from *a signal* to *no signal*. Assuming normalcy to this point, we question the oscillator. Tune the signal generator to a frequency, which is equal to the setting of the station selector. Retune station selector. If the oscillator of the receiver is operative its signal will mix with that of the signal generator in the first detector and give rise to an output indication which will be larger than that obtained when an I.F. frequency alone was fed to the first detector. No output indicates an inoperative oscillator, or ineffective coupling to the mixer. To test for oscillation insert the proper universal adapter into the oscillator socket, place a milliammeter in the plate lead. Place your finger on the grid jack of the adapter now in the oscillator. If the oscillator tube is generating a local signal there should be marked increase in plate current. In sets using a simple detector-oscillator tube measure the cathode voltage. A measurement of the plate current may destroy oscillation. Touching the control grid or shorting the oscillator tuning condenser will stop oscillation, causing a change in plate current and a consequent change in cathode voltage. If the modulator-oscillator section is functioning proceed with the stage by stage elimination test through the preselector, the signal generator being set to the frequency of the station selector of the receiver. Once the defective stage is located, question the input circuit, power supply and emission control. With an all-wave receiver each band (preselector-oscillator section) is tested in the same way, unless one range is dead—then your efforts are directed to that particular band.

Observe that the defective stage has been isolated while the chassis was in the cabinet. Of course, this is only possible if the clearance between cabinet and chassis is sufficient to allow you to work. When this is found impossible, more than likely any other method of chassis-in cabinet probing would be found inconvenient. If you use the universal adapters and make your connection before the tube is put into the socket of the adapter, you will experience more freedom in your testing. In all other cases remove the chassis from the cabinet—you will have to before your service job is completed.

If the receiver being tested has A.V.C. you should have no difficulty in tracking down the defective stage even if the A.V.C. tube remains in the receiver. Should you desire to follow through with the gain check, take the A.V.C. tube out, if a separate controlling tube is used. You may also use a universal adapter with an insulation peg in the heater or filament lead. Where a combined A.V.C.-detector is encountered, usually diodes and duo-diodes, either the biasing resistor in the A.V.C. section must be shorted or the A.V.C. return leads from the controlled to the control tubes must be disconnected from the controlling bias and connected to the chassis if gain checks are desired. For example, in Fig. 9, short to ground the terminal of resistor B-5458-12 that connects to condenser A-9962. To test whether the A.V.C. tube is controlling the R.F. amplifiers, insert by means of the universal socket adapter a milliammeter in the plate of a controlled tube. With increased receiver R.F. input it should show decreased plate current.

Special circuits, like muters and interstage noise suppressors may require a little ingenuity before a conclusive test can be decided upon. Much will depend on the circuit used. Always try to apply a dynamic (working) test. Ordinarily where noise suppression is used the aural output will be appreciable until the audio system cuts off. Therefore, by reducing the signal that the generator feeds to the receiver, this cut-off, indicating normalcy, is observed. If you find that the output of your signal generator does not reduce sufficiently, use about 6 inches of insulated bell wire connected to ANT post of the receiver. Wrap one or more turns of the insulated portion of the bell wire over the active probe of the signal generator cable. The more turns you wrap on, the greater is the signal fed to the receiver. This scheme will work if the receiver and generator are well shielded. Use this scheme, too, when you want reduced signal generator output for other purposes.

TYPICAL CASE. To help you visualize and fix in your mind the procedure used in testing by the "direct stage by stage elimination" method, let us consider the receiver whose circuit is as shown in Fig. 9. The diagram is as presented by the manufacturer for the serviceman. This manufacturer has accurately drawn the tube sockets and the position of the tube connectors so you will have little difficulty in knowing which socket terminal is P, G, G_{su}, etc. If you wish you may write the numbers *1, 2, 3,* etc., in on the diagram, so that the universal socket adapter may be used with greater ease. The scheme of numbering the tube connections may be used where the diagram merely shows schematically the tube connections. In illustrating this technique we shall follow through all stages. Actually this would not be necessary as you would find before one-half the tests were made that the defective stage would be isolated. We assume first that you have studied the diagram, know how the set has been designed to operate; and can locate any of the tubes in the chassis. Furthermore, the set is inactive.

SCHEMATIC DIAGRAM
SPARTON MODEL 78 SUPER HETERODYNE

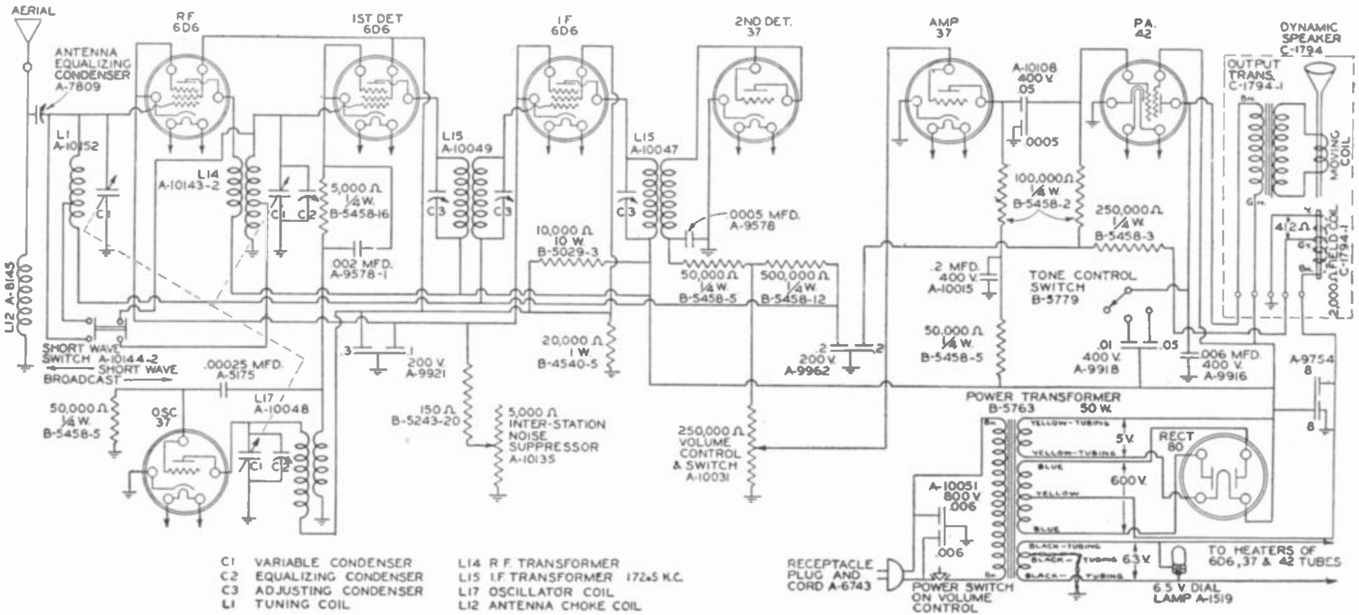


FIG. 9

Using the two plain probe leads and the universal pee-wee clip and prong connector adapter, connect the output meter to the plate-chassis of the 42 power output tube. Insert a 5 prong universal socket adapter into the second detector tube socket and insert the tube into the adapter socket. The signal generator may be connected between the plate or grid (both connected in the chassis) and the chassis; or if the signal generator output has no blocking condenser insert the signal generator in series with the cathode. Turn on the set and signal generator. An output meter indication and an audible speaker output sound (signal generator modulation pitch) informs us that the detector-A.F. system is intact. Meter indication without audible indication indicates a defect in the output transformer or voice coil. No output indication of either type may be due to a defect in the detector-A.F. system or lack of supply voltage. We may test the main voltage supply by measuring the voltage between the chassis and the plate of tube 42P.A. or by measuring the plate current in the output tube. If found to exist, proceed to check the detector and detector-amplifier. However, any abnormal indication such as weak output, choky or distorted output calls for immediate and complete tube supply voltage analysis and in this case including the speaker field which furnishes the C bias for the output tube.

If no output is heard, check the plate-chassis voltage and if found to exist, advance the output indicator to a prior stage. We actually should go directly to the output load of the detector, which would be resistor *B-5458-5*. This means getting into the chassis. The next best plan is to connect the phone, by means of a 5 prong socket adapter, to the grid-cathode of the first audio tube. (Note that the A.F. input to this tube and its C bias is controlled by the combination switch and potentiometer A-10031. Increasing the A.F. input increases the C bias.) Upon getting audible signals advance the phone indicator to the plate-cathode of the 37 amplifier tube and then to the grid-cathode of the 42 P.A. tube. In passing from a signal to no signal the location of the defect has been isolated. Test the tubes. Then a point to point resistance analysis from the sockets should isolate the defective part or give a closer approximation of the defective part.

In the above analysis we used two 5 prong adapters. By using the prong and pee-wee adapters to connect the oscillator to the detector, one socket adapter is needed.

Now suppose that the detector-A.F. system checks O.K.

Leave the output meter connected to the plate-chassis of the 42 P.A. tube. If silent testing is desired, open the voice coil of the speaker.

Tune the signal generator to the I.F. frequency, in this case 172.5 kc.—information fortunately given on the diagram. By means of a 6 prong universal socket adapter, a contact plug-in and the pee-wee universal clip, connect the signal generator to the control grid-cathode of the 6D6 I.F. tube. Observe that the control grid is on the glass envelope of this tube.* Output indications inform us that this stage is active. If no output is heard, connect the signal generator to the plate and cathode. If signals are now heard, question the input circuit, as C_8 in the input circuit may be shorted—use an ohmmeter; check plate current by inserting the universal break-in plug attached to a milliammeter into the plate jack of the adapter; test the tube while the milliammeter is in the circuit by shorting the cathode to the chassis, watching for increased plate current. This shorts the biasing resistors *B-5243-20* and A-10135, the latter the inter-station noise suppressor control.

Suppose the 6D6 I.F. stage tests active. Advance the signal generator, tuned to 172.5 kc., to the input of the 6D6 first Det. tube. Make connections to the external control grid and chassis. If the circuit parts between the first detector input and the I.F. tube are normal, an increased output reading will be obtained. If no output is obtained, check input resistance, plate emission current, and emission current control (shorting cathode to chassis). Assume the first detector is active. Set the frequency range switch to the broadcast position.

Tune the signal generator to 1,000 kc. and tune the receiver to 1,000 kc. and to maximum output reading.† If an output reading can be obtained, the local oscillator is functioning. As a further check on the local oscillator, insert the 5 prong universal socket adapter into the 37 OSC. socket and the tube in the adapter socket. By means of the universal break-in plug measure the D.C. plate current, while set is in operation. Place your finger on the control grid jack, finger to metal. An active oscillator

---

* As all other tubes have external control grid connections, we may omit temporarily the use of the universal adapter. With one probe of the shielded cable on the chassis and the other placed on the control grid cap, check down the line as indicated by the following procedure. Once the defective stage is isolated, use the universal adapter to make interstage tests.

† In testing all wave receivers, set the frequency range switch to each position and set the signal generator to some frequency in that range. Harmonics of the signal generator are satisfactory provided the fundamental is not the I.F. frequency.

will be indicated by an appreciable change in plate current.

Having tested the frequency converter system, advance the signal generator to the grid-cathode terminals of the first 6D6 R.F. tube. Tests used for the I.F. tube are duplicated here except the signal generator is set to some broadcast or high frequency range of the station selector. By the time you advance your test to this point, you will isolate the defect. If not, check the resistance and continuity of the coil input L_{12} and the condition of condenser *A-7809*.

Repeat the tests on the preselector by setting the frequency change-over switch to the Short Wave position and adjust the signal generator to 2400 kc.—second harmonic of 1200 kc. The only remaining check is the inter-station noise suppressor. Insert a milliammeter into any controlled tube, 6D6 I.F., and as you vary the adjustment A-10135, you should observe a change in plate current. Then increase the output of the signal generator. If the milliammeter reading decreases we have evidence that the A.V.C. is functioning.

Note that your tests are made with the set in operation. Failing to get normal dynamic indications you proceed to make static checks in the defective section which isolates the defective part. It is also possible to locate the fault with the chassis in the cabinet. Once the defect is located, a new part or a corrected connection solves the repair job.

Revitalizing Receivers

INTRODUCTION: We have repeatedly said that the correction of a defect as indicated by the customer is the least that is expected of a serviceman. The defect may be traced to conditions external to the receiver, a broken or overloaded part, a poor or incomplete connection or a defective or exhausted tube. If the chassis that you are working on has for example loose sockets, or loosely bolted transformers, you would hardly think of returning the chassis before such minor things were repaired.

If you work in a moist climate, in the tropics, near the seashore, or the set you repair has been exposed to the elements, you will find that drying out the machine will "pep-up" the operation. Vibration, corrosion will weaken or even destroy connections, particularly in automobile sets. Here is another service that can be rendered.

We spoke of aligning or matching tubes to the receiver as an aid in getting better performance. Tuned stages get out of alignment requiring in T.R.F. receivers a simple alignment adjustment and in superheterodynes I.F. alignment and preselector-oscillator tracking adjustments. Some of the old neutrodyne receivers may need neutralization. Perhaps the receiver you are repairing fails to give the desired results due to lack of alignment.

You may find that the receiver works well at your work bench but poorly in the customer's home. This may be due to a poor aerial and ground system or to the fact that the antenna coupler in the receiver is not correctly adjusted to the pick-up system to make the entire tuning system track.

All such adjustments are necessary if you wish to give your customer the ultimate in service. Of course, there is a limit that you can give as part of the service job. This must be determined as you learn to serve your trade. Some servicemen include a simple revitalization as part of their charge for the initial call. Generally this would include an antenna-ground inspection, chassis inspection, cabinet polishing and scratch fill-in, tube testing, tube alignment, stage alignment if possible without removing the chassis from the cabinet, soldering of any external connection and minor repairs that are quickly done. Assuming that they spend one hour including the time it takes to come from the last call, they would charge at their usual hourly rate.

It is surprising how much better a receiver will work if a complete revitalization or "pepping up" job is made. We will shortly consider in greater detail the various phases of this subject, but we want to mention that some servicemen offer a complete revitalizing job at a specific net price, depending on the average time it takes them to do a job. About three hours would be the average. This may be a part of a one year service contract that you sold the customer.

Some of the better receivers are made to withstand adverse conditions, others require constant attention. Such information only comes from direct contact with all kinds of machines.

If there is any doubt in your mind regarding an adjustment or alignment always refer to the set maker's service manual.

MECHANICAL DEFECTS: Where the chassis and speaker are taken out of the cabinet or out of an automobile and brought to the shop for repairs, carefully go over all bolts, rivets or screws that hold parts to the chassis or hold the chassis in shape. Do the same for the speaker.

Turn the chassis with the wiring facing you and with a clean hot soldering iron resolder all joints, making sure that the solder flows at the joint. Good soldered joints show solder covering the entire joint. If a complete resoldering job is not included in the service job, at least inspect joints for possible poor connections. Corroded joints should be questioned by pulling on the wire with a pair of pliers.

Needless to say that all tubes should be out of the socket and the power shut off—in fact, power cord disconnected from the wall socket. As you return the tubes to their correct socket position, be sure that the prongs make good contact. If any look doubtful replace the socket, they are inexpensive.

BAKING OUT THE CHASSIS: A receiver that has become damp, or soaked is a very poor radio device. This condition is common where the set is used in the tropics, in a valley, at the seashore, or has been through a fire or flood. People who take their receivers on their vacation complain when brought home that the receiver has lost its "pep." This is remedied by baking out the moisture, a procedure that is not as absurd as it seems.

If the occasions for driving moisture out of receivers are rare, then the procedure taken should not involve great expense. Servicemen generally use an electrical heater, one with a reflector, directing the heat rays on to the chassis. A fan is used to drive the vapor off the chassis. If you adopt this plan, be sure to change the chassis position so all parts are equally dried.

If you find that you get a large number of sets to bake out, build a special oven as shown in Fig. 10. A large portable cooking oven may be used. When the chassis is placed on the grid shelf, the entire asbestos lined box should be closed tightly, the heater started and after a while the fan turned on so that it drives the moist air up the funnel and exhaust stack. Watch temperature with a thermometer the bulb of which is in the oven and the reading stem exposed outside. Keep the temperature 55 degrees centigrade (130°F.).

Fortunately the better sets are now built so the coils are moisture proof. If you find that the revitalized set comes back too often for rebaking, it would

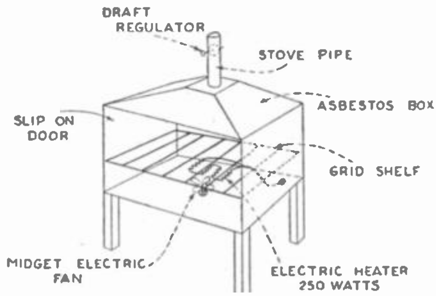


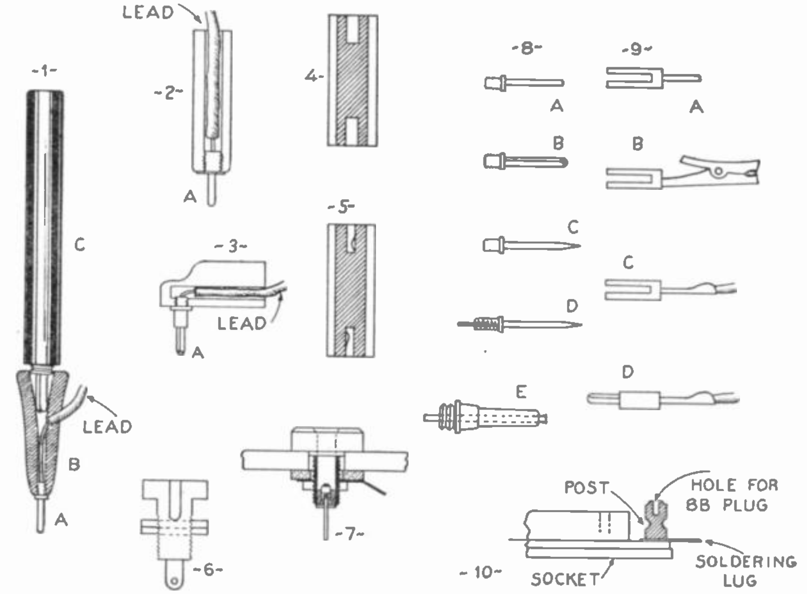
FIG. 10

be wise to dip the coils that are not moisture proof in pure hot paraffin. Be sure to bake them well just before you dip them in paraffin. Such treatment will call for set realignment.

Once the set is perfectly dry blow out all dirt and dust with a small hand bellows. With cheese-cloth clean all available surfaces. Using pipe cleaners (obtained at any tobacco store) remove all dirt and dust from between the plates of the variable condensers. This cleaning process should be performed on all revitalization jobs, even if baking is not required.

TUBE TESTING AND ALIGNMENT: In another text the subject of tube testing is taken up in greater detail. At the bench a standard portable or counter tube checker may be used. When the set operates, the apparatus used in the stage by stage elimination trouble shooting method, may be employed to test tubes and align them. A method of tube comparison is used.

Connect the signal generator to the ANT and GND posts of the receiver, using the shielded cable; and connect the output meter to the plate of one of the output tubes and the chassis, using the two probe leads with a pee-wee universal clip and prong connector adapters. Turn on set and signal generator. Set the signal generator to 1,000 kc. and tune the receiver to maximum output indication. Reduce the signal generator output so that a one-



NA-ALD STANDARDIZED CONNECTORS
(Alden Products Company, Brockton, Mass.)

1. Probe: *A*, point or plug; *B*, handle; *C*, extension; *A* and *B* constitute a basic handle connector, with flexible or shielded lead through side; *B*, supplied with points *8A*, *8B*, *8C*, *8D*, *8E*; *B* and *C* furnished in red or black moulded bakelite.
2. Small space handle; red or black. Supplied with point *8A*, phone tip plug; *8B* pressure expansion plug; or *8E* series circuit plug.
3. Finger grip handle; furnished with pressure expansion, pin or series circuit plugs.
4. Insulated female coupler for pressure expansion plugs, *8B*.
5. Insulated female coupler for phone tip plugs, *8A*.
6. Standard jack, made for pressure expansion or pin tip plugs.
7. Current-voltage jack. Measures current when plug *8E* is inserted, measures voltage when plug *8B* is inserted. Jack normally closed.
8. Points or plugs available; *A*, phone tip; *B*, pressure expansion; *C*, hard needle point; *D*, spring push hard needle point, makes contact only when pressing on point, for safe testing; *E*, current plug for jack No. 7.
9. Connector adapters: *A*, pressure expansion to phone tip connector; *B*, alligator clip, slips on pressure or phone tip plugs, made in several pee-wee and large sizes; *C*, solderless female pressure expansion jack connector for end wire connection; D, solderless pressure expansion wire connector jack, fits with *9C*.
10. Standard experimental type binding post, each terminal and solder lug, and a knurled nut, the latter with a hole to take pressure expansion plug, used preferably with No. 3 handle.

third output meter scale deflection is obtained of the signal generator using a short piece of bell wire attached to the receiver ANT post.

Starting with the rectifier tube replace the old tubes with a new tube, tested at the bench or by the tube distributor and note the scale deflection. If the deflection increases at least to 2/3 scale deflection, the new tube should be retained in the socket. Continue this procedure from output to input. Output tubes used in push-pull should draw similar plate currents, quickly checked by the universal socket adapter.

After all tubes are tested in this comparison method, interchange similar tubes (there may be 3 type 58 tubes, 2 type 27 tubes, etc.) in the receiver, leaving them in the position which gives the maximum output reading. Always readjust signal generator and output meter range so a deflection at the start of a tube replacement is about 1/3 up-scale. You will find that old tubes make better detectors. Before accepting them be sure they handle strong signals without distortion. Tune in a powerful local broadcast and listen to the quality of reproduction.

Automatic volume controlled receivers may or may not offer a little trouble. Generally if the signal generator output is low enough, increases in output will be apparent. If you find it difficult to get the input below threshold conditions, open the filament circuit of the A.V.C. tube, a possible procedure where separate A.V.C. tubes are used.

To select a good A.V.C. tube (when a tube is used exclusively for this purpose), set the signal generator to the lowest possible output giving a visual output indication. Try several tubes and select the one that reduces the output the least. Test the tubes for A.V.C. control by gradually increasing the signal and noting that the threshold condition appears—output increases to some deflection and further signal increases cause little output increase.

In A.V.C. sets, turn set off for a few minutes; turn on set and signal generator. The output meter needle will quickly assume a position. If the volume after this point increases, gas exists in some amplifier tube; if the output decreases, the A.V.C. tube may be gassy.

ALIGNING T.R.F. RECEIVERS: We assume first that the tuned stages have not been tampered with and that the ganged condensers are mechanically aligned.* Nevertheless, the R.F. system may need trimming to get the best possible gain. Consider first, the case where trimmers are only used on the ganged condensers.

Connect the signal generator and output meter as for tube testing. Set the signal generator to 1400 kc. and tune the receiver to maximum output. Use a low R.F. input and a sensitive output meter range. Adjust the trimmers on each section of the ganged condenser, using a neutralizing tool, so the output meter gives the maximum deflection. Set the signal generator to 600 kc., tune the receiver to maximum output and readjust the position of trimmers, carefully observing the direction and amount of adjustment on each trimmer to give maximum gain. Repeat for 1,000 kc. If all three positions differ, select a position for average good gain over the entire tuning range.

Consider the case where split end rotors are used as well as the trimmers. After adjusting the trimmers at 1400 kc. tune the variable condenser so the first split section just meshes with the stator. Tune the signal generator to

* When coils and condensers are badly out of line, a special procedure is necessary . . . explained elsewhere in the Course.

maximum output and if the signal generator has body capacity retune the receiver. Then each split segment is bent in or out for greatest output meter deflection. This is easily done by overbending the segment outward and with an orange wood or bakelite stick bending the segment back to maximum output. Turn the variable condenser so the next segment just meshes with the stator and repeat the alignment procedure. Repeat until the entire rotor meshes with the stator.

ALIGNING SUPERHETERODYNES: We can only consider the alignment of the average super. If in doubt about some receiver, refer to the manufacturer's service manual. We assume that the selector dial is calibrated in kilocycles, and the I.F. frequency is known. The procedure will consist of first aligning the I.F. system, then making the preselector-oscillator align at a high frequency station selector position, and then make the preselector and oscillator track.

I.F. ALIGNMENT: There are two ways of aligning the I.F. system. The entire I.F. system may be aligned with a single connection of the signal generator; or each stage of the I.F. aligned separately by connecting the signal generator to the input of the stage to be peaked. Either a modulated or unmodulated signal generator may be employed. If a modulated generator is employed then the regular output meter is connected to the output tube. In the case where exact I.F. frequencies are used, an unmodulated generator previously checked by beating its signals with some broadcast station is needed. This requires a D.C. milliammeter or high resistance D.C. voltmeter in the plate load of the second detector as an output indicator. The procedure was previously explained.

Considering the first and general method of aligning I.F. stages employing either type of signal generators: Connect the signal generator to the control grid and chassis of the first detector. Set the signal generator at the exact I.F. frequency and adjust the volume control of the receiver to the maximum volume position. Adjust the output meter sensitivity and the attenuator of the signal generator. A low output indication is essential. Adjust with a non-metallic screw-driver or wrench the trimmer across the secondary of the I.F. transformer feeding the second detector to give maximum output indication. If the needle reads off-scale, try first a lower signal generator output and then a less sensitive output meter range. Next adjust the primary of the same transformer for maximum output indication. Repeat this procedure for the next preceding I.F. transformer and continue through the various I.F. stages until all have been checked. Repeat the adjustments starting with the last I.F. transformer. It may be observed when using a neutralizing tool that the output indication shifts as you remove the tool from the adjustment of the condenser. Compensate for this by over-adjusting so that maximum output is obtained when the tool has been taken out of the adjustment screw. This will come with experience.

Many servicemen prefer to use the following method of peaking the I.F. stages. The signal generator is connected to the control grid-chassis of the tube preceding the transformer to be peaked. The secondary and then the primary of the transformer are adjusted for maximum output. The signal generator is advanced to the grid-chassis of the preceding tube and the following transformer peaked.

The I.F. stages in some receivers must be adjusted for flat top response. This is accomplished by first peaking all stages at the I.F. frequency. The signal generator is fed to the grid-chassis of the tube feeding the transformer to be adjusted for flat top resonance. Increase slightly the capacity of the secondary condenser and decrease slightly the primary condenser capacity. Move the signal generator two or three kilocycles above and below the I.F. frequency, to make sure that the output remains practically fixed.* The cut-off frequency should be sharply defined. Should the signal generator have too much hand capacity, use an insulated extension rod to move the dial above and below the peak frequency.

Combination oscillator and detector tubes may appear perplexing. However, if you connect the active lead of the signal generator to the control grid of the detector section and the other lead to the chassis, very little difficulty will be experienced. When the I.F. and the first detector tubes are of the type with the control grid cap on the glass envelope, there will be no difficulty in making the control grid connection. Where the control grid is a prong submerged in the socket, it will be necessary to use the universal socket adapter. For the first detector, a connection to the stator of the variable condenser connected to the grid of the first detector will suffice. The shunting effect of the resonant circuit feeding the first detector will be negligible in service work.

Preselector-Oscillator Tracking: After aligning the I.F. system we turn our attention to the preselector-oscillator tracking. Connect the signal generator to the antenna-ground post of the receiver. Adjust the signal generator to exactly 1400 kc. Set the receiver station selector exactly at 1400 kc. Be sure, however, that the tuning dial of the selector tracks accurately over the indicator from maximum to minimum. The number of trimmer condensers to be adjusted will be equal to the number of variable condenser sections in the ganged condenser. Adjust these trimmers for maximum output, adjusting first the oscillator trimmer. Turn the adjusting screw with a non-metallic screw-driver or wrench until the greatest output indication is obtained. CAUTION: When adjusting the oscillator trimmer condenser you may get two settings of maximum output, in which case you choose the trimmer condenser position with the least capacity.

Now set the signal generator to exactly 600 kc. and turn the station selector until the output reading is at maximum. The next adjustment is made on the oscillator padding condenser. As you adjust the padding condenser for increased and decreased capacity, tune the receiver slightly up and down the initial dial position. Stop when you get the greatest output, as the preselector is then exactly tuned to 600 kc., and the oscillator is tracking properly. The entire procedure is referred to as the *rocking* adjustment, and in broadcast band super-receivers having a padding condenser this rocking adjustment is made at the 600 kc. setting of the preselector. Usually the variation of a padding condenser will be insufficient to give two maximum

---

* When aligning I.F. stages in A.V.C. receivers, prevent the A.V.C. action

positions for a given setting of the receiver station selector. If there should be two such positions, use the setting with the least capacity.

As it is usually said, we now have two tie down points. To check if the preselector tracks with the oscillator over the entire tuning range, slowly increase the signal generator up to 1400 kc., tuning the receiver to the signal as you progress up-scale. If the output does not drop to zero and rise again, you have acceptable tracking. This should be followed by a recheck at 1400 kc., adjusting the trimmer condensers for maximum output.

For better alignment over the complete tuning range of the receiver, rotate the receiver selector dial until the first section of the slotted rotor segments meshes with the stator. Tune the signal generator to maximum output and retune the receiver for increased output if necessary. Bend the first segment of each condenser until the output meter shows maximum deflection. This is repeated until all rotor segments have been adjusted.

Some supers employ ganged condensers with a special cut oscillator rotor

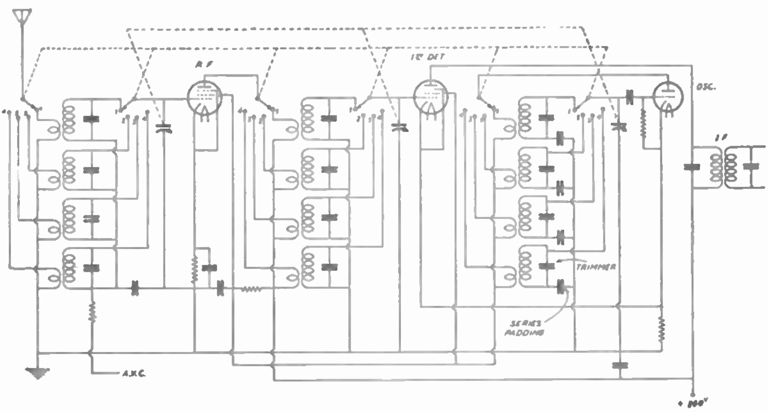


Fig. 11

plate. In this case you would treat the entire R.F. system as if it were a T.R.F. receiver. Adjust the trimmers first at 1400 kc. (Remember the precaution in regard to the oscillator trimmer.) Afterwards, adjust each segment of the split rotors for maximum output.

In aligning A.V.C. receivers, there should be no difficulty if you keep the input to the receiver sufficiently low. Some manufacturers suggest that the filament circuit of A.V.C. tubes (if a separate one is used) should be opened. This is best done with the universal socket adapter and the neutralizing peg.

Aligning All Wave Receivers: You will find in studying the general design of an all wave tuner, Fig. 11, that generally a three section ganged condenser is used; one to tune the oscillator, one to tune the input to the first detector, and the third section tunes the output of the antenna coupler. The all wave feature is obtained by three groups of coils, each group connected by means of a multi-pole switch to the three main tuning condensers. Different ranges are obtained by connecting the proper group of coils to the tuning condenser. Each coil has across it its own trimmer condenser and in many cases the oscillator has a series variable padding condenser. Therefore, in adjusting any range you would proceed exactly as you would in the previous section on preselector-oscillator tracking, always starting first with a high frequency in a given range, and then proceeding to the rocking method of adjustment at a low frequency. The use of separate trimmers makes each range adjustment independent of the other. All wave tuners are made in a number of modified forms, so be guided by the manufacturer's service manual.

We should mention that if you want the ultimate in stage alignment, the chassis should be brought to the customer's home, connected to the antenna and ground, the signal generator loosely coupled to the antenna, and the trimmer across each section of the antenna secondary coil adjusted for maximum output deflection. This scheme applies to all wave, tuned R.F. and regular superheterodyne receivers.

NEUTRALIZING NEUTRODYNE RECEIVERS: The oscillator and output meter may be used for neutralization. The usual procedure consists of connecting the output of the signal generator to the antenna and ground binding posts of the receiver and connecting the output meter to the output of the receiver. Use a modulated signal. The tube in the stage to be neutralized is removed and the proper universal adapter inserted. Return the tube to the socket of the adapter and insert a neutralizing or insulation peg into the filament jack of the adapter. In place of the universal adapter one of the filament prongs may be insulated with a soda-water straw. Place the tube shield over the tube, if one is provided. Always neutralize with the tube you plan to leave in the socket. Starting with the first R.F. stage employing a neutralizing system, tune in the signal from the signal generator as loud as you can to maximum output, leaving the volume control on maximum. The neutralizing condenser adjustment associated with this stage is then adjusted for least output, both from loudspeaker and the output meter. If you cannot reduce the output to inaudibility, then adjust it at least to minimum audibility. After this has been done repeat the same procedure for the other stages to be neutralized.

Tune the receiver over the entire broadcast band, all tubes in place and lighted. Determine if oscillations are obtained at any position of the tuning scale. If this appears neutralize at that position. In general, neutralize a neutrodyne receiver before aligning it.

TEST FOR STATION OR RECEIVER HUM INTERFERENCE: Customers complain of a hum when the receiver is tuned to a station. This may be due to a receiver defect, hum modulation; or may actually be broadcast by the station. The unmodulated oscillator will quickly identify the source. Set the signal generator to the frequency of the interfering station (usually a local) and tune the receiver for maximum sound output. If the signal generator is battery operated and emits an unmodulated signal, hum will be heard if the defect is due to a receiver defect. If no hum is heard, try several other frequencies. If no hum is still heard, it was a part of the broadcast. Curing hum modulation is taken up elsewhere in the Course.

TEST QUESTIONS

Be sure to number your Answer Sheet 39RH.

Place your Student Number on every Answer Sheet.

1. What change in the plate current would be observed in a grid leak-grid condenser detector if the unmodulated R.F. signal fed to its input were increased?
2. Show by means of a diagram how the usual grid leak-grid condenser modulated oscillator may be changed to give both modulated and unmodulated output.
3. Where would you look for the defect if a signal generator tuned to the I.F. frequency and connected to the input of the first detector of a super gives an output reading, but when tuned to the receiver dial setting, gives no output reading.
4. Where would you look for a defect if the plate-chassis output indicator connected to the power stages showed normal deflection but no speaker output is heard?
5. To what frequencies would you tune a broadcast receiver to calibrate an unmodulated I.F. oscillator at 460 kc. by the beat method?
6. In revitalizing a neutrodyne receiver, would you align or neutralize first?
7. In interstage A.F. amplifier tests, what output device, that a serviceman should have, is more sensitive than a rectifier type voltmeter?
8. What are the three important tests once the defective R.F. stage is located, assuming that a signal generator connected to its plate shows operation?
9. At what frequency setting of the preselector is the rocking adjustment usually employed in a broadcast band super receiver.
10. If a signal generator is not available, what may you use for a signal in a stage by stage elimination test in a T.R.F. receiver?

Revitalizing Receivers. No. 39 RH

1. Plate current would go down.

2. Fig. 1C.

3. In the local oscillator or its coupling to the first detector.

4. Secondary of output transformer and voice coil of speaker.

5. 920 and 1380 kc.

6. Neutralize first, then align and neutralize again if necessary.

7. A headphone with a series protective condenser.

8. Plate current or emission test, emission control test, input resistance check.

9. At low, usually 600 kc., preselector setting.

10. The antenna lead in wire, the receiver tuned to a local station.

SERVICING BROADCAST AND ALL-WAVE SUPERHETERODYNES

40RH-1

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

Better jobs go naturally to the man who learns things about his present job which others consider unnecessary.
—J. E. SMITH.

NATIONAL RADIO INSTITUTE

WASHINGTON, D.C.

1942 Edition

A LESSON TEXT OF THE N. R. I. COURSE
WHICH TRAINS YOU TO BECOME A
RADIOTRICIAN & TELETRICIAN
(REGISTERED U. S. PATENT OFFICE) (REGISTERED U. S. PATENT OFFICE)

NCP2M1241

Printed in U. S. A.

Servicing Broadcast and All-Wave Superheterodynes

INTRODUCTION

AS THE old tuned R. F. radio receivers find their way into the scrap heap, the superheterodyne receiver assumes a more prominent place in the daily work of a Radio-Trician. The superior qualities of the superheterodyne circuit have led to its universal adoption by radio designers, and today all except a few small receivers (which are usually inexpensive and of the universal A.C.-D.C. type) are superheterodynes. From your previous studies it should be clear that the superheterodyne circuit has made possible the all-wave receiver, where only one separate section, the preselector-mixer*-oscillator coil assembly, is needed for each frequency band, and the remaining stages of the receiver are used on all bands. In the modern all-wave receiver the change from one frequency band to the other is made electrically, by means of a multiple-contact multiple-gang switch.

If you bear in mind *this* simple difference between a superheterodyne designed for the broadcast band and a superheterodyne designed for two or more bands, that in *multi-band* receivers there is one extra preselector-mixer-oscillator coil assembly for each band, the servicing of the all-wave receiver becomes simple. Briefly stated, those tests which you would make on the *preselector-mixer-oscillator* of the broadcast band of the receiver should be repeated for the preselector-mixer-oscillator used for each of the other bands. To be sure, the presence of idle coils and complicated switching systems may introduce some radio and mechanical difficulties, but they are relatively unimportant. Mechanical difficulties are easily located by the observant man; electrical difficulties in design should be given little or no attention by service men. Let me make clear this problem of design before we start on actual servicing problems.

The final design of every receiver is the result of balancing deficiencies in performance with desirable features. The price of a receiver governs its refinement and perfection, and improvements are made in receiver models each year. You cannot expect a seven-tube super of last year's manufacture to be as good as this year's seven-tube model, and it is foolish for the Radio-Trician to try to make them alike by changing the design. In asking you to repair his receiver, Mr. John Q. Public has in mind one fact—the restoring of his receiver to a condition which compares favorably with its original performance. In

* Or first detector, which is also inferred by the word "mixer." It is best to consider the tuned input circuit of the first detector as a part of the preselector circuit.

this lesson we are only going to consider the problem of restoring superheterodynes to their original condition.

Furthermore, only those troubles which are characteristic of the superheterodyne circuit will be considered. Such service problems as hum, internal and external receiver noise, intermittent reception, defective tubes, power pack and audio system troubles, and failure to get high fidelity reception are either general or special troubles which apply to other circuits as well, and are therefore covered elsewhere in this Course.

Many different servicing procedures, each suited to a particular circuit, appear in this lesson, but emphasis is laid on *why* and *when* a certain procedure should be used rather than on complete step-by-step instructions which might apply only to a limited group of sets. Advantages and disadvantages of each method are given, training you to pick automatically the best method for each job, and to adapt your method to the job at hand.

THE SERVICING PROBLEM—A REVIEW

In previous lessons the servicing of a receiver by the socket analyzer, point to point voltage, point to point resistance, and the stage by stage elimination method was considered for TRF and super receivers. The problem of servicing a super is sufficiently important to warrant a review of these methods which will give you a new slant on the approach to a servicing problem.

Starting from the beginning, we encounter two basic conditions: *1, the set is "dead" and does not play; 2, the receiver plays, but improperly,* in a manner which is not satisfactory to the customer. In the case of the all-wave receiver the set may be dead or play improperly on some bands but may be satisfactory on others; however, if at least one band plays properly we know immediately that the I.F., second detector, and A.F. stages are okay, and that the trouble is in the preselector-mixer-oscillator *coil sections* or in the *switches* belonging to those bands which give unsatisfactory or no reception.

Servicing a *dead* receiver is a comparatively simple task compared to the servicing of a set which gives below normal reception. In the case of a receiver which does not play it is merely necessary to isolate the defective section or stage, analyzing that stage and its parts and replacing or correcting that part which is found defective. We will consider this problem in greater detail shortly.

When a receiver *plays improperly* the cause may be a simple defect or something more serious. Usually the failure to give good reception is accompanied by other symptoms which, if studied carefully, will lead you directly to the "sore spot." The purpose of part of this lesson is to train you to reason from *effect to cause* in locating troubles peculiar to the superheterodyne circuit.

Important superheterodyne receiver complaints are:

1. Lack of sensitivity or no "pep," and poor distant reception.—In general a super may lose "pep" without having broad tuning; when selectivity is reduced it is usually evidenced by inability to separate adjacent stations on the dial. When a receiver loses both "pep" and adjacent-station separating ability on semi-local stations over the entire tuning range, there will generally be a defect in the I.F. alignment of the receiver, or in the I.F. signal circuits. When powerful local stations are both broad and weak, check the oscillator tube, especially its C bias. When the super lacks "pep" but still has good selectivity, the trouble will in general be due to poor tubes, improper operating voltages or a circuit defect.

2. Interference.—This is a common service problem with supers. Image and code interference are encountered, and double spot tuning is occasionally annoying to the customer.

3. Oscillation.

4. Distortion.

There are, of course, many complaints against the performance of an all-wave super which cannot be considered the fault of the receiver. Ignition interference will be picked up by sensitive short-wave receivers; here it is your duty to explain to the customer the limitations of short-wave reception. Fading on foreign and other distant stations is to be expected even with the new receivers which have quick-acting AVC, although a fast AVC reduces the amount of fading. Receiving conditions change continually in the short-wave bands, giving continually varying signals. Finally, inexpensive receivers may give satisfactory performance in exceptionally good locations, but in general they cannot compare with the bigger and more costly models. Briefly stated, carefully consider the design and purpose of a receiver before you pronounce it defective. The public has been led to expect marvels from modern all-wave receivers, a situation which unfortunately cannot as yet be met.

HANDLING THE DEAD SET OR SECTION

The set is dead. Are you going to test each and every tube in the receiver, then analyze the voltage and current at each socket—are you going to measure point to point voltages and resistances—or are you going to make a preliminary trouble-localizing search? Naturally you want the quickest solution to the problem, for time is an important factor in profitable servicing. Here is a sane and sensible procedure to follow:

1. Look for surface defects; see if all the tubes light; listen for tube warming noises, which indicate the presence of supply voltages; look for misplaced or open connections above the chassis; note whether any one has tampered with the set or antenna system.

2. Isolate the defective section or stage.

3. Analyze the defective stage and the offending part or connection.

4. Make the required repair or replacement.

We have already stressed the importance of searching for surface defects and the defective stage isolation procedure, but let us briefly review the latter. Remember that if a tube (the rectifier tube is a general exception) is pulled out of a socket and returned one or two clicks will be heard in the loudspeaker if all stages following that tube are operating and the tube is drawing a reasonable plate current. The sudden change in the plate current causes a voltage to be induced in the following circuits. The same click should be heard if the control grid of a tube is touched with your finger* or temporarily shorted to the chassis. Either "stunt" is satisfactory; use whichever is more convenient.

The starting point for an isolation test is, as you know, the second detector; a click heard when this tube is pulled out or its grid is touched indicates a working A.F. system. If no clicks are heard, try each audio amplifier tube in turn, testing the power tube last. In general it is not wise to stop a large plate current drain by pulling out a power tube, especially when it will cause a large voltage to appear across the filter condensers and rectifier tube, but it is being done every day by expert Radio-Tricians without harm. As a precaution save the power tube for the last.

Assuming that the A.F. stages are acting normally, proceed to pull tubes or touch grids (easier when the control grid is on top of the tube) of the I.F. stages and the first detector until the click is no longer heard. Try the preselector stage tube before the oscillator, because if this gives a click the oscillator is probably working.

The critical point is the first detector or mixer. It is wise to connect a signal generator between the grid of the first detector and the chassis—a simple task if you remember that it is easy to reach the stator of that variable condenser which is connected to the grid of the first detector. Tune the modulated S.G. (signal generator)† to the I.F. frequency of the set; modulation tone in the loudspeaker indicates

---

* This is the only method to use when tube filaments are in series.

† Always use a modulated S.G. when you are making audio checks of signal strength or when an output indicator is connected in place of the loudspeaker; you can use either a modulated or unmodulated S.G. when signal strength is being measured by a milliammeter connected into the cathode return circuit of an AVC-controlled tube, as shown in Fig. *5* for the last I. F. stage. A high resistance 0-10 volt D.C. voltmeter connected between point x and ground may also be used as an output meter, maximum voltage indicating maximum signal. The output of the S.G. should be adjusted carefully so that no stages of the receiver are overloaded. Overloading is present when the indicating meter connected into the cathode circuit of an AVC-controlled tube fails to decrease further with increased S.G. signal strength.

that the first detector is okay. Now tune the S.G. to the frequency at which the receiver happens to be set; hearing an output modulation tone means that the oscillator is okay. These tests are more conclusive than pulling mixer and oscillator tubes, and are especially recommended when a combination mixer-detector-oscillator (pentagrid or tetrode) tube is found in a set.

Before taking the chassis out of the cabinet, it is wise to make certain that you have isolated the defective stage. In the case of a metal tube stage, touch the tube lightly to see if it is hot; a cold tube would suggest immediately that you try a new one. If the tube is hot, it is suggested that you check the isolation of the defective stage with an S.G. Connect the S.G., set to a frequency corresponding to the resonant frequency of the circuit under test, to the input of the stage which you have isolated as defective. If the signal comes through the loudspeaker the original disturbance test failed (this occurs only rarely). Advance the S.G. stage by stage, making contact to control grid caps or to control grid prongs of tubes which do not have caps (by pulling a tube slightly out of its socket you can use a probe point to make contact with the prongs), until the signal is no longer heard. If connecting the S.G. to the input of the suspected defective stage fails to give a tone output, connect it to the output of that stage (plate to chassis). If the signal is now heard the defective stage is definitely isolated. If no signal is heard and a click was previously heard when the tube next in line was pulled, it is a fair indication that there is a defect in the coupling of that stage or in the input to the next tube. Finally, check the tube in a tube tester to clear it of suspicion, and proceed to analyze the stage by any method you prefer—the ohmmeter, voltmeter or plug-in analyzer. Inasmuch as the defect is now traced to under-the-chassis trouble, it is wiser to remove the chassis from its cabinet before analyzing the stage.

All-Wave Receiver Is Dead In One Or More Bands.—In the all-wave receiver the first detector stage is the central checking point for defective stage isolation when one or more bands are dead. Connect the modulated S.G., set at the I.F. frequency, to the grid and chassis of the first detector. If the modulated tone comes through, the detector is okay. Now tune the S.G. to at least one frequency in each band, tuning the receiver to the same frequency. When the S.G. signal cannot be heard from the loudspeaker, an oscillator or mixer connection or defect in that band is causing the trouble. If signals are heard on all bands, the defect is apparently in the R.F. (preselector) tubes or their associated circuits. This can readily be checked by pulling out the R.F. tubes once for each band and noting whether a click is heard; make further check for input, output, or coupling defects with an all-wave signal generator, by connecting the S.G. to the R.F. tube control grids and to the *ANT.* and *GND.* terminals in succession.

It takes longer to tell how the isolation test is made than it takes to make the actual test. The average man can often make the check in less than 30 seconds, and in most cases not more than 3 or 4 minutes are required. Observe that the circuit disturbance test (pulling tubes) allows you to go down the line very quickly, isolating the approximate region of the defect; the S.G. allows you to trace the defect to one exact location. After this the internal stage analysis completes the trouble hunt.

There are cases where the disturbance test seems to give questionable results. For example the clicks may all be weak, indicating a weak voltage supply; there may not be any clicks at all, suggesting a voltage supply or loudspeaker failure; the receiver under test may have series-connected filaments, in which case this tube-pulling test will naturally fail. When you are in doubt, return to the stage by stage signal generator test, which is the most conclusive of all defective stage isolation checks.

Other possible defects include those in AVC systems, noise squelching circuits, tuning indicator devices, and bass compensation circuits. There should be no serious difficulty in isolating these troubles, as the indications resulting from the defect are perfectly obvious and lead you immediately to the trouble. A signal generator connected to the input of the receiver replaces the signal of the broadcasting station and permits reliable inspection of the operation of the questioned section.

HANDLING THE RECEIVER WHICH LACKS "PEP"

Now let us consider the receiver which fails to pick up as many stations as it once did; in this case the stations to which the customer usually tunes are heard with less volume than before. It is important to know what the set is capable of doing, or what it did before this defect appeared, for after all some people merely imagine they are getting poor reception. Again, you should ascertain whether conditions in the atmosphere have changed. You should know that distant reception is poor in the broadcast band during the summer time, and that stations above 20 megacycles are rarely received after dark. After all, only local or semi-local stations are reliable; should several of them be heard with weaker volume than is customary you have a bona fide defect to correct.

It is not hard to tell whether the lack of "pep" is due to an R.F. or A.F. defect. If many stations are tuned in but the loudspeaker output level is low, the defect is isolated in the A.F. stages; if too few distant stations are heard but the locals are fairly loud, an R. F. defect is indicated. We will take up the latter case first.

Tubes are the first item to question. It is a good plan to check them at once. Use a tube tester or try new tubes. The oscillator tube and the pentagrid tube (or some other combination oscillator-detector-mixer tube such as the tetrode) are especially critical and should be checked carefully. A weak rectifier tube may also create a general lowering of receiver "pep." It is even a wise plan to check the main voltage supply to be sure that a power pack defect is not lowering the operating voltages fed to the R.F. section.

Antennas always deteriorate with age. First check for open circuits and grounds in the antenna, lead-in, and lightning arrester. Yes, even make sure that the antenna is up, as storms raise havoc with the flimsy structures commonly used for antenna systems. Here is another thought; is a good antenna system being used? Many sets are installed in the winter when any wire strung between two points "brings 'em in"; these slipshod antennas are worthless during the summer and during times when atmospheric conditions hinder distant reception. Erect a good antenna system—the best the customer can afford, and make sure it will be easy to take down for repairs and tests. Put up a reliable noise-reducing antenna if there is man-made interference in the vicinity. If the customer prefers to receive stations from definite parts of the country or world, antenna pick-up directivity is important. Remember that an inverted "L" type antenna receives signals best from the direction toward which the lead-in end of the horizontal section is pointing. A "T" antenna receives well from all directions; the longer the vertical part the better will be reception. A doublet antenna, regardless of how it is coupled to the transmission line, always receives best from its sides, or at right angles to the horizontal sections. For instance, if the doublet runs east and west, maximum pick-up will be from north and south directions.

For long distance reception the direction which the radio waves actually take in traveling from the transmitter to the receiver should be determined by locating the two points on a good globe of the world and joining them with a tightly stretched string. Directional antennas (assuming they are in the open and away from any high objects) should be located according to the direction indicated by the string, for this is the great circle route—the shortest distance between the two points. Ordinary flat maps are of little use in determining directions between widely separated points on the earth.

Circuit defects are always possible causes for poor receiver sensitivity, but remember they must be defects which do not destroy receiver operation. A poor joint or connection in a signal circuit is a possible source of trouble. An open plate, screen or grid bias by-pass condenser may set up R.F. voltages which in some cases neutralize or degenerate the signal, giving poor sensitivity, and in other cases cause regeneration. Undesirable leakage or capacity coupling bridging across an open coil or condenser in a circuit may still permit the receiver to operate weakly. Coils and condensers may be damp, reducing their effectiveness in the signal circuit; bake the chassis to drive off moisture. If a super using a combination detector-oscillator tube such as a 36 or 24 tetrode responds weakly or is dead at the low frequency end of the broadcast band, check the C bias to the oscillator section of the tube* before condemning preselector-oscillator tracking. Such tubes are often critically affected by a high negative C bias; measure the bias resistance, then reduce it to about two-thirds of its original value; this will in general make the receiver oscillator operate at the weak or dead range.

Receivers may lose sensitivity because a current is being bled to the initial C bias resistor through a leaky condenser connected from B+ to cathode, raising the negative bias. Oscillations in an I.F. stage may send an R.F. signal (not the desired signal) to the AVC tube, thus placing an increased negative bias on the AVC controlled tubes even when weak signals are received and giving weak distant reception. In the latter case check for possible causes of oscillation in the I.F. stages; an open by-pass condenser or open bleeder resistor is the most probable cause. The fact that the plate currents in the AVC controlled stages are below normal, even when tuning between stations, indicates excessive AVC voltage, but this is not necessarily due to an oscillating stage.

Where a high C bias voltage is evident, check the by-pass condensers to the cathode for leakage; where an open condenser is suspected try shunting each condenser in turn with a good unit (a .5 mfd., 600 volt condenser connected to test probes is ideal), until you find a place where the test condenser, shunted across a receiver condenser, restores normal reception. Of course, the receiver must be tuned to a broadcasting station or to a signal generator.

In the case of high resistance joints or open coils in the signal circuits, an ohmmeter is the best radio test device. Before you begin extensive tests, try to locate the improperly working stage with a signal generator.

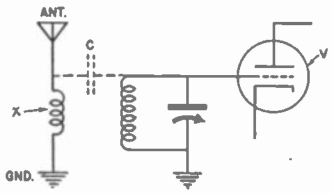
Typical circuit defects which cause poor sensitivity are schematically shown in Figs. *1A* to *1D*. Study them carefully; if possible, introduce these defects into your own receiver and note their effects.

Alignment Defects.—It is a strange fact that many radio service men immediately think of poor alignment when weak reception is encountered. To be sure, this may be a perfectly reasonable cause, but enough has been said already to show you that many other defects are likely sources of trouble. Be sure that all these other defects are "ruled out" before you start the alignment procedure, for it takes time to make the careful alignment necessary for effective results. There

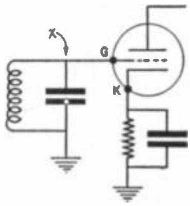
*Quite often a new tube will restore normal reception, but in a month or so the set will again be weak at the low frequency end of the band. Adjust the C bias, using the same tube, for better low frequency response.

are, however, definite effects or symptoms in a super which indicate the need of alignment. These trouble symptoms may be the result of natural aging of the receiver or may be due to tampering by some inexperienced person.

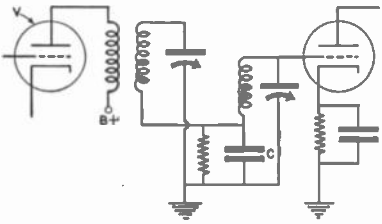
If through a mechanical shock the variable tuning condenser loses its mechanical alignment, weak reception may be expected over the entire tuning range. If the low frequency oscillator padder has been



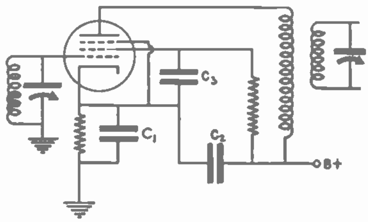
A. An open circuit in the antenna coil, as at x, will weaken reception and introduce circuit noise. The coil to coil capacity C allows some signal pick-up. Pulling tube V will give a click, concealing trouble; only an *ANT.* to *GND*, ohmmeter test shows defect.



B. A high resistance joint at x will weaken reception. A G to K voltage check will shown normal C bias, concealing defect, but a G to chassis ohmmeter test will locate the trouble, provided the tuning condenser is not shorted.



C. Weak reception would be obtained if condenser C in this typical band-pass circuit opened. Normal voltages would be obtained, and pulling tube V would give a weak click. Shunting C with another condenser of similar capacity would restore reception.



D. An open condenser at C_1, C_2 or C_3 could cause degeneration and weakened reception, as well as regeneration and squeals. A leaky condenser at C_2 would bleed current from B+, shooting the C bias up and weakening reception even more.

FIG. 1. Here are a few typical defects which can cause poor sensitivity.

tampered with or the mica insulation used as its dielectric has cracked or slipped out of place, weak reception may be expected at the low frequencies; in some cases no reception will be obtained in the middle part of the band. Improper adjustment of the high frequency variable condenser trimmers may result in weak high frequency reception, and again may destroy middle band reception.

Remember that oscillator adjustments are more critical than adjustments in the preselector circuit. For a quick check of the preselector insert headphones in the plate circuit of the first detector and pull out the oscillator tube (or short its grid to prevent oscillation); tune the receiver to a strong local station or feed into its input circuit a modulated S.G. signal in the frequency band under test. Now if a signal is heard in the phones and this signal can be tuned, the preselector for that band, as well as the first detector, are working. Repeat this test for each band. When a defect is traced in this way to misalignment (the signals will be weak or will not track with the dial calibration), it is always wise to realign completely the preselector-mixer-oscillator circuits.

If you suspect misalignment, do not try to adjust the trimmers until you have made a positive check of the alignment. There is available for this purpose a simple and inexpensive device, a servicing tool called by some technicians a "tuning wand." The general appearance of this wand is shown in Fig. *2*. If the powdered iron or radio transformer steel end is inserted in a coil, the inductance of the coil goes up due to the increased permeability of the core; when the brass end is inserted in a coil, the coil inductance goes down, due to the reduced magnetic field caused by eddy currents induced in the brass. The tuning wand can be used only where the coil ends are open, and fortunately they are in most all-wave superheterodyne preselector-mixer-oscillator circuits. The tuning wand is a valuable tool inasmuch as 9 to 12 coils and 10 to 14 trimmer condensers are often found in 3- and 4-band receivers.

The tuning wand is easy to use, but a well calibrated signal generator is necessary for positive indications and results. Set the receiver to the desired frequency band, then set the receiver dial in turn to a high, to a low, and to a middle frequency in each band and tune the modulated S.G., connected to the *ANT.* and *GND.* posts of the receiver, to *exactly* the receiver frequency setting in each case. Start with the oscillator coil, as it is in the most critical circuit; insert first one end of the tuning wand, then the other, in the coil. If inserting the *powdered steel* end *increases* the signal output the trimmer needs *more capacity;* if the *brass end* increases the signal output, *less* trimmer capacity is needed; if both ends of the wand reduce the signal output at all three frequency settings, the oscillator adjustment is correct. By carrying out this test for all coils in the preselector and detector circuits, you will be able to tell just how badly the receiver needs realignment. If only a few trimmers are out of adjustment, you can readjust them by checking with the tuning wand; if quite a few are bad, it will be necessary to realign the entire receiver.

When you are only partially realigning, remember that for oscillators the low frequency padder must be adjusted if the test is made at a low frequency in any band; if testing at a high frequency, adjust the trimmers which are in parallel with the variable condenser (these are not necessarily on the gang condenser). For the preselector and first detector input circuits adjust the trimmers only for the high frequency end of each band.

Troubles Peculiar to All-Wave Receivers.—Weak reception resulting from poor alignment in all-wave receivers has just been considered; a more common defect, weak reception in the very high frequency bands, may be traced to a weak oscillator tube and in particular to a combination detector-oscillator tube. Be sure to try new tubes.

All-wave reception is, of course, possible with the antenna usually employed for broadcast reception, but more reliable and stronger signals can be picked up if an all-wave antenna is used. This is particularly true in the highest frequency bands. Always recommend the installation of a modern antenna if one is not already used. The doublet all-wave antenna is best for noise elimination.

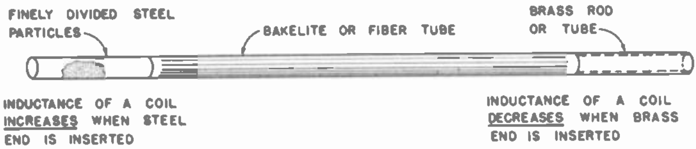


FIG. 2. The "tuning wand," construction of which is shown here, is used to make a positive check-up on the need for alignment in a super, as well as to tell how to adjust the preselector-mixer-oscillator alignment condensers.

In existing all-wave antenna installations give special attention to the connection between the transmission line and the receiver; oftentimes the customer is not familiar with the use of the special coupler which is provided with a short and long-wave switch. Correct adjustments and correct connections to the receiver can make all the difference in the world.

Band changing switches are often to blame for weak and even noisy reception, especially in the older models of all-wave sets. Be sure to wiggle the switch while checking for poor contacts. If a replacement is indicated, secure a duplicate switch from the manufacturer or his distributor, for he will have made every effort to correct defects in the original design of the switch.

Thousands of all-wave receivers were made with improper coil assembly and coil changing systems, which did not eliminate the effects of idle coils; these sets usually have dead tuning spots. Unfortunately the elimination of this trouble is too expensive to be attempted by the service man, unless specific information from the set manufacturer is available. If the customer insists upon correction of this fault, contact the nearest distributor or the manufacturer of this receiver and inquire if repair information is available. Unless this information is obtained you may find that more experimental time will be required to work out the solution than the customer will care to pay for.

Dynamic Stage by Stage Test for Weak Reception.—Quite often when there is so much conflicting evidence to confuse the reasoning of the probable cause, or there is no evidence at all, it is quite valuable to isolate the trouble to the defective stage. For such a test the modulated signal generator has no equal. As the grid is the easiest element to reach in a stage (connect to the control cap, or to the stator of the variable condenser), it is generally used. To prevent the signal generator from shorting the C bias feed circuit, it is wise to insert a .001 mfd. condenser in series with one of the S.G. probing leads. Naturally this unit should be inserted permanently into the probe circuit.

The procedure to be used in isolating the stage which is causing weak reception is identical with the stage by stage analysis test; the S.G., connected to successive inputs, is set to the I.F. or R.F. frequency, depending upon the stage. As you proceed from the second detector to the antenna circuit, each amplifying stage must give a decided gain in the output level. A decrease in output or failure to give an increase isolates the defective stage. Now check voltages, currents, continuity and separate parts until the defective part or connection is spotted.

INTERFERENCE TROUBLES PECULIAR TO SUPERS

The superheterodyne circuit, although essentially a very selective circuit, is subject to a number of unusual interference difficulties.

Image Interference and Double Spot Tuning.—Any signal which can get through the preselector to beat with the oscillator and produce the I.F. frequency will cause interference. At any position of the receiver tuning dial there is always the possibility of interference from a station whose frequency is equal to the receiver dial frequency plus twice the I.F. frequency. (This assumes that the oscillator frequency is always higher than the station selector frequency, the difference of course being equal to the I.F. frequency.) Such interference is called image interference. The image interference signal may be heard with the desired signal, in which case it can be immediately identified as image interference, or the two stations may beat to produce a squeal. In the latter case it may be difficult to distinguish between this type of oscillation and oscillation created by undesirable feed-back. For a positive check disconnect the antenna and feed into the set *(ANT.* and *GND.* terminals) a modulated signal corresponding to the frequency of the offending station, the receiver being left at the setting where interference was heard. If the S.G. signal now comes through and is heard you have proved that image interference was creating a squeal. As an additional check, set the S.G. to the receiver frequency; in this case a squeal indicates that there is oscillation in the circuit, while a clear modulated S.G. tone means that the circuit is okay and the trouble is due to image interference.

On the other hand, it is quite possible for strong local signals to be heard at two places on the dial. Still assuming that the oscillator operates *above* the receiving frequency, a strong signal may be heard at the correct dial setting and at a point equal to twice the I.F. value *below* the correct setting. This is called double spot tuning, and is quite annoying in large cities where many powerful stations exist. Here is an example: The receiver, which has a 260 kc. I.F. frequency, is being tuned to a 1,100 kc. station, which places the oscillator at 1,360 kc. To demonstrate double spot tuning, set the receiver at a frequency equal to 1,100 minus 2 x 260, which is 1,100 minus 520 or *580 kc.* Clearly the oscillator is now at a frequency equal to 580 plus 260 or *840 kc.*, making the difference between the oscillator and the 1,100 kc. station frequency equal to *260 kc.*, the I. F. frequency. If the 1,100 kc. station can get through the preselector (set at 580 kc.) it will naturally beat with the oscillator to give a signal at this setting of the receiver dial. Double spot troubles will be more common on receivers having low I.F. frequencies, 175 kc. or less, for in these cases twice the I.F. will fall more often in the broadcast band.

Getting rid of image interference and double spot tuning is a job initially considered by the receiver designer. He overcomes it either by using a well designed preselector with plenty of selectivity and a selective I.F. amplifier, making it more difficult for image interference signals to get through the preselector, or by using a high I.F. frequency value. But the service man cannot be expected to redesign a receiver which has these faults—what is he to do? A few suggestions will help.

First you should make certain that all tube and coil shields are firmly in place, for there is a possibility that interference from a local or semi-local station may enter directly at the mixer stage, thus getting around the preselector. Be sure that there are no stray wires running from the antenna to the mixer stage. Closing up the bottom of the chassis with metal may help in some cases.

If the preselector is improperly aligned it may not have the desired selectivity, with interference resulting. If a band-pass preselector stage is used, it may be out of adjustment. Realignment is the answer in these cases.

If the I.F. stages are not peaked, you may hear two stations at the same receiver dial setting. The lowest frequency station will be that to which the receiver is tuned and the other will be a station whose frequency is equal to *a little more than* the sum of twice the I.F. and the frequency of the station to which the set is tuned. This is simply a type of image interference, and in ordinary supers peaking the I.F. is the solution.

Perhaps the double spot tuning elimination circuit occasionally found in receivers using an I.F. below 150 kc. is not properly tracking and may need realigning. Compare the schematic diagram of the set with the double spot tuning suppression circuit shown in Fig. *3A*, for only a few receivers, having low I.F. values, use this scheme.

If only one local station is causing image or double spot tuning interference, the quickest and most direct solution is to install a wave trap which is set to the interfering station frequency; connect the trap as shown in Fig. *3B* or *3C*.* This will reduce the signal intensity of that station and thus reduce image and double spot tuning troubles.

Code Interference.—Coast Guard radio, airway beacon and weather reporting stations, as well as marine communication stations, use frequency bands which include common I.F. frequencies; if located nearby, one of these stations may cause severe code interference. If the station creating the interference happens to broadcast on the exact I.F. value of the superhet in question, the station is very likely to cause interference at all settings of the tuning dial.

When code interference is encountered, the first step is to disconnect the antenna and ground, then short these terminals on the receiver. If the interference is still heard it may be due to direct chassis pick-up or to interference coming in over the power supply lines and feeding directly into the I.F. amplifiers. The latter possibility should be eliminated by inserting a balanced choke-condenser filter (two chokes and two condensers with the common condenser terminals grounded as in Fig. *4*) in the supply line. If this filter eliminates the interference when the antenna and ground are shorted, but not when antenna feed is restored, try placing a wave trap in the antenna circuit and tuning it to the offending station. The primary of an extra I.F. transformer, connected into the antenna circuit as at L_T in Fig. *3B*, forms a simple wave trap. If interference gets into the chassis directly and the same station is a constant offender, it is best to shift the I.F. frequency about 10 kilocycles above or below the former value, and realign the entire receiver.

Faulty shielding, faulty location of antenna lead wires, especially those coming from the band changing switch and passing near an I.F. amplifier lead, failure to have the I.F. peaked, and poor preselector design are all possible sources of station interference; these points should be checked.

OSCILLATIONS

Because of the nature of the superheterodyne circuit, oscillations occur for many different reasons in addition to high plate and screen

*In a few old supers a continuously varying trap like those shown is used to eliminate image interference over the entire tuning band. This circuit may be out of alignment; use a signal generator signal which is set at the image frequency to check for image signal elimination.

voltage, open condensers and the other common faults. We have already considered how image interference may result in an oscillation squeal.

I.F. Harmonic Feed-Back Troubles.—If harmonics of the fundamental frequencies commonly found in the plate circuits of detector tubes are allowed to feed back to the preselector, beat oscillations may occur. In the second detector the I.F. is the only fundamental frequency, but in the first detector there are three fundamentals—the oscillator frequency, the incoming R.F. signal frequency, and the I.F.; only the harmonics of the I.F. fundamental will cause trouble.

When I.F. harmonics, because of some defect in the circuit, get back to the preselector, that harmonic which happens to be about the same frequency as the incoming signal will produce an audio beat note. After being modulated on the carrier of the desired signal and amplified by the receiver, this beat note will come from the loudspeaker as an annoying signal.

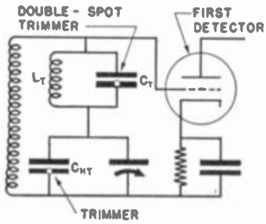


FIG. 3A. A typical double spot tuning suppression circuit for supers with a low I.F.

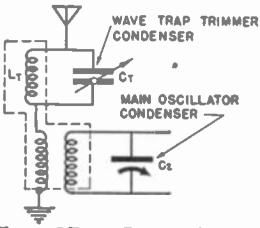


FIG. 3B. L_T and C_T form a wave trap which suppresses image interference signals.

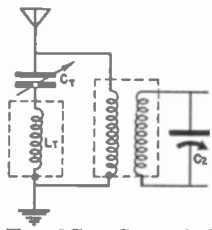


FIG. 3C. C_T and L_T here by-pass image interference signals to the ground.

Possible Defects.—An open or a defect in the plate by-pass condenser in the second detector circuit may cause a large I.F. current component to appear in the plate supply leads, causing harmonic feed-back by common coupling to the preselector.

Inasmuch as the first detector is near the preselector, undesired coupling between these two stages can easily occur, and harmonics of the I.F. may then cause interfering squeals. Open by-pass condensers and misplaced grid and plate leads are common causes. Of course it is not easy to locate all possible undesirable coupling, so the best plan is to keep the harmonics weak. Check the C bias and plate voltages of the first detector, for incorrect values may cause distortion and a high harmonic output. When you cannot readily locate the cause of harmonic feed-back, the best procedure is to shift the I.F. frequency about 5 kc. This will move the offending harmonic to a point on the dial where no station exists to beat with it; in some cases, however, this shift in I.F. may cause some other harmonic to interfere.

Trouble with harmonics is encountered most often in receivers having high I.F. values. For example, an I.F. value of 450 kc. will produce strong second and third harmonics at 900 kc. and 1,350 kc., frequencies which are in the broadcast band, and an interfering signal may be obtained when stations are tuned in at these frequencies. If the I.F. is adjusted to 452.5 kc., the harmonics will be 905 kc., where no station exists, and 1,357.5 kc. The latter is a third harmonic (always weaker than a second harmonic) 2.5 kc. away from a station, so interference should be reduced considerably by the shift in the I.F. frequency.

Second Detector Oscillates.—If the second detector plate circuit becomes inductive because of an open R.F. by-pass condenser, it is possible for this circuit to go into self-oscillation and cause intense interference. You can detect an oscillating tube by bringing your hand near its grid or some other part in that stage. If the pitch of the squeal changes, indicating that the tube is oscillating, it is a simple task to check the condensers. If the frequency of oscillation is not affected by hand capacity, and a squeal is still heard after by-pass condensers are proved okay, check for misplaced wires causing a coupling which would allow I.F. harmonics to feed back to the preselector and give a beat oscillation.

First Detector Oscillates.—It is perfectly possible for the first detector to act as a tuned-grid tuned-plate oscillator. This will occur if a station at about 550 kc. is tuned in and the I.F. is between 400 to 500 kc. If the I.F. plate trimmer of the first detector is out of adjustment, making that circuit resonant or nearly resonant to the incoming signal, feed-back will occur, causing blocking of the signal. Try adjusting the first detector plate trimmer, especially if a high I.F. is used and the oscillation is of a low frequency. Turn the trimmer in either direction while listening to the oscillation; if this does not cure the trouble set the trimmer back to its original position and look for other causes of feed-back; if this procedure does stop the oscillation, reset the trimmer by using a signal generator, just as if you were aligning this stage.

Finally, some all-wave receivers have a beat frequency circuit to help locate distant stations. If the switching mechanism is defective, oscillations may occur even if the beat signal circuit switch is in the *OFF* position.

DISTORTION

Distortion may appear in any stage which has excessive feed-back or oscillation, where the C bias, the plate, or any other electrode voltage is incorrect (especially in second detector and audio stages), or where a weak tube is used. The distortion most often encountered in supers, however, centers around the first detector-oscillator.

A weak oscillator stage (the result of a poor tube, low plate voltage, or high C bias) may allow a strong incoming signal to over-modulate the local oscillator signal, creating distortion. Pentagrid and tetrode converter tubes are quite critical in this respect; it is always a good policy to try a new tube when distortion appears. Separate oscillator tubes should be checked for voltage. Over-modulation and consequent distortion occurs also if the incoming signal is too large. If distortion occurs in an AVC receiver, make certain that the R.F. preselector is under automatic volume control by inserting a milliammeter in its plate circuit and noting whether the current drops for a strong signal (do not use a plug-in analyzer to make this check, for it introduces capacity and prevents the true action of the circuit). If no AVC action on the preselector can be observed, make a thorough check of that stage as well as a continuity test between the preselector tube grid and the AVC tube.

Of course, a sharply peaked I.F. amplifier causes most of the distortion or poor tone quality troubles in a super, especially when feedback is just starting. Broadening of the I.F. peaks is always recommended when sufficient gain is present to permit this adjustment.

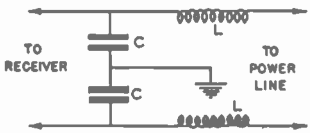


FIG. 4A. This balanced choke-condenser filter may be used to check code and other interference which is coming in over the power line. Try various values of C, with and without L in the circuit; the chokes are needed only in very bad cases. The choke and condenser combination indicated by trials or by an interference analyzer should be mounted in a metal box and attached permanently to the device causing interference or the power outlet of the radio set.

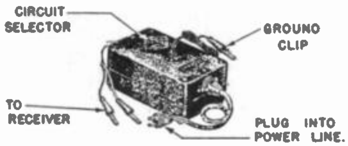


FIG. 4B. The Sprague interference analyzer may be used to select the proper values for L and C in the balanced choke-condenser filter. There are six positions of the selector switch; in the first three, condensers of different sizes are connected across the line, and in the last three positions choke coils as well as condensers are connected in different combinations. This analyzer may also be connected to the power input terminals of any devices suspected of creating radio interference. Adjust the selector switch for minimum receiver noise.

DIAL CALIBRATION OFF

Mechanical Trouble.—Even though the dial setting of a receiver does not agree with the frequency of the station being heard, normal reception can still be obtained. This calibration fault is objectionable, as a rule, only to those set owners who listen to a large number of distant stations; in these cases it should be corrected. First of all be sure that the dial has not slipped on the condenser shaft. This can be detected by noting if the dial is off the same number of divisions for all stations; if it is, resetting the dial on the condenser shaft cures the trouble.

Improper Alignment.—When the scale readings are off only at one end but normal reception is obtained, the most probable cause is improper alignment of the receiver, caused by failure to take into account the dial readings when high and low frequency tracking adjustments were made. To obtain exact dial readings, assuming that the dial was carefully designed for the receiver, the first step is to check the I.F. amplifier frequency. Connect an accurate S.G. to the first detector and adjust for peak output. If the I.F. value indicated now by the S.G. is more than 10 kc. off the frequency specified by the manufacturer, make the correction before realigning the receiver. Be sure that the receiver dial is accurately set to the frequency being used, for each of the tie-down points on each band.

Circuit Defects.—On the other hand, if the dial readings are off and signals are weak, you may have either a circuit defect or improper tracking. In either case it is necessary to realign, so do that first. If upon aligning the I.F. stages you find that you cannot make the preselector-oscillator track by adjusting the low frequency padder and high frequency trimmer condensers, look for defective circuit parts. First check visually and electrically for a shorted or open padder or trimmer condenser and for cracked mica separators. Check for defective by-pass condensers and R.F. filter chokes, especially in the oscillator circuit. Check the oscillator coil for continuity and resistance, and if this fails to show a defect check for shorts.

To check for coil defects, set the station selector at a frequency where the calibration is off, let us say at 1,300 kc. Bring an insulated wire somewhere near the oscillator coil of the receiver and connect this pick-up wire to the antenna terminal of another receiver (an accurately calibrated all-wave receiver with an I.F. beat oscillator is the best test set for the service bench). Tune in the oscillator signal on the test receiver, using the beat oscillator to get an audible output in the loudspeaker. If the test receiver has no beat oscillator, use a meter connected into the cathode circuit of an AVC-controlled I.F. stage as a resonance indicator. If the frequency indicated on the test receiver dial at resonance differs much from the sum of the receiver dial frequency setting and the I.F. of the receiver under test, a coil defect must be preventing alignment, since all other parts have been checked. (It is always wise to check the accuracy of the test receiver with an S.G.) If the above frequency difference is *greater than* the I.F. of the receiver, the coil has shorted turns, and a new exact replacement coil is required. You might try changing the frequency of the oscillator by aligning the oscillator trimmer or padder to the correct oscillator frequency (the dial setting plus the I.F.); if this is possible a preselector resonant circuit is improperly aligned. The remedy is obvious; place a pair of headphones in the plate circuit of detector and align the preselector and first detector circuits just as you would a T.R.F. receiver. Temporarily stop the operation of the receiver oscillator when doing this. Now couple the receiver oscillator (again in operation) loosely to your test receiver (by running an insulated wire from the antenna post of the test receiver to a point near the oscillator tuning circuit of the set being aligned). Set the station selector dial of the receiver under repair to each of the following frequencies: 1,400, 1,200, 800 and 600 kc., tuning the test receiver for maximum output in each case and noting the frequency setting of the test receiver dial. In each case you are determining the exact frequency of the receiver oscillator. For each frequency figure the difference between the readings (in kc.) of the two receiver dials. Add all these differences and divide by four (the number of settings). The average difference is then the safest I.F. value to assume as correct. This method of determining an unknown I.F. is simple and rapid.

If the receiver gives fair performance, seeming to need only better alignment to bring back lost "pep," and if you are fairly certain that the receiver *has not been tampered with*, you may directly measure the I.F. value of the intermediate frequency amplifier and use the value obtained—*if it seems reasonable.* This direct procedure may be considered if you do not know the I.F. value. Connect an S.G. to the first detector by using the connection shown in Figs. *5* and *6*, then connect an output indicator in one of the ways shown and tune the S.G. between 100 kc. and 500 kc. The I.F. value will be the highest S.G. test frequency which comes through the I.F. amplifier (lower frequency settings of the S.G. produce harmonics which are of I.F. value but which are hard to identify). Bear in mind that I.F. values of 130, 175, 262.5 and 465 kc. are in common use; if your measured value is *near* one of these, *use that standard value* instead of the measured value. It is always wise to select a frequency ending in 5 or 2.5, as this produces the least harmonic feed-back interference.

Peaking the I.F. Amplifier.—In realigning a super, the I.F. peak adjustments are independent of the preselector-oscillator tracking adjustments and can always be made before you decide how to handle the circuits ahead of the first detector. The simplest procedure is to set the S.G. to the I.F. value, feed this signal into the first detector and adjust each I.F. trimmer in rotation until peak output is registered on the output indicator connected to the last audio stage.

The usual connections for aligning the I.F. stages are shown in Fig. *5*. Note that the signal generator (S.G.) is connected to the grid of the first detector and the chassis. As this connection should have a minimum effect on the input and bias circuit, it is customary to use a 10,000 to 250,000 ohm resistor connected between the control grid of the first detector and the control grid cap, and a .001 mfd. condenser connected between the control grid and the high R.F. terminal of the S.G. The other terminal of the S.G. is connected to the receiver chassis. Figure *6* gives the circuit of the coupling unit and a suggested assembly of the condenser and resistor, while Fig. *5* shows how the unit is connected into a super circuit. A direct connection between the control grid and the hot R.F. signal generator terminal may be made if the first detector grid return goes to the chassis and the level of the S.G. is high enough to overcome the shorting effects of the input circuit.

Several output meter connections are possible. You may connect an output indicator (an A.C. indicator) into the audio circuit (as shown by M_1 in Fig. *5*) only if a modulated signal is used; you may employ the tuning indicator if one is used in the receiver; and if the

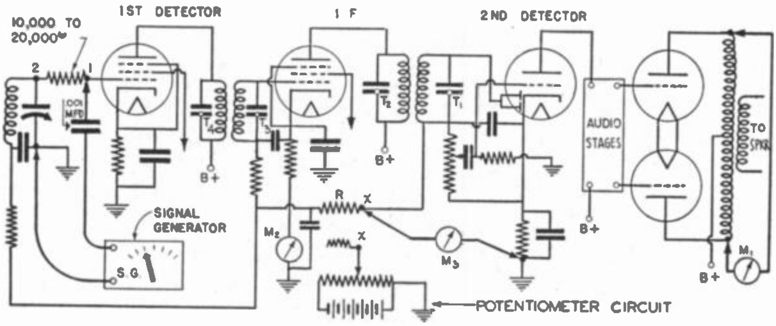


FIG. 5. Simplified schematic diagram of typical superheterodyne receiver, showing one method of connecting S.G. to input of first detector and three methods of connecting output indicators to set. The *potentiometer circuit* is sometimes needed to supply the correct C bias when A.V.C. is disconnected at *x*.

set has no tuning indicator, connect a D.C. milliammeter in series with the plate or cathode circuit of one of the AVC-controlled tubes (meter M_2 in Fig. *5*) or use a D.C. voltmeter connected as indicated by M_3. All but the first connection will work for either modulated or unmodulated signals. When starting the I.F. alignment set the S.G. at the desired frequency, then slowly tune it above and below this value until you obtain a peak output indication. (This would be indicated by minimum plate current in an AVC-controlled tube.) This immediately tells you whether the I.F. amplifier is below or above the desired frequency. Should the I.F. of the receiver be above the desired value, you know that the trimmer adjustment screws must be turned clockwise, for more capacity must be added to lower the frequency. Standard trimmers are made in such a way that a clockwise adjustment increases their capacity, and therefore lowers the frequency in their resonant circuit. Of course, if this test shows that the I.F. amplifier is peaked below the desired value, the trimmers should be turned counter-clockwise. Figure *7* gives the complete story of trimmer condensers.

Now that you know which way to turn the I.F. trimmers, set the S.G. exactly at the I.F. frequency and turn each of the trimmers (T_1, T_2, T_3 and T_4 in the example in Fig. *5*) in the direction indicated by the previous test, turning each trimmer an equal amount. As the output starts to respond adjust each trimmer carefully to peak output. Go over all the trimmers at least once after this initial peak adjustment. If turning one of the trimmers in the direction indicated by your first test reduces the output, simply turn that trimmer in the opposite direction.

Sometimes the I.F. is so far off that the S.G. cannot push a signal through at the correct I.F. value. In this case set the S.G. to the frequency nearest the rated value which will come through, peak the I.F. trimmers to this frequency, then set the S.G. another step closer to the correct I.F. value and peak the trimmers again. Repeat until you are able to peak the trimmers at the correct I.F. value.

The question of peaking AVC supers constantly arises. If you use a well shielded signal generator, one having an attenuator capable of reducing the signal output to a very small value, you will have no trouble in following the above procedure provided that you maintain the S.G. signal below the AVC threshold value. Almost any reliable modern signal generator can be used. If you prefer you may use the visual tuning indicator, if the set has one, as an output indicator; in this case use a strong S.G. signal. Another procedure involves placing a milliammeter in the plate circuit of an AVC-controlled tube, as previously described.

Should the peaking of an I.F. amplifier cause oscillations, it is wise to check filter chokes, resistors and condensers; check applied voltages and correct any defects which might result in oscillation before you attempt to cure the trouble by throwing adjustments off peak. Of course, many circuits which are intended to be band-passed cannot be peaked without oscillation. In this case the secondaries of the I.F. transformers can be temporarily shunted with 25,000 to 100,000 ohm resistors until band-pass adjustments are made. This will prevent oscillations and allow further preselector-oscillator adjustments.

A Survey of the Preselector-Oscillator Adjustments.—The preselector, which we shall consider as all of the tuned R.F. circuits ahead of the first detector, must of course be tuned to the incoming signal. The oscillator must be tuned above or below the incoming signal by the I.F. value. In the broadcast band of a super it is customary to operate the oscillator at a frequency above the broadcast signal frequency; this holds true as well for the other bands of a multi-band receiver except at ultra high frequencies, when the oscillator is often designed to operate below the frequency of the incoming signal. You can always check the oscillator frequency with the calibrated test receiver.

It is primarily the oscillator setting which determines whether a signal shall be passed on to the I.F. amplifier; the oscillator frequency must differ from the incoming signal frequency by *exactly* the I.F. value. If the preselector is tuned exactly to the incoming signal, the receiver output will be high; if the preselector is off resonance weak reception results, and if the preselector is very much off resonance no reception will be obtained. The oscillator adjustment is therefore the most critical of all preselector-mixer-oscillator tracking adjustments.

In order to make the station selector dial indicate correctly the station being received, the preselector must resonate at the dial frequency setting for all points on the dial. This condition is easily ful-

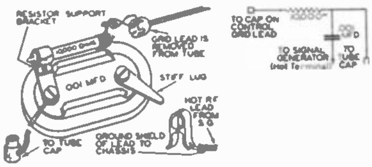


FIG. 6. Circuit diagram and sketch of a standard coupling unit which can be used to connect an S.G. to the first detector control grid of a super with minimum circuit disturbance.

FIG. 7. Turning a trimmer condenser screw *clockwise* usually *increases* the capacity, decreasing the frequency of the resonant circuit. Turning a trimmer condenser *counter-clockwise* usually *decreases* the capacity, increasing the frequency of the resonant circuit.

filled in a properly designed circuit by setting the station selector exactly at the frequency to be tuned in, setting an S.G. to this frequency, connecting it to the receiver, adjusting the receiver's oscillator for maximum output, and finally adjusting the trimmers in the preselector for maximum receiver output.

Because of the nature of the preselector-mixer-oscillator design two adjustments, one at a low and one at a high frequency setting of the station selector, are sufficient to give satisfactory accuracy at all other points on the dial. Each such adjustment is referred to as a *tie-down point;* no less than two tie-down points per band are necessary for a preselector-mixer-oscillator tracking adjustment.

Because of the need for exact oscillator adjustments, both low and high frequency adjustments are provided; the trimmer mounted on the chassis and connected in series with the variable condenser is the low frequency oscillator (or low frequency padder) adjustment. Unfortunately, the preselector has only one adjustment, the trimmer across the variable condenser, or in the case of multi-band receivers, the trimmer in parallel with the tuning coils of each band—and this is used for adjusting the preselector at the high frequency point in the band. The only preselector adjustment available for low frequencies is the bending of the rotor plates in the variable condenser.* You can eliminate this procedure by choosing a compromise adjustment between the preselector and dial settings, using a method which is commonly called a rocking adjustment. This results in good sensitivity but at the sacrifice of accurate dial readings. The plate bending procedure is preferable where accurate results are required, but in an all-wave receiver it can only be applied in one band; all the other bands must be rocked into an approximate low frequency adjustment. This exact procedure should be used for that band in which the customer is most interested.

Further improvement in any one band can be made by bending the rotor plates of the variable condensers in the preselector and oscillator circuits. It is thus possible to make either a simple or an extensive preselector-oscillator tracking adjustment, as you prefer. The procedure you choose depends upon the time you can give to the job, and that in turn depends upon the maximum charge the customer will pay.

Bear in mind that some preselector-oscillator circuits have oscillator variable condenser plates which are cut in such a manner that the oscillator tracks the preselector without the need for a low frequency padder; in this case better adjustments are made by bending the rotor plates.

A Speedy Tracking Procedure.—This is the one most often used by service men, for it results in a reasonable alignment within a very short time. It is assumed that the receiver is in good working condition and the I.F. amplifier has been peaked. The receiver is set to a high frequency, usually to 1,400 kc. for the broadcast band, and the signal generator, operating at the same frequency, is connected to the input of the receiver. An output indicator is connected next; it may or may not record an output, depending upon how far off the preselector circuit may be. If no output is observed, raise the level of the S.G. to its maximum value. To secure a tie-down point, turn the oscillator high frequency trimmer up tight (clockwise) and then slowly turn it counter-clockwise. Usually you will pass through two peak output indications; choose the one in which the trimmer is turned farther out (counter-clockwise), if the oscillator is to operate at a frequency above the incoming signal (as it does in most cases). Next adjust the preselector trimmers for peak output. Up to this point the dial settings of the receiver and S.G. are not changed.

Now set the receiver to a low frequency in the band (preferably at 600 kc. for the broadcast band), and adjust the S.G. to this frequency. Let us assume a 600 kc. frequency for this example. It is perfectly possible at this point to adjust the low frequency padder for maximum output, but will this really be the maximum possible output? It will

*Do not attempt to bend rotor plates unless they are serrated or split.

be only if the preselector is resonating at 600 kc. In other cases there will be one setting of the station dial, above or below the 600 kc. setting, at which the preselector will be resonant to 600 kc. If you can adjust the oscillator low frequency padder for maximum output at this position you will get the maximum possible output from the receiver. In making this exact adjustment after the padder has been adjusted for peak output, shift the receiver dial a small amount and readjust the padder for peak output. Try several positions of the receiver dial above and below the 600 kc. dial indication, choosing the one which produces the greatest output deflection. This can be done so quickly after a little experience that it appears to be a dial-rocking test; actually you do not move the dial while the padder is being adjusted. Some service men prefer to rock the receiver dial back and forth while first turning the padder trimmer clockwise and then counterclockwise, selecting a padder adjustment which gives the maximum output. After this low frequency adjustment, check and adjust the high frequency tie-down point.

Each band of a multi-band receiver is handled in the same manner. In an all-wave receiver the high frequency trimmers are not on the variable condensers, but near the coil circuit that is to be adjusted. Switching makes each trimmer and padder in a band independent of all other bands. When the coils are open at one end it is a good plan to test each adjustment by using a tuning wand. The wand tells which way the trimmer or padder is to be turned, eliminating confusion.

The Multiple Tie-Down Method is quite helpful when a receiver is badly out of adjustment. A signal generator capable of giving three or four strong harmonics is connected to the *ANT.* and *GND.* posts of the receiver. Assuming that you are aligning the broadcast band, adjust the S.G. to a 300 kc. fundamental; this fundamental will also produce harmonic signals at 600, 900, 1,200 and 1,500 kc., which can be picked up by the receiver. Set the receiver dial at 900 kc. and adjust the oscillator low frequency padder and high frequency trimmer of the receiver at any one of their possible combination settings to give highest signal output at this 900 kc. dial setting. Now check at 1,500 kc. (or 1,200 kc.) and also at 600 kc. and note where maximum outputs are obtained when the receiver dial is rotated *near* these marks. The chances are that maximum response will occur at one side or the other of these settings, showing that improper combination settings of the padder and trimmer were made during the first trial adjustment at 900 kc. In this case return the receiver dial to the 900 kc. setting, then increase (or decrease) the padder and also decrease (or increase) the trimmer adjustments for a new trial combination which will again give the highest output at this 900 kc. mark on the dial. This time when you check again at 1,500 kc. (or 1,200 kc.) and

600 kc. you will note that the peak response setting of the dial will be either (1) in closer agreement than during the first test or (2) will create a greater error than before. If the first case (1) is true, then you moved the trimmer and padder adjustments in the right direction during the second trial at the 900 kc. setting. Of course, if you created a greater error, as in the second case (2), you should move the trimmer and padder adjustments in the opposite direction.

For instance, you get maximum output in each case at 900 kc. However, if the responses come in at 620 kc. and 1,190 kc., as shown in Fig. *8A* (instead of 600 and 1,200 respectively during the checking), then this shows that the low frequency padder will have to be decreased and the high frequency trimmer will have to be increased. On the other hand, if the responses come in at 580 kc. and 1,210 kc., as shown in Fig. *8B*, this shows that the low frequency padder will have to be increased and that the trimmer will have to be decreased during the next set of trial adjustments at the 900 kc. mark on the dial. This same method is even more effective on the higher frequency bands. Rotate the padder and trimmer adjustments at 900 kc. until all three frequencies tune in as nearly correct as possible. Now you may proceed to align the whole preselector-mixer-oscillator circuit. This multiple tie-down method is even more effective on shortwave bands than on the broadcast band.

A Complete Tracking Adjustment.—When the rotor plates of the tuning condensers are serrated or split, a very complete tracking alignment procedure is possible for the band most often used; this will give the best possible selectivity and sensitivity to the receiver. The procedure involves making the preselector follow the dial as closely as possible, tying down the oscillator and preselector at the two usual points, and finally making a complete tracking alignment by bending the plates of the variable condensers.

The greatest problem in this procedure lies in making the preselector follow the dial readings. Two methods are in general use; both involve connecting a modulated signal generator to the receiver antenna-ground input and removing temporarily the oscillator tube (or shorting its grid circuit). The receiver dial is set to 1,400 kc., and the signal generator is tuned exactly to 1,400 kc. The preselector trimmers are now adjusted for maximum output, using an indicator connection which will be given shortly. The receiver dial is next turned until the first section of the split plates meshes with the stator, and the S.G. is set to the new frequency indicated by the dial. Determine with a tuning wand whether more or less capacity is needed, then bend the first section of the split rotor plates in or out as required to correct the capacity and give maximum output. Bend both outer rotor plates of each variable condenser if necessary. Repeat this procedure until all sections of the split rotors have been adjusted.

One method of determining maximum preselector output in the above procedure involves placing headphones in the plate circuit of the first detector. This gives you a simple tuned R.F. receiver, and the headphones can be used as an output indicator. The other more preferable method involves introducing a 0-1 or 0-3 ma. D.C. milliammeter into the plate of the first detector and tuning for maximum or minimum deflection, depending upon the type of detector used. A maximum reading will be correct unless grid leak and condenser detection is used.

Assuming that the I.F. amplifier has been peaked, set both receiver dial and S.G. at 1,400 kc. and adjust the oscillator (which is now

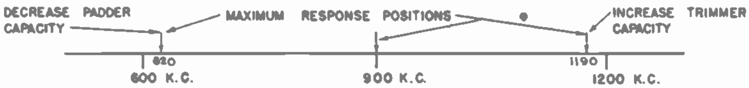


FIG. 8A. If maximum response positions are between correct posisions and 900 kc., decrease capacity of low frequency padder and increase capacity of high frequency padder.

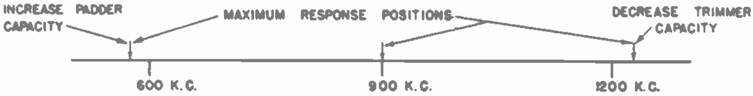


FIG. 8B. If maximum response positions are less than 600 kc., and greater than 1,200 kc., increase the low frequency padder capacity and decrease the high frequency trimmer capacity.

placed into operation) by means of its high frequency trimmer, using an indicating meter in the cathode circuit of an AVC-controlled tube as your guide. Make a second tie-down adjustment at 600 kc., adjusting the oscillator low frequency padder. At this frequency the rocking adjustment is omitted, as we know that the preselector is tuned exactly to 600 kc.

Finally, set the station selector so the first section of the variable condenser plates meshes with the stator, set the S.G. exactly to the receiver dial frequency reading, and bend the oscillator rotor plates for maximum output. Repeat for each other section of the plates in rotation. You can check the alignment of the preselector with the tuning wand and make further bending adjustments if they are necessary.

The same procedure applies to any band in a multi-band receiver, but remember it can only be applied to one band in any one receiver. It is customary to choose the broadcast band if the customer does not indicate which band he prefers "pepped up," making all other band tracking adjustments by means of the two tie-down adjustments.

ADJUSTING DOUBLE SPOT TUNING SUPPRESSION CIRCUITS

The adjustment of the double spot tuning trap shown in Fig. *8A* is quite simple. The signal generator is connected to the receiver input and set to a high test frequency, about 1,400 kc., and the preselector of the receiver is adjusted for maximum output at this dial frequency indication. Now the station dial is set to the second tuning spot, a frequency equal to the station frequency minus twice the I.F. value. For example, in the case of a 130 kc. I.F., this would be 1,400 minus 130 minus 130, or 1,140 kc. Now increase the output of the S.G. and adjust the double spot trap trimmer C_T to give *minimum* receiver output. Return the receiver to the 1,400 kc. setting and adjust the preselector high frequency trimmer C_{HT} in the trap circuit for *maximum* output. Repeat these adjustments until further minimum and maximum changes cannot be obtained.

ALIGNING SUPERS HAVING REGENERATIVE SECOND DETECTORS

In some inexpensive superheterodynes the second detector is regenerative. The amplification and selectivity so gained makes it possible to omit the I.F. amplifier tube and still obtain fair results. In such a set the output of the first detector is fed through the I.F. transformer into the second detector input. The second detector circuit is shown in Fig. *9*, the remainder of the receiver being conventional in design. When aligning a set of this type the

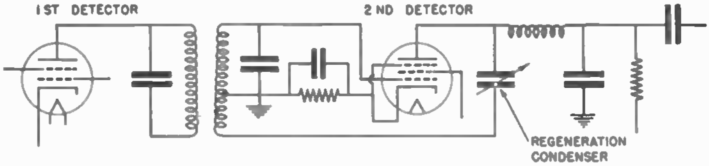


FIG. 9. Typical regenerative second detector circuit used on some inexpensive superheterodyne sets.

regeneration condenser is adjusted for minimum capacity (least regeneration) and the I.F. trimmers for maximum signal output. The regenerative condenser is then adjusted until a squeal or howl is heard, after which the control is backed off just enough to stop the howl without reducing the output too much. Adjust the I.F. trimmers and regeneration condenser again. Regeneration condensers are generally controlled by a fibre nut which may or may not be colored red.

Whenever the second detector tube is changed, readjustment of the regeneration control is necessary. Do not go through the entire alignment procedure; just throw the set into regeneration, back off the control until regeneration ceases and give the control an extra ¼ turn in the minimum capacity direction.

TEST QUESTIONS

Be sure to number your Answer Sheet with the *number* appearing on the front cover underneath the title of this text.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your Course, and you will receive the best possible lesson service.

1. In what section of an all-wave receiver would you expect to find the defect, when all bands except one give satisfactory reception?
2. If a super loses *both* "pep" and adjacent-station separating ability over the entire tuning range when receiving semi-local stations, where in general would you expect to find the defect in the circuit?
3. In an all-wave receiver what stage is the central checking point for defective stage isolation when one or more bands are dead?
4. If a super using a tetrode tube as a combination detector-oscillator responds weakly or is dead at the low frequency end of the broadcast band, what would you check before condemning preselector-oscillator tracking?
5. In using a tuning wand to check the adjustment of a trimmer, what trimmer adjustment is indicated if inserting the brass end of the wand increases receiver output?
6. How could you quickly reduce image or double spot tuning interference if only one local station was causing the trouble?
7. What procedure would you use to eliminate I.F. harmonic feedback when you could not readily locate the circuit defect which was to blame?
8. What trouble causes most of the distortion or poor quality in a super, especially when feed-back is just starting?
9. Which preselector-mixer-oscillator circuit tracking adjustment is the most critical?
10. State the least number of tie-down points per band which are necessary to make the oscillator track with the pre-selector in a super which has a low frequency padder in the oscillator circuit.

1. The defect would be in the preselector-mixer-oscillator coil section or in the switches belonging to the band which is "dead."

2. In the I.F. alignment or in the I.F. signal circuits.

3. The first detector.

4. The C bias to the oscillator section of the tube.

5. This test indicates that less trimmer capacity is needed; the trimmer must therefore be turned counter-clockwise (in most cases).

6. Use a wave trap.

7. Shift the I.F. frequency about 5 kc.

8. A sharply peaked I.F. amplifier.

9. The oscillator adjustment.

10. Two tie-down points.

HOW TO INSTALL AND SERVICE AUTO RADIOS

41RH-1

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

INTRODUCING AUTO RADIOS

The radio training which you are receiving not only prepares you for a career as an expert in your chosen field of Radio, but also gives you that important knowledge of fundamentals which is necessary to master the many specialized branches of Radio. Auto radio, aircraft radio, police radio marine radio, and even television have much in common with the familiar entertainment receiver. In the lesson texts and reference books dealing with these specialties, then, you will study only those few special features which are characteristic of each particular branch.

Auto radio, one of the most important and fastest growing of these sidelines of Radio, is taken up in this text. Police patrol car radio is merely an extension of the familiar auto radio. You will be pleasantly surprised to find that you need extend your present knowledge only a little to master this subject. Think of an auto radio as simply an ordinary home receiver having a special type of power supply and a few differences in mechanical details of construction.

Your success in any new field depends upon your mastery of fundamentals. J. E. SMITH.

NATIONAL RADIO INSTITUTE

WASHINGTON, D. C.

1942 Edition

A LESSON TEXT OF THE N. R. I. COURSE
WHICH TRAINS YOU TO BECOME A
RADIOTRICIAN & TELETRICIAN
(REGISTERED U. S. PATENT OFFICE) (REGISTERED U. S. PATENT OFFICE)

NCP18C1241 Printed in U. S. A.

How to Install and Service Auto Radios

To be sure, an automobile radio is different from an ordinary home receiver, but the differences are not as great as most servicemen think. The physical and electrical differences are necessary because of the special conditions that present themselves in an automobile. Furthermore, these conditions impose special installation problems. Before we consider the problems of installing and servicing peculiar to a mobile (car) radio, let us analyze the general design features of auto radios. By revealing that the differences are relatively unimportant, you will acquire greater confidence in doing automobile radio service work. You should, as experts are required.

HOW AN AUTO AND HOME RADIO DIFFER

An automobile is a "hotbed" of man-made static. Then too, a modern car has a total steel body and if you have ever tried to operate a home radio in a steel building using a wire around a window as the pickup you will quickly realize how little signal energy is available. Furthermore there are only two possible sources of power, the engine and the car battery. The car engine is not an ideal source as it can only be used when the car is active. As people may even want to operate their auto radio when parked, the car battery is universally used. On the other hand, the battery is charged by the generator coupled to the engine, so the engine is actually the ultimate source of power.

Now let us take up some of the details that go to make a reliable automobile radio. It is easy to understand why a car must be tightened and the parts inspected regularly. Constant road shock and engine vibration loosen the parts of the car. Aside from the fact that this condition detracts from comfortable driving, it cannot be allowed to exist if good radio reception is desired. A car must always be tightly assembled. If ordinary usage will loosen up a car, what would it do to an ordinary radio chassis? It is needless to say that it would not stand up. Consequently an auto radio must employ a welded, riveted and locked bolt construction. The parts should be small to prevent undue vibration.

Space in a car is limited, so the receiver must be compact. Unfortunately some designers have overdone this idea of compactness. Auto radios should be designed as compactly as possible without destroying accessibility to the parts when repairs are required.

The ignition and electrical systems of automobiles are perfect generators and radiators of damped radio waves; and the noise picked up by an ordinary receiver when placed in a car would be unbearable—reception would be ruined. For this reason, an auto radio is not only compact and sturdily built but extremely well shielded. In fact, the chassis and speaker are placed in heavy metal boxes.

A pickup system is, of course, required. The ideal automobile antenna is a wire mesh placed in the roof of the car, naturally insulated from the body which in turn is used as the counterpoise or ground. There are other alternative antennas, less effective but often employed. The antenna may be a plate placed under and insulated from the running board. Usually two are used, one under each running board, both plates connected together. Another scheme is to use a V arranged antenna wire under the car, the point of the V anchored to the transmission housing. Even in the latter two cases, the body or car chassis is used as the ground. A large proportion of the new cars are delivered with a roof antenna already built into the automobile; most old cars require an antenna installation.

An automobile antenna system at best can only be a poor collector of radio signals. This weak pickup can only be compensated for by a sensitive radio receiver; in fact, a sensitivity of 1 microvolt for 50 milliwatts output is not unusual. Furthermore, this sensitivity must be automatically controlled. A car is a movable object being first in an area of high signal level and an instant later in a poor signal zone. Cars ride over buried pipes, trolley car tracks, under and over bridges and in cities first among high and later small steel buildings. On an open road the pickup is the best, yet the car may be moving to or away from the station tuned in. A sensitive automatic volume control is an indispensable feature of a good auto receiver.

The designer has been forced to resort to the use of multi-function tubes and the superheterodyne circuit in order to obtain sensitivity combined with compactness. Thus you will find the pentagrid converter; the duo diode triode or pentode; the double tube of which one part is used as a detector, the other part as an I.F. or A.F. amplifier; and, the twin output tube extensively employed. Reflex circuits are not uncommon, and the only reason for their use is to cut down the space required for an extra tube. Multiple functions of tubes, of course, reduce the amount of power supply required.

Now let us consider the important problem of power supply. It has been already stated that the 6 volt car storage battery is the ideal source. To feed the tube filaments directly from the battery required the design of a new series of tubes whose filaments would operate at 6 volts. The 6.3 volt series of tubes were originally developed for automobile service. Because the battery when charged may be well over 6 volts, the value of 6.3 was chosen so under normal conditions the tube filaments would not be overloaded. These tubes work well if the voltage of the battery varies from 5.9 to 6.5 volts. They are ruggedly designed to take road shock and car vibration.

Early in the art, the B and C voltages were supplied by B and C batteries. It was quickly recognized that constant replacement was a nuisance as well as far from being an economical procedure. Too many replacements discouraged the purchase of automobile radios. Still using the car battery as the primary source of power, three of the methods originally developed to change 6 volts D.C. to higher B and C voltages became standard practice. These methods are:

1. A midget D.C. motor-generator weighing not more than 10 pounds was designed to be placed under the seat or floor boards near the driver to convert 6 volts D.C. to 180 volts or more D.C. Lower D.C. voltages are obtained with the familiar resistance voltage divider. A simple brute filter is connected to the generator output to smooth out or remove commutator ripples or current fluctuations.

2. A step-up transformer is connected to the car battery, the primary current interrupted by a vibrating reed having contacts to open and make the circuit. The reed may be magnetically actuated by the core of the step-up transformer, or as is more usual, by a small electromagnet built in with the reed. The latter is nothing more than a high grade buzzer. The A.C. voltage of the secondary is then rectified by a diode rectifier tube, the pulsating current filtered by a coil-condenser arrangement. Again, various D.C. voltages are obtained by means of a voltage divider. Usually, the entire high voltage supply system is built right onto the chassis of the receiver.

3. A scheme similar to method *2* is used except the tube rectifier is replaced by a mechanical rectifier. This is nothing more than a relay to close the secondary circuit when the primary is closed. In the case of a full wave mechanical rectifier both the primary and secondary are center tapped, the respective primaries and secondaries closed simultaneously by contacts on the same reed vibrator. The secondary voltage is fed in the same direction or with the same polarity to the brute filter.

Designers thoroughly recognize the need of conserving the charge in the storage battery. Multifunction tubes and reflex circuits keep the filament and plate current load down to a minimum. Another very important way of conserving power is to use a class B push-push output stage. Thus the largest load in the receiver, the power furnished the output stage, is low until large output levels are desired. To keep the car battery at full charge, it is usual to advance the charging rate of the car battery generator.

Now that you are familiar with the general features of an automobile receiver, we may proceed to the problems encountered in servicing. The two main phases of this work are installation and servicing, and the former will be considered first.

INSTALLATION OF AUTO RADIOS

The problem of installing a car radio, assuming, of course, that a proper receiver selection has been made, includes three important steps. First, if the car is not already equipped with an antenna, one must be installed. You can quickly tell whether the car has an antenna. Examine the wires in back of the instrument or dashboard and look for an antenna lead wire that is probably coiled up to be out of the way. This wire should lead down from the roof and will usually be found at the right or left windshield post, most likely at the battery side. Either an ordinary or shielded lead wire will be found. To be sure that it is in order, connect an ohmmeter between the lead and the car chassis. No reading should be obtained.

The second phase of the installation problem is really considered before the antenna is installed but actually performed second in order. We are now referring to locating the best position for the radio, the proper attaching and the connections. A good deal will depend on the kind of an auto radio that is being installed.

The final and at times the most vexing step is the elimination of interference. Because there is no one cure for noise, the customary procedure is to follow a generally accepted scheme or plan of noise suppression, employing the standard or approved methods. This is then followed by special or even trick methods of noise elimination. All this will be considered shortly, as we plan to take up these three phases of installation in the above order.

ANTENNA INSTALLATION. As was previously explained, car aerials may be divided into two main classes: 1, roof antennas; and 2, sub-chassis antennas. It should be stressed that the roof antenna is considered the most satisfactory type and is quite easy to erect if you possess a fair degree of mechanical skill. As one serviceman puts it, the only hazard is the mental one. If you feel that you lack confidence or skill, have an auto top repair man do the top work while you do the electrical part of the installation. However let us consider the complete job, and the procedure you take will depend on the top construction. There are, in general, five types of automobile tops to consider, namely: *1*, slat; *2*, poultry wire; *3*, fabric; *4*, metal brace; and *5*, folding tops. We will consider the antenna installation for each of these tops and in the order mentioned.

ROOF ANTENNAS, Slat Top. The most frequently encountered top construction consists of conventional wood bows running across the top; and slats or laths nailed to the top of the bows, spaced a small distance apart, run lengthwise. The slats are covered with padding before the weatherproof top is fastened on. Inside the car, a head lining (the fabric over your head) is fastened to the bows by listings. The latter is usually nothing more than a one or two inch wide cloth tape, one edge of which is sewed across the inner side of the head lining while the free edge is tacked to the side of the bows. The edges of the head lining are covered by trim or moulding of various sorts in order to conceal the raw edges.

To install the antenna, first remove the moulding over the windshield. This is generally held in place by three or four machine or wood screws. Remove the trim, starting at the windshield and working back over the door to the rear of the car. The head lining may now be removed by pulling out the tacks which hold it to the front and sides of the car and to the roof bows. The head lining is lowered by removing the tacks driven through the listings. Of course, you need only lower the head lining back to where the rear metal body, called the apron, starts.

For the antenna material, use a copper screen approximately 36 inches wide and with an 8 to 16 mesh. In tacking this screen to the top bows bear in mind that the head lining listing strip is tacked to the side of every second or third bow, see Fig. *1*. Therefore, it will be necessary to tack the screen to the side of these bows instead of to the bottom. Start at the back of the car and tack the screen to the bow at the rear, about 3 inches from the metal apron in the back of the car. Should the car be equipped with a dome light, it will be necessary to cut a hole in the screen around the dome light. The screen should be at least 3 inches from the dome fixture and wires. The edges of the hole should be soldered or the ends of the wires curled up, to prevent loose wire strands from projecting through the head lining. If the leads to the dome light run toward the windshield through the center of the top, they should be re-routed in such a way that there will be a minimum of coupling between these leads and the antenna screen. When the entire screen is securely tacked to the bows it should be tested with an ohmmeter to make sure it is not grounded. Also examine it to be sure it does not extend closer than 3 inches to the metallic body around the top of the chassis.

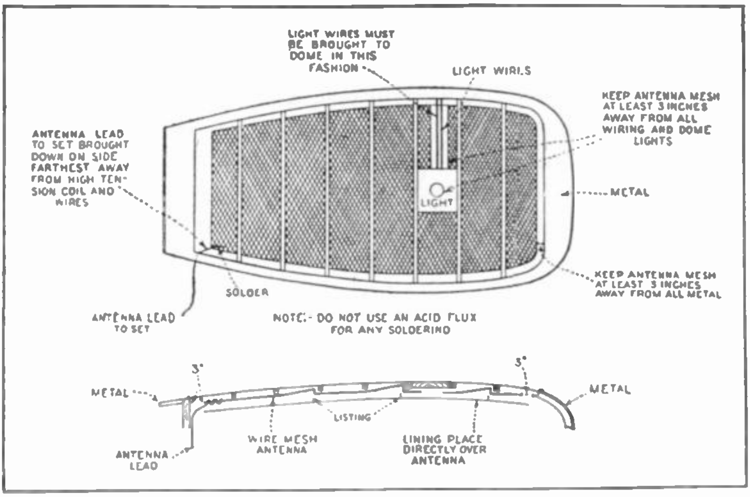
A shielded lead-in should be soldered to the front edge of the antenna nearest the side on which the set is to be mounted. Remove the shielding from the wire for a distance of about 3 inches and securely tape it for prevention of any possibility of a future ground. The lead-in wire should be concealed behind a section of the windshield or front door trim to make it invisible. It is worth while to note that the shielded lead-in aids in eliminating the motor noise pickup, but that at the same time it decreases the signal voltage applied to the set due to the capacity it introduces between the antenna and ground. If the shielding is too near the central or lead wire, an excessive loss of energy will occur. Therefore, a shielded wire as short as can be used with as thick an insulation between the conductor and the shield as can be secured, is the best compromise. The shield on the lead-in must be grounded (bonded) to the body of the car near the antenna and also near the instrument board. Do not ground the shielding to any part of the car which is not bonded (connected to a part of the body), otherwise motor noises may be introduced into the lead-in. If the instrument board is not grounded you should bond it to the car chassis.

Poultry Wire Tops. There is a type of top construction which has a heavy, galvanized wire mesh welded to the body around the top, the top covered with padding and the weatherproof material. The underside is lined with fabric. We have called it the poultry wire top construction. There is some question whether the mesh should be opened at the edges or a subchassis antenna used. Then too, there is the construction where the poultry wire is also supported by wood cross bows. In the latter case it is perfectly possible to free the mesh, electrically. Perhaps the mesh is already free. This may be tested with an ohmmeter, connecting one of its probes to the chassis; the other probe, a long needle point, is pushed through the head lining and to the mesh.

If the poultry wire is grounded, it will be necessary to free it from ground. This is done by removing the head lining as we have already described and cutting a three-inch strip from the poultry netting away from the four sides of the top. The part to be used for an antenna should then be checked again to be sure it is free from ground. Where a support for the freed mesh is required it should be laced to the portions remaining in touch with the car with a strong waxed cord and in several places on each side. The shielded lead-in may be connected in the usual manner.

If, when you first make your ohmmeter test you find that the poultry wire is not grounded, it is only necessary to attach the lead-in wire to use it for an antenna. Then, you will only have to let down a small edge of the head lining to get at the wire.

Fabric Strip Tops. Some automobiles have a top construction very similar to the slat construction top except that muslin



COURTESY RADIO NEWS

Fig. 1

strips instead of wooden slats are employed to keep the top padding material in place. In some cases the wire screen for the antenna may be slid between the roof bows and the muslin strips and tacked in place at the sides of the first and last roof bows. If, however, the muslin strips are tacked at the top of each bow, the screen antenna should be tacked to the bottom and sides of the bows just as explained under slat top construction. The lead-in should be attached to the antenna in the usual manner.

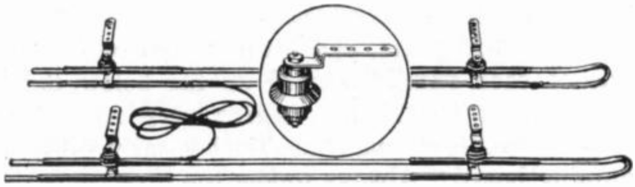
Metal Brace Tops. Some automobiles have two diagonal metal braces running from corner to corner and crossing in the middle. These braces are usually grounded to the metal frame at the front of the car and are supported at the wooden frame in the rear of the car. Before the antenna is installed, these braces must be electrically freed or the installed antenna will be very inefficient. This can be done by disconnecting the braces from the front of the car and drilling the holes larger to permit an insulated sleeving to be slipped over the mounting bolts. Use large fibre washers under the bolt head and nut and between the brace and the body. The antenna screen may then be slipped between the metal braces and the roof bows. The screen must be soldered to the metal braces in several places. If you do not do this, contact will be made and broken while the car is being driven over rough roads, causing noise in the radio reception.

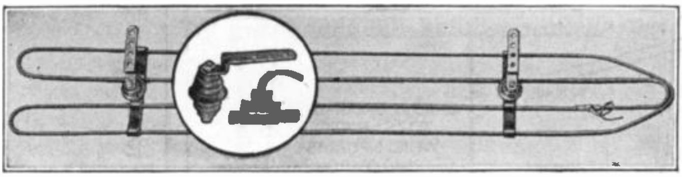
In a few cars, a metal brace will be found in the center of the roof, replacing one of the roof bows. The antenna screen must in this case be cut in half and two independent pieces installed, one in the front of the car and one in the back. These two separate antennas should not come closer than three inches to the metal brace or to any other metal part of the roof. The two screens are electrically connected together in two or three places with well insulated jumpers (wires) and the shielded lead-in connected in the usual way.

Folding or Convertible Tops. A last and final type of top construction which you are apt to encounter is the folding top. It will be found in roadsters, touring cars, convertible coupes, and convertible sedans. The wire screen cannot be employed because it does not have sufficient flexibility to permit the top to be easily folded back. A top of this type requires a regular wire antenna. Although the antenna surface in this case is not as large as in the case of a sedan (closed car) it is equal to or better than a good roof antenna because there is not the shielding effect of the metal body and roof apron to contend with.

To install the antenna in the roof, remove the tacks that hold the top material to the front bow over the windshield and lay the top back. This will expose the cloth pad on each side of the top bows. It is to these pads that the wire antenna is to be fastened. Use about 75 feet of number 18 rubber covered stranded wire and starting near the windshield, run the wire the entire length of the cloth pad, holding it in place with thread in an individual knot, about every six inches. The wire should be run back and forth on the pad until six or eight rows of wire about an inch apart are fastened to one pad. The wire is then tacked across one of the roof bows and operation repeated on the opposite pad. The lead-in which is not totally shielded in this case is connected at the rear of the top, brought down in the rear behind the back seat and through the floor, in such a manner as not to interfere with the operation of folding the top back. The lead-in wire must have heavy, weatherproofed insulation to prevent it from grounding to the chassis under the car at some future date. Thick insulation keeps the lead-in wire itself away from the chassis, thus reducing the capacity to ground. The shielding on the lead-in should start about 1 foot from the storage battery and should be grounded in two or three places to minimize motor noise pickup.

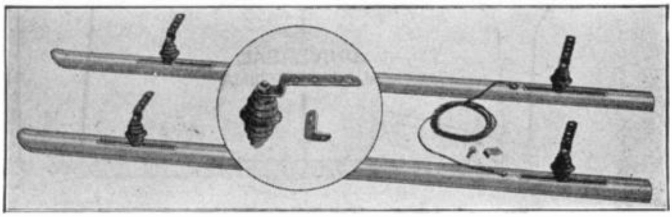
A





B

C



D

COURTESY WARD PRODUCTS CORP.

FIG. 2. Typical running board antennas for auto radios. A—Ward "Twin Marvelwave" aerials, one for the underside of each running board, consist of cadmium-plated tubes connected together by an insulated wire. B—Ward "Streamline" aerial, a single unit. C—Ward "Magic-Ski" antenna, which may be used singly or one under each running board; brackets are adjustable. D—Ward "Magic-Super" aerial with pick-up flap which, according to manufacturer, improves pick-up of ground wave.

The wire type roof antenna is recommended for cars having a folding top, when the top is to be used up most of the time. It does not give sufficient pickup in most cases when the top is down, because then the antenna is too close to the metal body of the car. If the top is to be folded back about half of the time, a sub-chassis antenna should also be installed with a single-pole-double-throw switch to change from one type of antenna to the other. If the top is to be down most of the time, a sub-chassis antenna alone should be installed.

SUB-CHASSIS ANTENNAS, Running Board Antenna. A running board antenna is a very popular type of sub-chassis antenna. Several are shown in Fig. *2*. These antennas are only about 50 per cent as effective as a roof antenna. They are generally used in pairs, one being bolted or clamped to the under side of each running board as far below it as possible. The shielding of the lead-in begins very near the plate, covered screen or rod antenna, the shield usually being connected to the running board. Always follow the directions the manufacturer

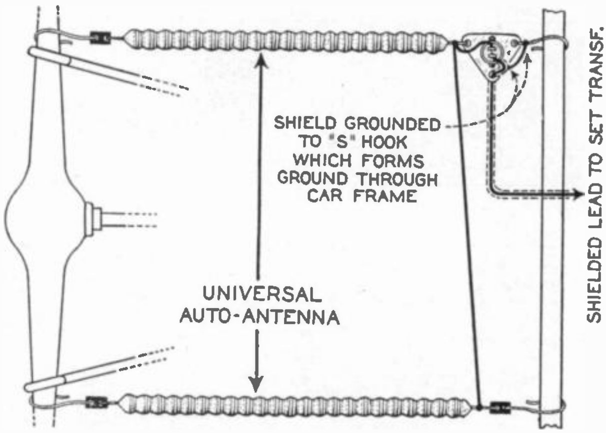


FIG. 3. Lynch coil-spring type under-car auto radio antenna.

supplies with running board antennas. They should be protected against slush and mud by a slush guard on the front fender, and should be connected together with a heavily insulated weather-proof wire at the rear, for best results.

The Wire Sub-Chassis Antenna. Many auto radio technicians prefer to mount the antenna under the car chassis. One insulator is fastened to the fly-wheel housing, one is attached near each wheel of the rear axle housing, and a wire is strung through the insulators to form either a "V" or a triangle antenna. The shielded lead-in wire is connected to the antenna at the forward end.

An improved type of sub-chassis antenna, shown in Fig. *3*, consists of coil springs placed in water-proof cases, each end of a coil being attached to but insulated from a mounting hook. Two coils are generally used on a car, being strung between the rear axle housing and some convenient point under the front of the car, such as the transmission housing or cross I beam. The forward ends of the coils are connected together by a heavy insulated wire, the shielded lead-in being attached to one end of this wire. An antenna transformer is used by some at this point, for it gives a slight gain in signal strength. A "V" antenna is obtained when the front ends of the coils are mounted together; the lead-in is then attached to the apex of the "V."

Exposed Antennas. Any one who is familiar with the performance of auto radios knows that a wire a few feet long, ex-

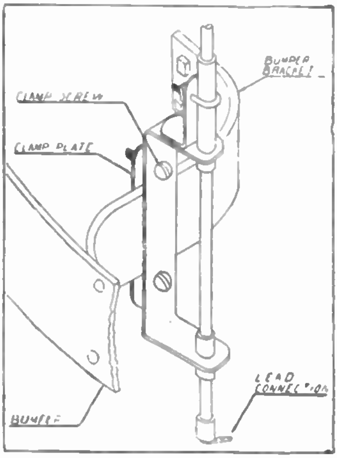
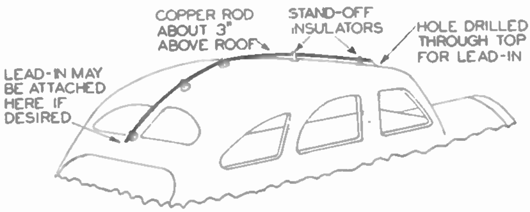


FIG. 4 (left). Bracket which clamps to bumper of car and supports vertical rod type of car radio antenna.

FIG. 5 (below). Tubular antenna which mounts above metal roof of car, being held in position by rubber suction cups which are cemented to the car roof.



tending out from the car, gives far better pick-up than a standard car antenna. The exposed antenna is practically the only one which can be used for transmission and reception of short-wave broadcasts.

Although a quarter-wavelength long metal rod is best for ultra short-wave police work and other mobile installations, an antenna of any reasonable vertical height is satisfactory for reception in the broadcast band. Figure 4 shows how one commercial type of auto pole antenna is attached; the pole is made in sections, and can be adjusted to the desired height.

Another type of exposed antenna, shown in Fig. 5, is coming into favor among owners of modern streamline cars, for it tends to conform to the lines of the car. Stand-off insulators are mounted on rubber suction cups which are cemented to the top of the car; these insulators support the flexible chromium-plated metal tube which serves as the antenna. The lead-in wire is attached to one end of the tube.

Cars with Steel Tops. Although the built-in roof antenna is the best of the concealed auto antennas, it obviously cannot be used on cars which have solid steel tops. With these, the spare wheel bracket at the rear or the rear bumper often is or can be insulated from the car by enlarging the mounting hole and setting in insulating bushings and washers; the entire bracket and metal tire cover or the entire bumper then serves as the antenna, the shielded lead-in wire being connected to these at some convenient point. In other cases, the serviceman must either use a subchassis type antenna or an exposed antenna.

MOUNTING THE RECEIVER. *The Best Position.* The actual mounting of the receiver is not a difficult job, but does require a little thought. To begin with the receiver must be located so it will be: *1*, easy to tune; *2*, accessible when repairs are necessary; *3*, out of the way of the occupants of the car; *4*, away from noise sources; and *5*, placed where it is not exposed to the heat of the engine, not exposed to the weather and not subject to wide changes in humidity and temperature. The best general position has been found to be one on the passenger side of the engine partition or bulkhead and behind the instrument panel. This location is now standard.

Of course, the exact position at the passenger side of the bulkhead will vary with the physical design of the receiver and the space arrangement under the instrument panel.

1. To begin with you will encounter the compact radio unit now quite extensively in use. The entire chassis with its power unit is built into a metal case, usually finished in crystalline black. Tuning and volume controls, the *off-on* switch (key type) are usually placed at the end of the box and the receiver clamped to the dashboard with brackets so the controls are in the same plane as the instrument board. This receiver should be placed near the battery side of the car; the lead-in brought down, and the battery leads extended up at the same corner. Some servicemen are willing to sacrifice short leads for a position usually to the right of the steering wheel so easier tuning is possible.

2. A more widely sold type of automobile receiver is the compact unit having a remote control unit mounted usually on the steering wheel post or on the instrument board. The tendency in design is to the latter mounting, especially in receivers made for definite cars. A remote control unit is popular because the receiver may be placed in an out of the way position yet the controls are within easy arm reach. Fig. *6* shows this type of receiver and the possible receiver positions. Positions *1* and *2* are both good. Position *3* is not to be used unless the customer insists that the box be out of the way or space does not permit either of the other two locations. When the receiver is bolted to the bulkhead, as in position *2*, it will be wise, if space permits, to locate the receiver near the battery and place the antenna lead-in at that corner. Many auto radio receivers now have control units which are matched with and fit into the dash.

3. Receivers have been and probably will be made with *a*, separate control, receiver chassis and extension speaker units; *b*,

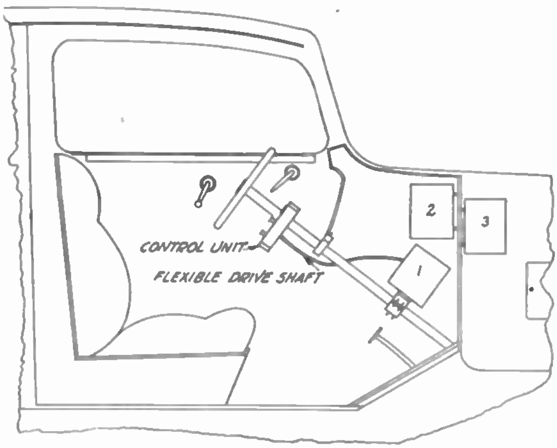


FIG 6 COURTESY WELLS-GARDNER

with a separate control, receiver, speaker and B supply units. Always locate the control unit on or near the steering wheel; the chassis near the center of the car under the dash, bolted to the bulkhead; and the B eliminator near the car battery, preferably under the seat. The speaker may be located in any convenient place although when it is placed behind the dash it should not be blocked by the instrument board. A typical case is shown in Fig. *7*. Note the extensive use of shielded lead wires and cables.

Now we may consider the problem of mounting an automobile receiver. When it is necessary to drill holes in the bulkhead use the drilling template furnished with the set by the manufacturer or if a template is not available make one out of heavy cardboard. The template is made by placing it against the mounting surface of the receiver or brackets and marking the holes on the cardboard. They are then cut or punched out, and after checking with the chassis serve as an accurate drilling guide.

The drill should either be of the heavy hand variety or electric—the latter is preferable when much installation work is to be done. The drill bit assortment should run from ¼" to ½" in diameter.

Never allow kinks or sharp bends to occur in the mechanical cable. Most controls are equipped with set screws, in addition to mounting clamps, and after the clamps have been tightened in place, screw down the set screws so they make a firm contact in the metal of the steering column. The cable is to be securely fastened in such a way as not to interfere with any of the mechanical controls of the car.

The Electrical Connections. The connection to the battery is usually a very simple job as the majority of modern receivers are completely self-contained, the speaker and B unit being built into the cabinet along with the chassis. Most sets have two leads, in addition to the remote control cables. These are the antenna lead and the "hot A" lead to the ungrounded side of the car battery. It is the general practice to connect the "hot A" lead at the car ammeter, so the ammeter will register the drain of the set. The connection to the grounded side of the battery is made through the grounded chassis of the set. Naturally this means that the chassis should be bolted to holes which have had the paint scraped off around the hole. Some manufacturers furnish two A leads and these should be connected directly to the car battery. The leads are marked to simplify connections.

On some receivers the polarity of the car storage battery is important. Most sets are designed for operation in a car in which the negative side of the storage battery is grounded. When confronted with an installation where the positive lead of the storage battery is grounded, reversal of the B eliminator connections is usually necessary. Note that we say usually because in some sets polarity is unimportant. Always follow the set manufacturer's instructions in regard to battery polarity.

Where separate speaker or B supply units are encountered you will probably find prepared shielded extension cables. Then too, you should by now be sufficiently familiar with radio to connect a speaker or power supply. The connections are no different than on home receivers except the shielding feature. Now that the supply connections have been made, connect the aerial lead-in, the lead wire to ANT post, the shield to the case.

One point in auto radio installations which may cause you some thought is the additional drain put on the car battery by the radio apparatus. This can be compensated for by advancing the charging rate of the car generator. Auto charging generators usually have three brushes under a removable metal plate on the generator. To advance the charging rate move the third brush (the smallest and movable one) in the direction of the armature rotation. To adjust, turn on head lights, the radio and advance the charging rate about 3 to 5 amperes. Now turn the radio and lights off, and be sure that the charging rate is not over 20 amperes. If the second test shows a lower charging rate, the brush on the generator may be advanced further. The motor should at all times be running at a normal rate.

When a set is installed in the car and connected to the aerial,

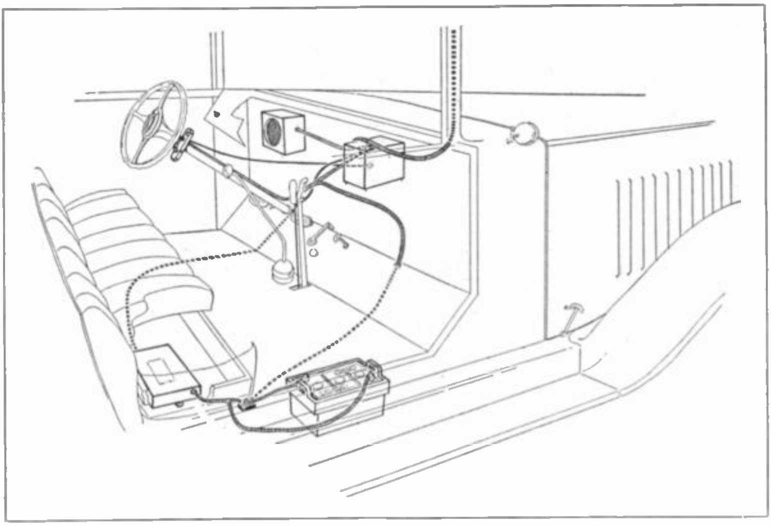


FIG. 7 COURTESY WELLS-GARDNER

is the job done? No indeed, it's only half finished. There still remains the important task of removing the noise interference.

INTERFERENCE ELIMINATION. Before we consider the methods employed to eliminate interference set up in an automobile, let us first get in our minds a clear picture of just what it is that creates the trouble. The trouble centers around the sparking that takes place at the distributor, spark plugs and the generator. Or in fact in any spark that may occur because of a poor connection or due to the accumulation and discharge of static electricity. For example a tire, especially in a dry atmosphere, may develop a charge which will spark over to the rim.

Of course, you know that a spark is the result of a difference in voltage between two points, great enough to ionize the intervening space, causing a discharge. Associated with the spark gap, are wiring or leads which act much like a doublet or Hertz antenna, that is, as resonant circuits. They are also radio frequency signal transmission wires. Thus there are created sharp changes in current which travel down the wires. At the same time damped high frequency currents are created which are fed to the entire chassis structure and automobile wires. These damped high frequency currents radiate radio waves that create interference if they get into radio receiver circuits. The main problem of noise interference resolves itself down to methods of preventing the created spark from sending strong electric impulses through the associated circuits and the body of the car.

To be sure, the entire electrical system including distributors, generators, spark plugs, spark coil, and cables, could be

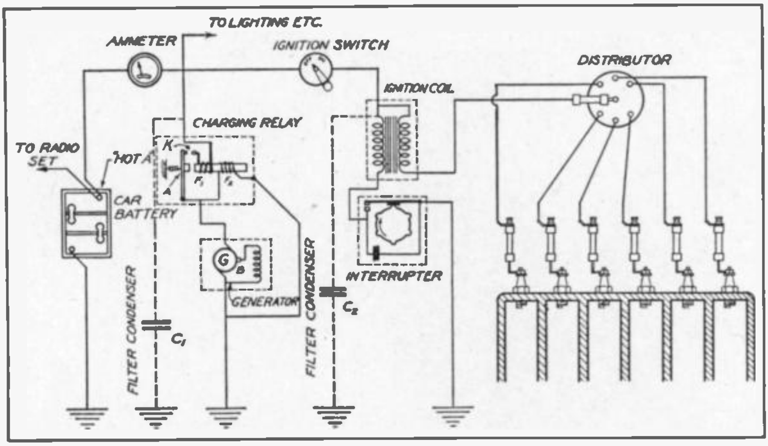


FIG. 8

placed in shielded compartments or flexible cable shields as is universally now the practice in aircraft radio installations. It is not done in cars because the cost is prohibitive. Hence it is your duty to locate the origin of the spark and actually destroy the surge of current before it can get into the rest of the system. Several schemes are used to suppress interference currents due to sparking. Choke it out with a series r.f. choke coil, suppress it by a series resistor, or bypass it to the chassis with a condenser. If the spark is not essential in the operation of the car, then stop the spark or greatly reduce its strength. The only condition where a condenser may be used to bypass a surge is where destroying the spark does not affect the operation of the car engine, as for example at extensions to the dome light or at the brushes of the charging generator.

To apply the usual methods of interference elimination it is essential that you know something about the electrical system. You must know the location of the distributor, spark plugs, spark or ignition coil and the generator. Figure *8* shows the ignition or spark creating system so essential for engine operation. Observe that the spark plugs are at the top of the exploding chamber of each cylinder which is fed gasoline in a gaseous state. The creation of the spark explodes the gasoline and creates the downward thrust on the piston that motivates the car.

Analyzing briefly the circuit shown in Fig. *8*, we start with the car battery, one terminal of which is connected to the chassis. The other terminal called the "hot A" feeds through the ammeter, to the ignition switch, through the primary of a step-up transformer, through a circuit chopper or interrupter and finally

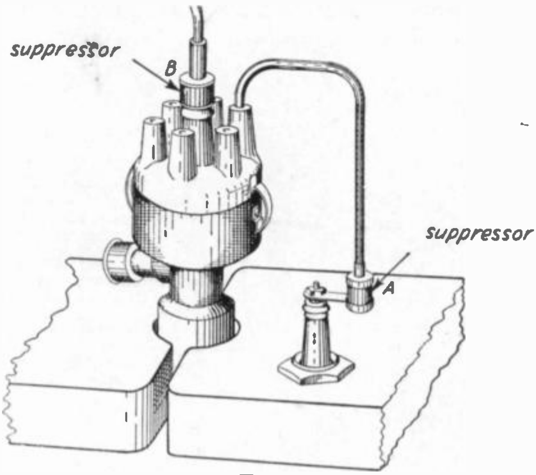


FIG. 9

to the chassis. The interrupter is rotated by the engine and there are as many breaks per rotation as there are cylinders. Thus for every stroke of a piston a high voltage is induced in the secondary which is fed to the correct spark plug by the distributor (an automatic distributing switch) and through the engine block to the chassis. The high voltage creates the spark which explodes the gas. Of course, the distributor and interrupter are mounted in a single unit as they work together in a definite manner. A typical assembly is shown in Fig. *9*.

Now for a little more detail of the ignition circuit shown in Fig. *8*. Observe that the generator *G* has a mid-brush B, which controls the charging voltage by controlling the generator field voltage. The generator is connected across the battery through a charging relay (cutout) which works as follows: With the ignition switch *off*, the armature *A* is held away from the core by the spring. Thus contact K is open and the battery cannot discharge through the generator. The motor is started by closing the ignition switch and operating the starter. As the voltage of the generator builds up, current through a high resistance winding F_2 increases and pulls armature A to the core, closing contact K. Now the generator charges the battery, causing current to flow through a heavy wire coil F_1. Coil F_1 produces magnetism in the core to aid F_2 in holding the armature and keeping contact K closed. Now, if the generated voltage drops below the battery voltage (as when the car engine slows down), the current flow through F_1 will reverse (as the battery feeds current into the generator), the two relay coils will oppose each other, and the armature will be released, opening contact K.

Sparks, of course, are produced at the generator brushes and contact K. We may neglect the interference created at K as

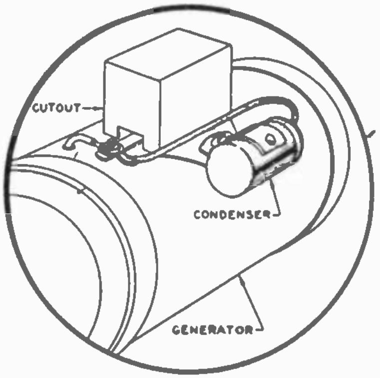


FIG. 10. The generator filter condenser is here connected directly across the generator. The connection shown in Fig. *8* for this condenser (C_1) is sometimes preferred, and is secured simply by connecting the single condenser lead to the other terminal of the cutout. The other condenser terminal is its metal housing, and this is automatically connected to the generator frame by the condenser mounting bracket.

it is only at rare intervals and should not be annoying. Sparking at the generator brushes is continuous and objectionable and the current rushes should be eliminated by a bypass condenser as shown by C_1. Where should this condenser be placed?

Usually the cutout or charging relay is mounted on the generator as shown in Fig. *10*. A lead wire is found coming through the generator housing to one terminal of the cutout. Connect a .5 mfd. paper condenser between this common lead and the generator frame. Condensers in special cases are available for this purpose, made to facilitate mounting and connections.

A spark is created at the primary chopper or interrupter. To be sure there is a built-in condenser, its purpose being to create a "fat" spark at the spark plugs. Quite often it is not sufficient to eliminate the interference created in the primary circuit. For this reason a second condenser is employed as shown by C_2 (about .5 mfd.) which is connected to the hot side of the primary and the chassis. This condenser is optional, used only when needed.

We have so far considered the primary or low tension circuits. Turning now to the secondary or high tension circuit, we realize that a spark may take place at the distributor or at the spark plugs. A condenser could be placed across each distributor contact but it would have to be of a very high voltage rating. Furthermore, one for each cylinder would be required. Hence another method is deemed advisable. A condenser at the spark plug should not be used, as it would affect the "hotness" of the spark. Therefore in the high potential circuits either a series r.f. choke or a resistor must be used. They are called suppressors. Any surge of current that starts to move down the connecting wires is suppressed or the amplitude is so much reduced that what damped r.f. currents that do exist are small.

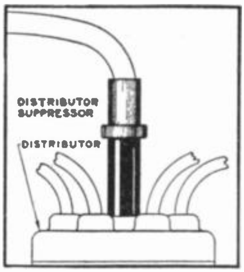


FIG. 11a

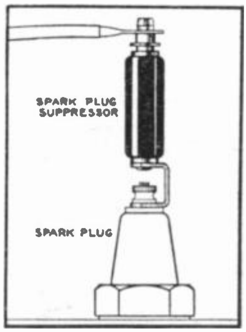


FIG. 11b

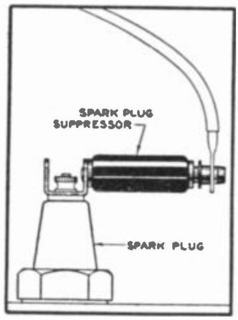


FIG. 11c

Figure *9* shows a suppressor at the distributor and at a spark plug, used to reduce interference currents created by the sparks in the high tension system. They may be of the choke coil or resistor type, although the latter type is in greater use. The resistor is generally about 20,000 ohms and of the carbon or metalized type in a suitable housing. This value by expert check does not appear to greatly affect the efficiency of the engine. Figures *11a, 11b,* and *11c* show the usual methods of adapting these suppressors. Remember, use one for each spark plug and one for each distributor. In some cars the lead to the distributor cannot be removed. The wire must be cut and a special suppressor spliced into the circuit as shown in Fig. *11d.*

The installation of noise suppression devices so far considered are standard for every automobile receiver installation. It suffices for a majority of cases. What are you to do when these so-called primary methods do not eliminate all the interference? What has really been done so far, is the suppression, not the elimination of interference in the electrical system. Should any lead wire pass through the bulkhead so that it is in the antenna pick-up field, even the weak interference signal currents will create a disturbance. There are several such possibilities.

The dome light is usually right in the center of the mesh type antenna. Electrical interference originating at the engine is conducted up to the dome light, and even a weak disturbance has serious effects. Disconnect the lead to the dome light, at the ammeter, fuse or overload relay and determine if this is the source of trouble. If it is, connect a .5 mfd. condenser between the lead and the chassis, either at the ammeter, fuse or overload relay; or at some point in the passenger compartment where it enters from the engine, perhaps at the corner post or switch. It may be necessary to use condensers at several points in the lead. What has been said about the dome light will apply to any *current carrying lead* which extends between the passenger and engine side of the bulkhead. Bypassing to ground at the bulk-

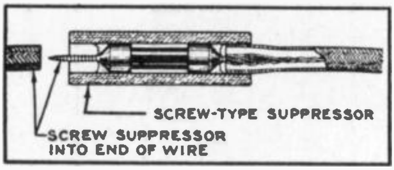


FIG. 11d

head should be tried. For quick test, connect a .5 mfd. condenser to two short flexible leads each with a jaw clip, and use this as a temporary bypass.

Equip yourself with a heavy flexible wire with a powerful jaw clip at each end. Connect this between the chassis and any rod or mechanical control wire that passes through the bulkhead at the engine side. Try various positions of the ground connection and when a connection is found that reduces interference, make a permanent soldered or clamp connection. Flexible ribbon braid connectors are generally used. For your own protection don't make any connection within the engine compartment or make any change while the engine is going. You must realize that the test must be made with the engine going; therefore always stop the engine when a temporary bond is being made.

Some servicemen have reported that excellent noise elimination has been obtained by insulating the receiver chassis from the bulkhead of the car using insulated bushings and washers. Then they bond the receiver to the bulkhead with flexible ribbon conductors. The bond to the bulkhead is not made permanent until various contacts have been tried and the one giving the least interference found. Radio currents exist at all parts of the body and in this case you are locating a point of zero noise signal on the bulkhead.

Another vital source of trouble is the ignition coil and the leads to it. First you may find that the high and low tension wires from the coil are grouped together. They should be re-routed and as far apart as possible. Next you may find that the ignition coil is mounted on the dash or the passenger side of the bulkhead. If it does not have a built-in lock, move it to the engine side of the bulkhead. Otherwise, you will have to shield it. First try metal loom (wire shield) over the high tension lead extending it to and bonded (connected) to the bulkhead. If this fails to remedy the trouble, a metal shield (can) must be placed around the coil and the can grounded.

Bonding. Let us go back to the pick-up system. The chassis of the car is the ground or counterpoise, and forms a capacity with the roof or sub-chassis antenna. If any part of the chassis is intermittently making and breaking, this capacity is disturbed and contact noise may show up. Another reason for bonding: R.F. current flow through the entire body and various parts of the car are at different potentials. Rubbing of any two points where a difference in potential exists will create a current and noise will be heard. All loose parts like control rods or oil and gas feeds must be either separated so they do not rub (use tape) or they must be bonded to each other. Using the heavy flexible wire equipped with end jaw clips (storage battery clips), temporarily bond any two parts that are questionable. When elimination of noise is noticed make a permanent bond.

We have assumed all along that the car was in good mechanical and electrical condition. You should question the customer about this before an installation or service job is attempted. It is rather foolish to bond a car that is mechanically loose; or to suppress the interference when the spark plugs, commutators and brushes of the generator, and the distributor contact spacings are not in perfect condition. The car should be gone over by a reliable auto mechanic.

Static Discharges. Quite often noise will be experienced only when the car is on the road. This is due to friction of the air or tire rubbing on the road that charges insulated or partly connected parts. If the interference disappears when the car is braked, apply what is called "brake juice." Static generated by the tire while the car is in transit may be eliminated by adding a little graphite grease in the wheel grease already in the front wheel hub caps. This is merely needed at the front wheels as the rear hubs are electrically connected to the car chassis. Where wood wheels are used it may be necessary to bond the rim to the hub. If the hub is electrically free, again add graphite grease to the inside of the hub. As a last resort, rim, brake drum, brake rods may be bonded in such a manner that they do not interfere with the controls.

Typical Procedure. Remember that there is no one sure procedure to eliminate noise interference. Always start with the primary methods and resort to secondary or "trick" methods. Radio magazines constantly suggest new and novel methods, which should be considered. If you have many auto radio jobs, be sure you file these suggestions for ready reference. With a knowledge of interference creation and elimination you will find the job rather simple. The following methods are recommended and are presented in the most effective order for noise suppression. Read this list* carefully as several new ideas are introduced.

(1) Apply suppressors to spark plugs and distributors.
(2) Apply generator condenser.
(3) Re-route primary wire from coil to distributor, keeping it as far as possible away from high tension wire.
(4) Connect dome light condenser to dome light wire at point where it enters front corner post; and a condenser at the ammeter.
(5) Shield high tension wire if coil is mounted on instrument panel.
(6) Shield antenna lead-in wire from radio set to top of front corner post, if not already shielded. Be sure that the shield is grounded at both ends.
(7) Shield primary wire from coil to distributor.
(8) Connect a .002 to .006 mfd. high grade mica condenser directly across the primary breaker points of the distributor, the primary chopper.
(9) Bond the upper metal parts of the car body to one another and return a heavy copper bond from these points down to the bulkhead of the car. (This is usually necessary in cars using composite wood and metal body construction.)
(10) Bond where necessary all control rods and pipes passing through the bulkhead.
(11) Cover floor boards of car with copper screening.
(12) Adjust spark plug points to approximately .028 of an inch.

* This excellent list is reproduced through the courtesy of the Galvin Mfg. Co.

(13) Clean and adjust primary distributor breaker points (job for auto mechanic).

(14) Engines in cars having rubber motor mountings (floating power) should be bonded. First connect a flexible metal braid between the engine and the chassis frame. If this is insufficient connect a heavy bond from grounded side of battery directly to frame of car.

(15) Connect a .5 to 1 mfd. condenser from hot primary side of ignition coil to ground.

(16) If ignition coil is mounted on driver's side of bulkhead move it to the motor compartment side using the same holes for mounting.

(17) Clean ignition system wiring. Clean and brighten all connections. Replace any high tension wiring having imperfect insulation.

(18) Ground metal sun visor and rain troughs if necessary.

(19) Make sure hood of car is well grounded.

(20) Ground instrument panel and steering column to bulkhead.

(21) When under-car aerial is used connect a .5 mfd. condenser to tail and spot light wires.

BALANCING AND FILTERING NOISE CURRENTS

Much has been accomplished within the last few years with regard to the reduction of ignition interference in auto radio installations. At first the method of damping out interference by means of suppressor resistors was universally used; car owners, however, are usually suspicious of any "gadget" connected to the engine, many believing that gas consumption is increased by the use of spark plug suppressors.

The answer of auto radio manufacturers to this objection was the development of special radio circuits and devices, based upon fundamental radio principles, which serve to eliminate interference without affecting the operation of the engine.

Perhaps the most spectacular of these devices was the "Magic Eliminode," developed by the Galvin Manufacturing Co. for use with their Motorola receivers. The circuit diagram of this unit, shown in Fig. *12*, reveals that there are two sources of signal pick-up, lead *A*, which connects to the regular car antenna and picks up both radio signals and ignition noise, and lead *I*, which connects to some part of the engine or car body and picks up only ignition noises. The interference signals flowing through coil L_1 induce in coil L a voltage which is opposite to the voltage of the interference signals flowing through that coil from the antenna. The degree of coupling between the two coils can be adjusted until the two interference signals cancel each other, and there is passed on through coil L_2 to the receiver only an interference-free signal. It is sometimes necessary to try several connections of lead *I* in order to obtain an amount of interference which is within the adjusting range of the Eliminode. Once the unit has been adjusted, it need not be touched until the radio is moved to another car or radical changes are made in the car wiring.

In some cases, however, a type of interference signal will be picked up which cannot be balanced out by ordinary means. This interference is due to noise-modulated ultra high radio frequency currents which are radiated by the ignition wires and get into the antenna circuit, shock-exciting the input stage of the receiver. To eliminate this type of interference, auto radio manufacturers are turning to choke-condenser antenna filter systems, such as the combination of L_2 and *C* in Fig. *12*. This combination of a coil and condenser cuts out the noise-modulated ultra high R.F. signal without appreciably affecting the strength of the incoming radio signal.

There is now available on the market, for use with any auto radio, a device known as the "Interferotrol," which, like the Eliminode, is a combination of the high frequency filter and an adjustable balancing circuit which completely eliminates the need for spark plug suppressors. The unit, shown in Fig. *13*, is simply installed in series with the car antenna and a lead connected from it to some point on the engine. If devices like this fail to give complete interference elimination, always use the three standard or primary methods of eliminating interference currents, such as by choking them out with an r.f. choke coil, by suppressing them with series resistors and by by-passing them to the car chassis with condensers.

SERVICING AUTO RADIOS

General Hints. Your method of attacking an automobile radio service job should be no different than with a home broadcast or high fidelity receiver. The process is the same; only your interpretations will be different because of the peculiarities of auto receivers. Your technique in servicing car radio receivers should include the usual steps of confirming the complaint, checking for obvious surface defects, reasoning out the cause by the effects, circuit disturbance test for defective stage isolation, dismounting of the chassis for repairs, repair of receiver defect, general receiver check and revitalization. There are bound to be some differences. For example, in some car receivers you may not be able to get at the tubes to make a circuit check unless you dismount the receiver. Therefore the cardinal rule that you follow with home receivers of not taking the chassis out of the cabinet (in auto receivers dismounting the receiver) until an internal defect is indicated is no longer true. In this case you have to dismount the chassis to proceed with a routine of isolating the defective stage. A little thought on each job will easily lead you to the correct procedure.

Be sure that you understand the customer's version of the trouble; then confirm the complaint by actually trying out the receiver. Troubles that you may consider of little importance

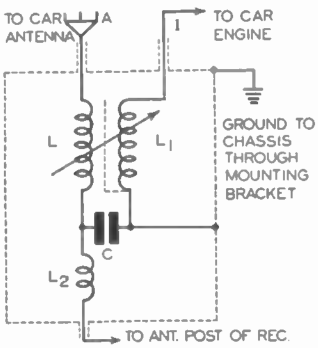


FIG. 12. Circuit diagram of "Magic Eliminode" used in Motorola auto radio sets to suppress ignition interference.

FIG. 13. I.C.A. "Interferotrol," an interference eliminator which eliminates the need for suppressor resistors in an auto radio installation.

and would overlook may be the very thing that disturbs the customer.

There are certain troubles which are peculiar to auto radios. You should be able to locate their cause by the effects you hear. Perhaps the most common complaint is noise interference. Be sure to ask the customer *when* this trouble started and *when* during driving the noise appears worse. Answers to these questions may guide you to the trouble.

It may be that the receiver was not properly installed in the first place, and the noise that existed was overshadowed by the novelty of having an auto radio. People become more critical of their auto radios the longer they have them. In these cases, merely continue the job of noise elimination.

Then too, noise may have arisen because of the general loosening of the auto or "wear and tear" of the electrical and ignition system. An auto radio installation that was originally free of noise should not be serviced until the car has been thoroughly inspected, tightened and readjusted by an auto mechanic. Caution the auto mechanic to use graphite grease in the hubs of the front wheels.

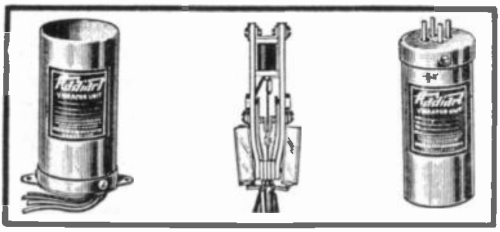
Poor sensitivity is another common complaint made by owners of auto receivers. The trouble may be due to defects in the receiving circuits or weak tubes. In most cases after the tubes have been checked and replaced and weak reception still exists, it can generally be attributed to an inadequate (poor) signal pickup system. Of course, if you have had previous experience with the installation under examination and know that it was previously in a satisfactory condition, it is logical after testing tubes, to analyze the chassis for defects or attempt an alignment of the amplifying stages.

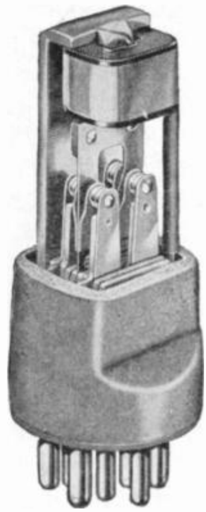
It is wise before you condemn an antenna installation, especially if it is of the roof type to test for leakage. If found in normal condition, you should roughly test the receiver for sensitivity either using a short piece of wire .5 to 2 feet long held by a pole out of the window (be sure the doors are closed) or remove the chassis to your work bench where a fully charged battery and a very short antenna is available. In either case do not make the mistake of using a long antenna. You will soon learn from experience how long the antenna should be. Select one that from experience indicates to you that if the receiver works well with it, then normal reception in an auto may be expected. If you fail to get good sensitivity at the bench with these precautions as to pickup, then you should consider a revitalization procedure. When the "pepped-up" receiver is placed in the car, and the antenna tuning circuit trimmer is adjusted to the antenna installed, and reception is still not acceptable, then a new antenna will be required.

You must be on the lookout for complaints that indicate a condition which cannot be remedied. They are conditions peculiar to all automobile receivers. The customer should be told that rushing noises are natural because the receiver is very sensitive and the antenna is so small. You, of course, know that it is tube and circuit noise and nothing of a practical nature can be done. Fading is common, and might be quite bad if efficient A.V.C. systems were not used. Check the A.V.C. tube and if found to act normal explain why fading is natural as we did earlier in this text. Don't make the mistake of immediately blaming fading on an open bypass condenser, or some circuit defect. Confirm the complaint and in this case try the receiver while the car engine is running.

Vibrator Troubles. When weak and noisy auto receiver reception is traced to low B voltages, you should not only inspect the chassis for circuit defects but question the condition of the vibrator which may be out of adjustment. Don't condemn the vibrator merely because it seems to be noisy. This is normal and you will find that when the receiver is open, as it is on the work bench, the noise may reach an alarming level. When you hear noise, check the voltage supplies and if found Okay, merely be sure that the vibrator case is floating, if such provisions exist.

Only when the noise comes through the speaker (car engine dead) and the voltages are checked below normal is a vibrator defect indicated; only then should you consider vibrator repairs





Typical auto radio vibrator units. In the diagram above, the Radiart units are, left to right: Unit mounted in can, with flexible leads for permanent connections; vibrator mechanism out of can; plug-in type vibrator, which can be replaced as easily as a radio tube. At right is a self-rectifying plug-in type vibrator, a Mallory product.

or replacement. Many servicemen love to adjust every part of the receiver that is adjustable; but you should curb this desire in the case of vibrators unless a definite defect is indicated.

Some vibrators are not adjustable and the only thing which can be done to them is to clean and smooth their contact surfaces with an ignition file, procurable at any hardware store. Some servicemen may resort to bending of the reeds to align the vibrator contacts for minimum sparking.

A number of manufacturers make their vibrators easily replaceable by building them into cases which are equipped with plug-in bases—pull out the old vibrator and plug in a new one. Many servicemen replace old vibrators rather than spend time on them, claiming that it is cheaper to do so and these men are not entirely wrong. But suppose you decide to repair vibrators?

As there are a large number of vibrators in use and these may vary radically from one another, it is only possible to suggest a general repair procedure. You should procure the manufacturer's detailed instructions for the receiver you are working on, and follow the information given. However, the repair of a vibrator may be divided into: *1*, mechanical inspection and adjustment; and *2*, with the vibrator connected and working in the receiver or connected to a dummy load, adjust for maximum efficiency and least sparking.

The first and most natural step to take is to remove the vibrator unit, open it and carefully inspect the reeds, springs and contacts. Experience will tell you whether they are in their normal condition and position. In the case of a self-rectifying vibrator, the spring will hold the reed to one side so that a primary and a secondary connection to the transformer is made. The buzzer contact, the one in series with the vibrator coil, should make contact. The other contacts will be open, their spacing will vary with the design of the vibrator. The factory service manual should be your guide. Be sure the contacts are clean and free of "pits." If the contacts only hit at a few spots, insert an ignition file between adjacent contacts, press the contacts together and draw out the file. Repeat until contacts are making complete contact. The open contacts may be treated in the same way. The next adjustment is made at the buzzer contacts. Push the reed towards the open transformer contacts. When these are about to make contact, the buzzer contact should be just about ready to break.

Having inspected for mechanical defects, made the necessary alignment and adjustments, the next step, when the receiver is at hand, is to put the set into operation and make the necessary adjustments to obtain peak electrical efficiency (peak output voltage) with the least sparking. A normal operating vibrator should deliver maximum output voltage with minimum input (primary current) and with the least sparking at the contacts. If you are repairing the vibrator at the bench, out of the chassis, it will be necessary to use an appropriate supply circuit applying to it a dummy load equal to the voltage (E) and current (I) output that is normal for the set the vibrator was intended to be used on. Of course, the load resistance will equal $E \div I$. This procedure is used where several vibrators are to be adjusted or repaired, as for example at a jobber's service bench.

Place a voltmeter across the dummy load, or the output of the set brute filter and adjust the buzzer spring and contact for maximum voltage. Now adjust all the other contacts for minimum sparking. Bending the reed so the sparking contacts have greater clearance is the usual adjustment for least sparking. If adjustment screws are provided the task is easier.

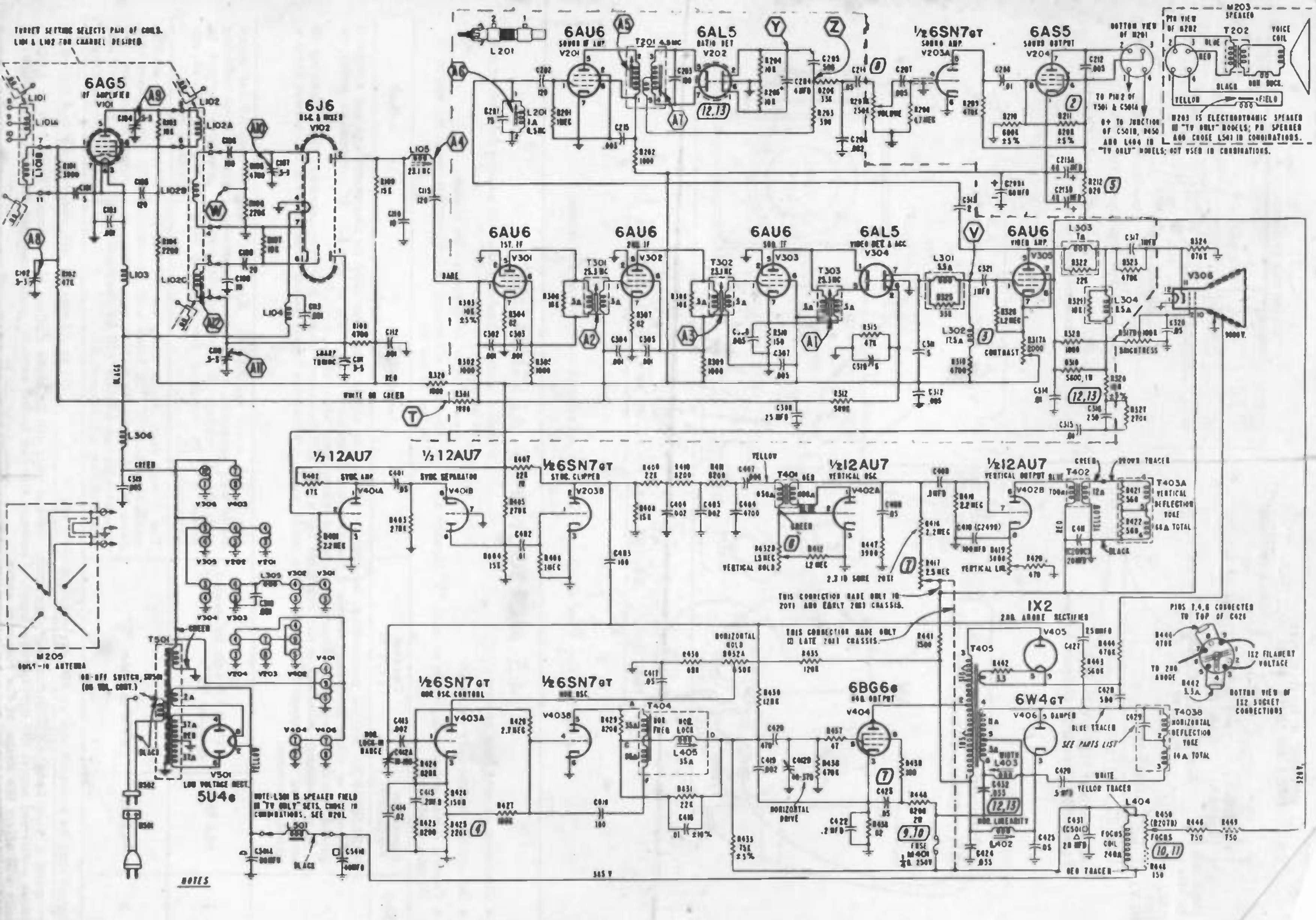
TEST QUESTIONS

Be sure to number your Answer Sheet with the number appearing on the front cover underneath the title of this text.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your Course, and the best possible lesson service.

1. In what three standard ways may interference currents, due to a spark, be reduced?
2. How would you compensate for the additional drain in the car battery due to the use of an auto radio?
3. What is the most satisfactory type of concealed auto antenna?
4. What should be the closest distance between the edges of a roof mesh antenna and the metal body of the car?
5. Where would you *mount* the condenser used to eliminate commutator sparking occurring in the charging generator?
6. In what two ways could you eliminate noise traced to a feed line rubbing against a control rod?
7. Would you bond a floating engine (floating power) to the car chassis?
8. How could you roughly test the sensitivity of an auto receiver?
9. What two facts indicate a defective vibrator unit?
10. How are the interference currents created by spark plugs reduced?



ALPHABETICAL SYMBOLS (A1), (A2)... (Y) (Z) ETC. INDICATE ALIGNMENT POINTS AND CONNECTIONS.

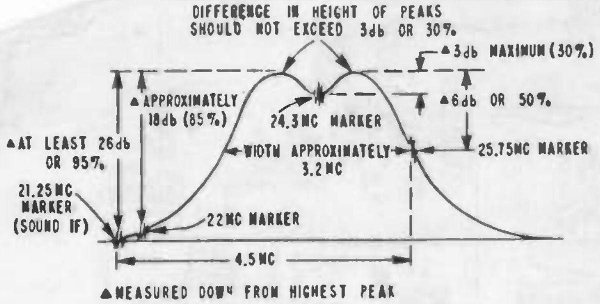


Figure 28. Overall IF Response Curve.

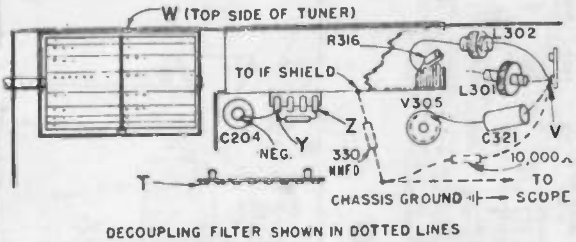


Figure 29. Bottom View of Chassis Showing Alignment Connection Points.

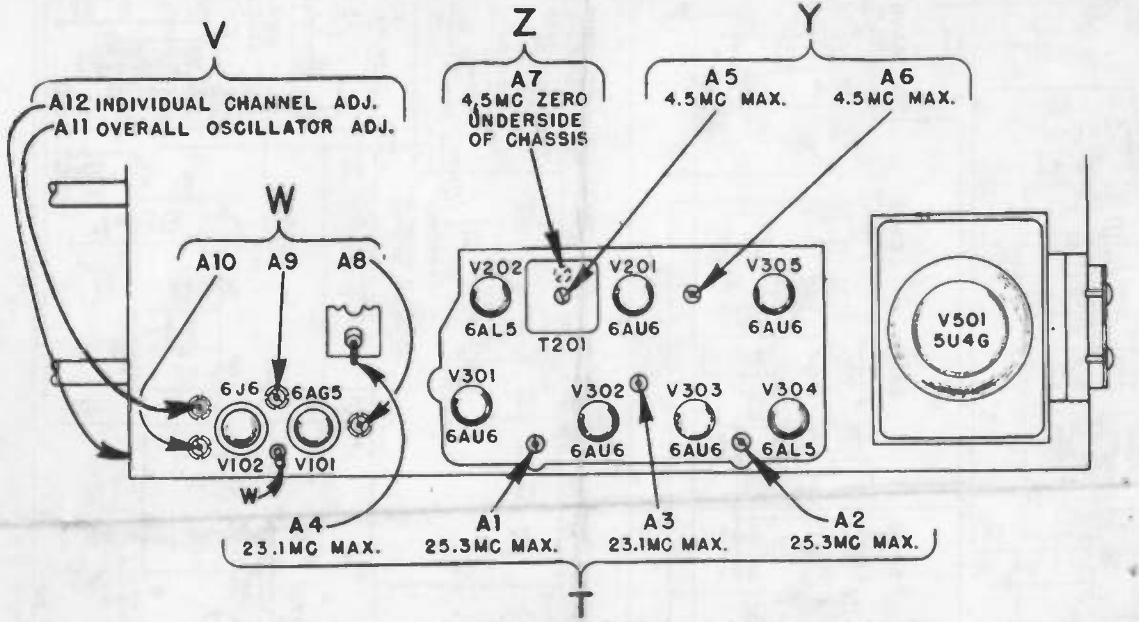


Figure 30. Top View of Chassis Showing Alignment Adjustment Locations.

4.5 MC SOUND IF ALIGNMENT

- Disconnect antenna from receiver.
- Set contrast control fully clockwise.
- Connect signal generator high side to point "V" through a .01 mfd. condenser.
- Before starting alignment, allow 15 minutes for receiver and test equipment to warm up.
- Speaker must be connected to chassis.
- Alignment adjustment and connection point are shown in figures 29 and 30.

Step	Signal Gen. Frequency	Connect VTVM to	Instructions	Adjust
	IMPORTANT: Before proceeding, be sure to check the signal generator used in alignment against a crystal calibrator or other frequency standard for absolute frequency calibration at the 4.5 MC alignment point required for this operation. Accuracy required within one kilocycle. If a frequency standard is not available for a 4.5 MC frequency check, it is recommended that touch-up of zero setting adjustment A7 in step 2 be made using a television signal rather than the 4.5 MC signal from a signal generator.			
1	†4.5 MC	VTVM (3 volt DC scale) to point "Y".	Use 3 volt scale on VTVM. Keep VTVM leads well separated from signal generator and chassis wiring. A non-metallic screwdriver will be required for aligning slug adjustment A5.	A5 and A6 for maximum (keep reducing generator output to keep VTVM at approx. 1 volt).
2	†4.5 MC	VTVM to point "Z".	Use 3 volt zero center scale on VTVM, if available. Keep VTVM leads well separated from signal generator and chassis wiring. A non-metallic screwdriver will be required for aligning slug adjustment A7.	**A7 for zero on VTVM (the correct zero point is located between a positive and a negative maximum).

† Signal may be unmodulated or 400 cycle AM modulated.

** If A7 was far off, readjust A5 and repeat A7.

When using a wide band oscilloscope for alignment, marker pips will be more distinct if condenser from 100 to 1,000 mmfd. is connected across the oscilloscope input. Caution: Use the lowest capacity condenser possible, since too high capacity will affect the shape of the response curve.

1. By choking them out with r.f. choke coils; by suppressing them with series resistors; and by-passing them to the car chassis with condensers.

2. Advance the charging rate of the battery charging generator.

3. The roof antenna.

4. Three inches.

5. On the generator frame (housing) near the cutout.

6. By separating them, using tape; by bonding them with a flexible braid connector.

7. Yes.

8. By trying it on a very short antenna.

9. Noise through the loudspeaker (car engine dead); and low B voltage.

10. By the use of suppressors.

v

SERVICE, BENCH AND LABORATORY TESTING OF VACUUM TUBES

42RH

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

PAY THE PRICE

You can buy anything—even Success—if you will pay the price.

"No man, no matter what his vocation, can attain genuine success without making sacrifices. Nothing worth while can be gotten anywhere for nothing. Things we get for nothing, we do not enjoy. Work and labor and study and sacrifice are all necessary to winning the kind of success that brings satisfaction with it."

DANIEL GUGGENHEIM.

NATIONAL RADIO INSTITUTE

WASHINGTON, D. C.

1942 Edition

A LESSON TEXT OF THE N. R. I. COURSE WHICH TRAINS YOU TO BECOME A

RADIOTRICIAN & TELETRICIAN

(REGISTERED U. S. PATENT OFFICE) (REGISTERED U. S. PATENT OFFICE)

NCP2M342 Printed in U. S. A.

Service, Bench and Laboratory Testing of Vacuum Tubes

TUBE TESTING IN THE HOME

The Radio-Trician encounters in the servicing and maintenance of Radio receivers, troubles which are directly due to vacuum tubes. Experience shows that a large number of service calls are due to defective tubes. Without exception, vacuum tubes must be considered as parts or components of the Radio receiver, just as much as the transformers or condensers. We are fortunate, however, in that it is far easier and takes far less time to check up on the tubes than on any other electrical part of a set.

What we believe to be the most sensible and satisfactory method of testing tubes in the field, is to carry a complete set of tested replacement tubes for the receiver you are called upon to service. On arrival at the job, the ordinary routine consisting of the regular visual inspection of the set, tubes, antenna and ground is made. If any of the tubes look abnormal—that is, have a blue or purple glow in them,* or a filament does not light, the voltages delivered to that tube should be checked before trying a new one. This will prevent new tubes from being destroyed.

A modulated R. F. oscillator and output meter are respectively connected to the input and output of the receiver. The receiver, if it is active, is tuned to the signal of the oscillator and the oscillator output varied for a one-third scale deflection on the output meter. If no output is indicated, the defective stage or part should be traced down and corrected. Then the various tubes are replaced one at a time, starting with the rectifier tube. If on replacing any of the old tubes with a new one, you note that the deflection has gone up a fair degree, you may be sure that the tube you have removed is defective or weak and should be permanently replaced by a new one. A visual test of this kind will convince your customer and will break down his sales resistance toward the purchase of new tubes.

These tests apply to the simple T.R.F. and superheterodyne receivers. Where A. V. C. is incorporated in the set, the serv-

* A glow apparently on the glass envelope (usually power output tubes) is normal. A haze or glow between the elements is unnatural when normal voltages are applied and indicates a defective tube.

ice oscillator output should be reduced to a point below the threshold sensitivity of the receiver—in that region where changes in the oscillator output cause marked changes in set output. A tube in an automatic squelch (muter) stage may be tested by reducing the service oscillator output to a low value and observing that the output cuts off sharply.

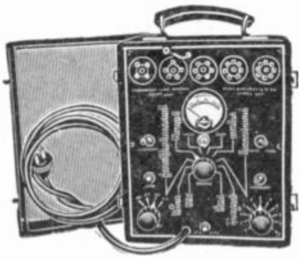
Remember that because of the many unique ways in which a tube may be called on to perform, it is important to connect the behavior of the tube with the function it is supposed to perform. Some tubes are better detectors than amplifiers, others are better A. V. C. or muter tubes than amplifiers, etc. Therefore, several tubes should be tried in these special positions before considering the substitution complete. In some cases, a time test is advisable. For example, gas in an R. F. or I. F. amplifier tube when in a circuit controlled by an A. V. C. tube will cause the output to creep up. In fact, this is an important test for A. V. C. receivers.

When a tube is to be selected for a special purpose, a systematic method of selection should be employed. For example, the following is a special procedure for selecting an A. V. C. tube. Remove the A. V. C. tube from the set socket; tune the set to a weak signal from the test oscillator or to a weak broadcast; try several correct type tubes in the A. V. C. socket and select one that reduces the output the least; and determine if the tube chosen actually causes the output to assume a constant output with increases in R. F. input.

When a service oscillator and output meter are not available, the serviceman may tune in a weak station and make tube substitutions. A good tube replacing a poor tube will show up as increased sound output. This test is by no means conclusive, as quite often a tube may be poor but not sufficiently poor to show up when substituted alone. A whole set of tubes may be required to show a marked audible change in sound output. Of course, no serviceman would resort to this sort of a test if a portable tube tester were carried to the service job.

Although there is a definite feeling among servicemen that a working test is the most desirable, many prefer the tube checker. There can be no question that they give a good indication of the worth of a tube, but the very same serviceman who prefers these testers always checks the performance of replaced tubes by tuning in a weak or semi-local station before and after tube replacements. Should you prefer the tube checker, do not fail to try several good tubes in a given location or interchange similar types.* Tube alignment is an added worth while service and takes very little time.

The older makes of set analyzers have a "grid shift" button which automatically inserts a 4.5 volt C battery into the control grid circuit. In the modern set analyzer it is easy to insert a 4.5 volt battery (for low bias tubes) or 13.5 volt battery (for high bias tubes) into the control grid circuit and note the change in plate current. The added bias is introduced so that the plate current decreases. The change in plate current is sufficient to give a rough indication of the mutual conductance of the tube and if the serviceman is willing to make a few rough calculations, a fairly accurate value of the transconductance may be obtained. Then by referring to a standard tube chart,



Radio City Products Tube Checker Model 303A, in which a modified switching gear connects to 4, 5, 6 and 7 prong sockets.

the value computed may be checked with the value in the table, using the one of approximately the same plate voltage as is supplied in the set. In some modern circuits, tubes operate without applied voltages; in others the voltages are not applied unless the signal circuits are active. There is, therefore, a limitation to the usefulness of the tube check in a set analyzer.

The real place for a tube checker and tube short checker is in the shop, on the tube sales counter, and in the laboratory. Their importance must not be underestimated, as they fill a definite need in service and radio development work. Tubes may then be tested with elaborate equipment and at rated operating voltages if extensive testing is needed. Simple tube

* Tubes used in a neutrodyne once the stages have been neutralized, cannot be interchanged without upsetting the adjustment.

checkers help select the good tubes to be taken on a service job. A visual counter tube tester is a valuable sales device as it convinces the customer. Tube checkers are taken up later in this text.

New tubes will gradually reduce the usefulness of most tube checkers unless they are continually brought up-to-date. Likewise, testers used at the service or laboratory bench should be flexible enough to test new tubes. Testers which change the tubes, for example, reducing pentodes and tetrodes to triodes by connecting the screen and suppressor grids to the plate when possible, for simplicity in tester design are not so reliable as tube checkers that check tubes as they are intended to be used.

Testers which do not test tubes at operating voltages are not as conclusive as those that do. Operating at exactly rated voltage is not imperative, but advisable. The characteristics that are measured may vary about 20 per cent before indicating an undesirable tube. It also is important to remember that the operating voltages and currents in a given receiver may vary as much as 10 per cent from the intended values.

From what has been said there are three practical methods of testing tubes; the tube checker, the tube comparison, and the set analyzer grid shift methods.

BENCH AND LABORATORY TESTS

For average service work the amount of tube testing required is limited and is adequately covered by a portable or counter tube checker, or with the oscillator-output comparison method. For the technician connected with set and tube manufacturers, or the men engaged in the design and construction of tube control devices, a further study of tube testing is essential. Servicemen should understand how emission, gas, dynamic transconductance, plate resistance, amplification factor and power output tests are made. Studying the usual methods removes the mystery of tube testing, makes advance reading easier and often helps in special service problems. Special bench and laboratory tube tests will now be considered.

Tube Short and Filament Open Checker: No service or laboratory bench should be without a simple obsolescent proof short-checker and open-filament tester, in fact, every practical test should start with a check for shorted elements. Of course, you can easily check for a short between elements of a tube or for an open filament by applying an ohmmeter to the prongs of the tube under test. The check is bound to take a little time and it would be easy to omit a vital check. A set-up which is simple to use, and quick to show defects is needed.

Figure 1 shows the details of a simple but effective device designed by the N. R. I. Instruction Staff. A 4, 5, 6 and 7 (one capable of taking the small and large base) prong socket is needed, connecting the prong terminals to six 250 ohm resistors in series. The resistors are connected to a 110 volt D. C. or A. C. power socket supply with a D. C. or A. C. 0.5 ampere meter and a 250 ohm limiting resistor in series. All socket filament connections are in parallel and are connected to the power supply, using a limiting resistance of 2,000 ohms. No

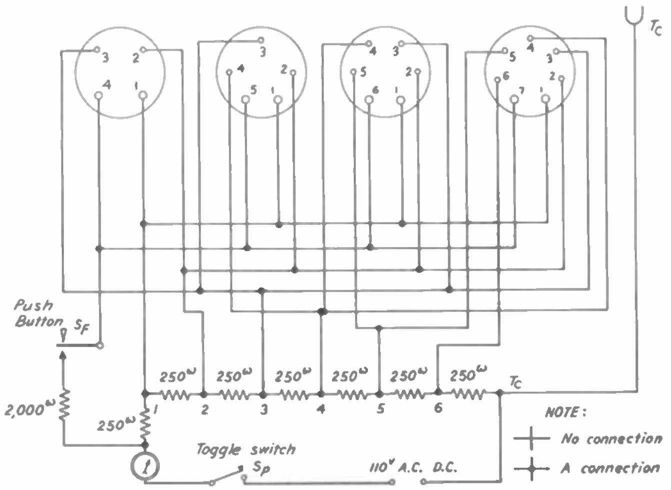


FIG. 1

mechanical details are given—build it to suit your needs. Use an inexpensive copper oxide rectifier type of ammeter for A. C. work or an A. C. moving vane ammeter (Readrite) having a good low range reading. Any type of D. C. ammeter may be used if the device is to be used on D. C. power systems. Five watt resistors should be employed.

To use the instrument, turn on the main power switch S_p and note the position of the meter needle. Insert the tube into the proper socket—a 5 prong tube into the 5 prong socket, etc.—and connect the top cap to the tube cap if the tube has one. No movement of the meter needle indicates a tube without shorted elements. Tap the tube to insure that tube vibration does not introduce a short. With your eye on the meter press the push-button S_F. A perfect filament is indicated by a slight increase in meter reading. No increase in meter reading indicates an open filament. A short from T_c to *1* would cause the meter to read, .44 ampere.

Emission and Total Emission Tests: When the life of a tube must be given careful consideration, the total emission from cathode to plate must be determined when the filament is supplied with rated power. The total emission must compare favorably with that of a standard tube. This, of course, assumes that there is no gas present in the tube, as gas will destroy quickly what emission qualities the cathode may have. A test for gas content will be given shortly.

The ordinary current in the plate circuit is often called the emission current, but it is not the total emission current. The emission current should be checked when using a set analyzer.

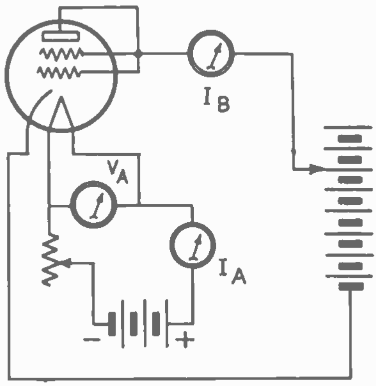


Fig. 2a

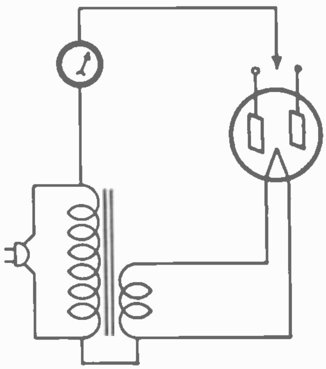


Fig. 2b

If it appears to be below normal value as governed by rated operating potentials, the tube should be discarded. Perhaps the better scheme is to compare the emission current with that of a tube known to be in good condition placed in the test socket of the receiver.

The total emission current is the maximum current which flows from cathode to plate, if all the electrons emitted from the cathode reach the plate. Of course, this will vary with the cathode temperature which in turn will depend on the applied filament power.

Theoretically, the total emission current of a tube is the plate current that would flow if we should connect the grids and plate together, as in the circuit of Fig. 2a, and place a large plate voltage upon the tube. However, such a measurement can hardly be made, for it would ruin the tube. For this reason measurements of the total emission of a tube are made at reduced voltages, plotting the results of the measurements on the special power-emission chart shown in Fig. 3, which has been designed for this purpose.

The power supplied to the filament, or to the heater in the

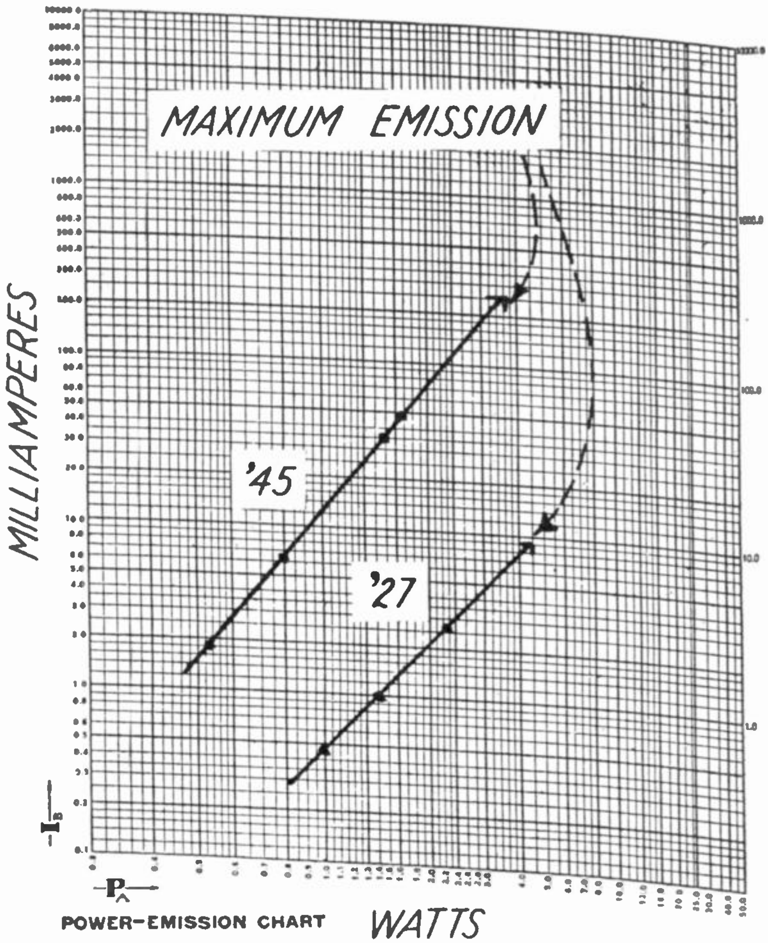


FIG. 3

case of heated cathode tubes, is plotted horizontally. This is the product of the current I_A in the heater multiplied by the voltage V_A across the heater. The plate current I_B is plotted vertically. With a low plate voltage, say about 25 volts, and with the heater voltage quite low, the plate current is noted. Then the heater voltage is increased slightly and the plate current noted again, and so on. This is done until the plate current is slightly higher than normally allowed when used in a receiver.

The points so obtained are plotted on the special chart. They should lie in a straight line. If the curve tends to bend downward, this is evidence that the plate voltage was too low—too low to attract to it *all* of the electrons emitted by the cathode, for that is what total emission is. The plate voltage should be increased slightly and the curve re-taken. If the curve bends upward, we have evidence of too much gas in the tube for reliable measurements.

Having obtained the straight line, we simply extend it out to the point which represents full rated power supplied to the heater. In other words, since we cannot take measurements at rated heater power, we make them at reduced powers and extend the curve.

As we have said, the importance of knowing the total emission of the cathode lies in the fact that the total emission is a measure of the life of the tube, a factor which is very important in tube design. Other things being the same, the greater the total emission the longer will be the life of the tube. Of course, the tube life depends upon other things as well, but this is of fundamental importance. The student must distinguish very carefully between the ordinary emission and the *total* emission. The ordinary emission, as generally used, simply refers to the ordinary plate current under operating conditions.

The emission test is the only means of testing rectifiers and the simplest procedure is used in tube checkers. Figure 2b shows an all A. C. emission checker, allowing testing of each half of a full wave tube. The tube rectifies its own test plate current. Comparing the emission current with a good tube is the only means of checking a doubtful tube. In service work total emission tests are not required.

Amplification Factor. In designing circuits, we find that the amplification factor of the tube plays an important part. Of course, this value and all others are given by the tube manufacturer in tube tables, usually only at a few sets of characteristic voltages. If a set of characteristic curves are given, the tube constants for any set of operating voltages may be obtained. Quite often the exact amplification factor, μ, is desired for the tube to be used and then it must be measured. For average design the tube characteristics as furnished by the tube maker will suffice.

The μ of the tube may quickly be obtained by setting it up in a simple circuit operating it at voltages that are to be used in the final circuit design. It is important that no load be included in the plate circuit and the plate milliammeter, which is necessary in this test, have low resistance. Note the plate current; decrease the C bias by a small but known amount; decrease the plate voltage so the plate current is the original value; compute the change in plate voltage. The change in plate voltage divided by the decrease in grid voltage is the static amplification factor. It is the static value as it is not taken under duplicate operating conditions. For ordinary work, the value obtained is quite satisfactory.

To obtain the dynamic μ the grid should be fed with a sine wave grid excitation voltage. Figure 4a shows a simple balancing circuit which will measure the dynamic μ of a tube. For simplicity a heater type triode is shown, although it should be re-

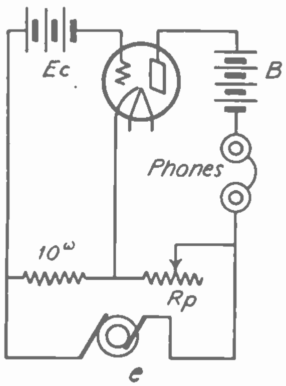


FIG. 4a

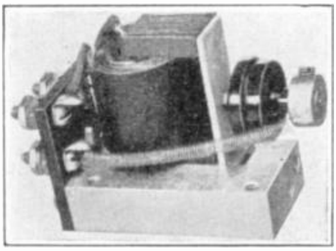


FIG. 4b

membered that the same circuit scheme is applied to all types of tubes, with all electrodes connected to and operated at voltages that are eventually to be used in the circuit to be designed. Generator *e*, may be a sine wave 1,000 cycle battery operated microphone buzzer, as shown in Fig. 4b; or it may be a sine wave audio frequency tube oscillator. The phones should have a low impedance in comparison to the plate resistance of the tube at the frequency used. In this circuit the A.C. voltage *e* divides between the grid-cathode and plate-cathode terminals, the two components thus formed being out of phase (180 degrees), that is, when the grid end of the 10 ohm resistor is positive with respect to the cathode, the plate end of the variable resistor R_p is negative with respect to the cathode. An increase in grid voltage causes an increase in plate current. At the same time the voltage across R_p

is becoming more negative with respect to the cathode. As this voltage adds to the B voltage, the net plate voltage decreases, with a resultant decrease in plate current. This action continues from instant to instant. If R_p is adjusted so no sound is heard in the phones (no current change), we may assume that the amplified grid voltage ($\mu \times e_g$, where e_g is the voltage across the 10 ohm resistor) is balanced by the plate A.C. voltage (e_p or the voltage across R_p). Obviously the current I through R_p and the 10 ohm resistance are the same so that if $\mu e_g = e_p$, and $e_g = 10I$ and $e_p = R_pI$, then $\mu \times 10I = R_pI$. By algebra the current I may be cancelled from both sides of the simple equation and

$$\mu = R_p/10$$

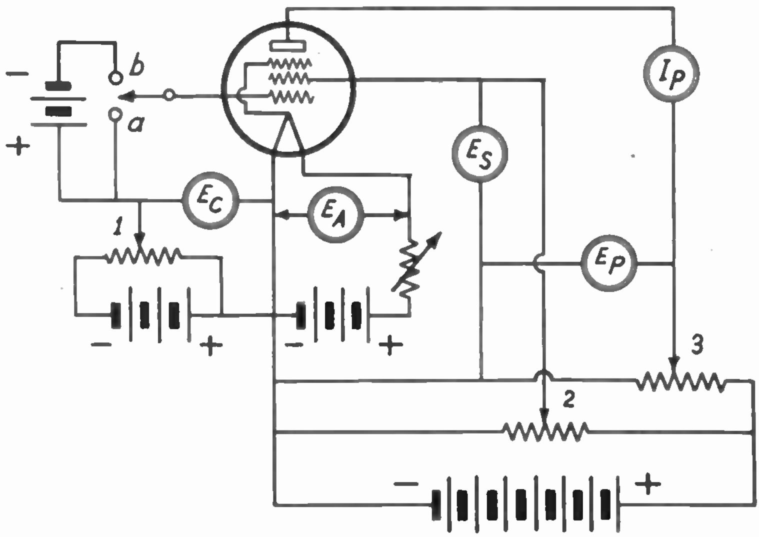


Fig. 5a

If a value other than 10 ohms is used, and this reduces the simplicity of the test, μ will be R_p/R_G where R_G is the ohmic value of the grid resistor employed. The value obtained is the dynamic amplification factor.

Mutual Conductance (g_m), often called transconductance * (s_m), may be measured in a number of ways. From a service viewpoint, it is the most important tube factor, as it establishes the merit of the tube. From our study of tubes we know that g_m, the mutual conductance, may be defined as the change in

* Transconductance is gradually being accepted as the correct term as it implies the effect of the grid on the output.

plate current divided by the change in grid voltage, which suggests a simple way of measuring the g_m of a tube.

To measure the static g_m value of a tube, connect the tube to be tested into a tube circuit operating all electrodes at rated or desired potentials. Figure 5a shows a connection for a filament type pentode. In this case E_A, E_C, E_S and E_P are adjusted by regulating the filament circuit rheostat and potentiometers *1*, *2* and *3*. The C bias is shifted by means of a battery in series with the control grid as indicated. If a 3 volt grid shift battery is used, the milliampere change in I_p divided by 3 multiplied by 1,000 is the static g_m of the tube in micromhos. This test is called the *grid shift* method used extensively in service tube checkers.

Figure 5b illustrates a more precise method of measuring transconductance, in that the plate current change is read

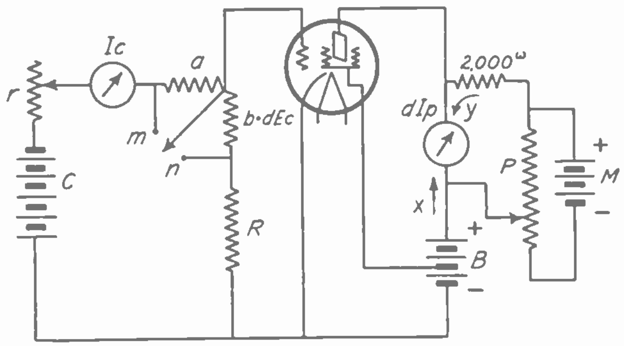


FIG. 5b

directly. Details in the control of the operating voltages are omitted for the sake of simplicity. The grid bias voltage placed on the tube is the voltage drop in the two resistors *R* and *b* in series—*a* is shorted. Battery C causes current to flow through these resistances. The amount of C current flowing is controlled by the rheostat *r* and measured by the milliammeter I_c. If the current I_c is 10 millamperes and a C voltage of 3 volts is desired, then the resistance of *R* and *b* in series should equal 300 ohms. Now suppose we want to change the grid bias by .1 of a volt—we should make *b* equal to 10 ohms and *R* equal to 290 ohms. Resistor *a*, which is shorted, should also be 10 ohms. With grid shift switch on *m*, the rheostat is adjusted to 10 ma; switch from position *m* to *n*. As the resistance in the grid supply circuit has not changed, I_c remains at 10 ma, but the net grid voltage has dropped to −2.9 volts.

The next part of the problem is to measure the change of plate current accurately. This can be done by using an accurate microammeter at dI_p. A battery is provided so that the sensitive meter is not overloaded. Notice that the battery M sends a current, in the direction y, opposite to the plate current (direction x), due to the B battery, so that if the potentiometer P is adjusted correctly the two can be made to cancel each other exactly.

So, with the switch on m we balance out the plate current; next, throwing the switch to n, the plate current through the tube is changed and we read the change on the meter dI_p. Since this is a microammeter we read directly the microampere plate current *change* for a grid shift of 0.1 volt. Suppose we find the

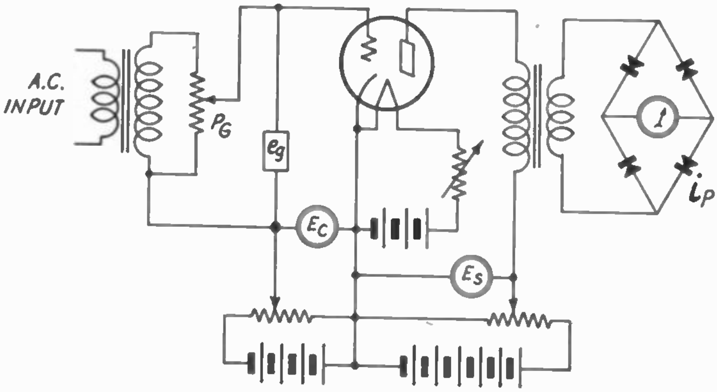


FIG. 5c

change of plate current is 100 microamperes, then the mutual conductance is:

$$g_m = \frac{100}{.1} = 1000 \text{ micromhos.*}$$

Note the convenience of using a 1/10th volt change on the grid; we simply take the change of plate current in microamperes and multiply by 10.

With a few changes the circuit shown in Fig. 5a may be quickly adapted to measure the dynamic transconductance. All that is needed is a low known A.C. grid voltage and an A.C. plate current meter. Figure 5c shows a heater type triode connected in a typical circuit. The A.C. input may be a step-down transformer connected to the A.C. power mains, its output voltage

* If the plate current change is read in milliamperes, the quotient should be multiplied by 1,000 to get g_m in micromhos.

controlled by a potentiometer and the voltage measured with copper oxide rectifier type A.C. voltmeter. A copper oxide A.C. milliammeter is connected into the plate circuit through a 1 to 1 low frequency audio type transformer. In this way the D.C. component is prevented from going through the meter and the A.C. current only is indicated. Instead, an electro-dynamometer milliammeter may be connected directly in the plate circuit, or a choke-condenser output system with any of the magnetic vane or copper oxide current meters may be used, but the choke and condensers must have high electrical values.

After the operating voltages are regulated to the desired values, the grid excitation e_g and the plate current i_p (milliamperes) are recorded. The dynamic transconductance is computed with the following relationship:

$$g_m = \frac{i_p}{e_g} \times 1{,}000 \text{ micromhos}$$

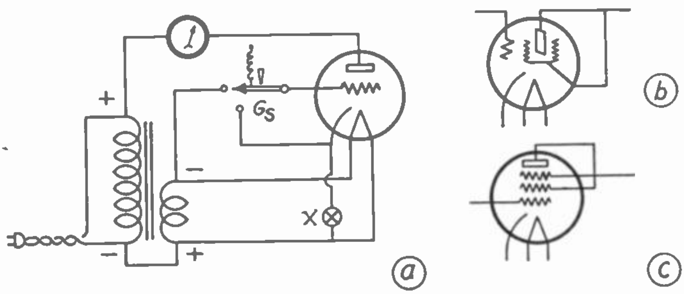


Fig. 6

Where the g_m sought for is to be used in stage design, the value of e_g should equal the excitation eventually to be used. For test purposes e_g may well be 1 volt, in which case, g_m will be 1,000 times the plate current in milliamperes. The circuit shown in Fig. 5c is the basis of most direct reading mutual conductance meters, the practical tester merely incorporating special switches and a power supply to properly connect the tube under test.

Judging from the type and number of practical tube checkers on the market, built especially for bench and counter needs, it is not necessary to go to such details as indicated in Figs. 5a, b and c. Tube checkers should be simple to operate, requiring little change-over and easy to read. The grid shift circuit modified for all A.C. operation is considered the most practical way of testing tubes at the present time, and is basically shown by Fig. 6a. The plate-cathode voltage is the self-rectified line voltage; the filament is A.C. heated through a step-down transformer and the grid is shifted from plate return and some low A.C. voltage. A shift in average plate current will be read. Observe that the G_s (grid shift) switch is spring controlled which normally keeps the grid at some average negative voltage. In preventing the grid from being at zero bias except on test, destruction of the emitter is prevented.

Ordinary tube checkers make no attempt to test tubes as specifically designed. It is felt that tubes that have no shorted electrodes may well be tested for serviceability by testing them as triodes. Figures 6b and 6c show how tetrodes and pentodes would normally be reconnected for test as triodes. All such tests are only comparative and it is necessary to determine in advance by trying good tubes what the minimum acceptable plate current change should be.

Dynamic Plate Resistance. Knowing the dynamic mutual conductance and the dynamic amplification factor, the A.C. plate resistance may always be computed using the important equation.

$$r_p = \frac{\mu}{g_m} \times 1{,}000{,}000 \text{ ohms}$$

Where g_m is in micromhos. For example, for a 2A3 tube $\mu = 4.2$ and $g_m = 5250$ micromhos. Hence $r_p = 4{,}200{,}000 \div 5250 = 800$ ohms.

The dynamic resistance may be measured directly in a balancing circuit like the one shown in Fig. 4a but slightly modified. Figure 7, the modified balancing circuit, will also measure μ. Without going into the theory of the method, we will describe how it operates. The tube and generator are in operation. First we leave switch S open and close switch K, thus short-circuiting the left-hand resistance R_g. On adjusting R_p to obtain a minimum tone in the phones, we have as before $\mu = \frac{R_p}{R_g}$.

Next without changing R_p or R_g, open switch K, doubling R_g. Also close switch S. A note will be heard in the phones, and by adjusting the resistance R this can again be reduced to a minimum. When this occurs, we have the simple relation that r_p, the dynamic plate A.C. resistance, equals R directly. By making the two R_g's equal to exactly 10 ohms, we have a very simple arrangement. On the first adjustment the μ is equal to 1/10th the setting of R_p, and on the second adjustment, r_p, is equal to R.

Power Output: A power output test is by far the best indication of the serviceability of a tube. The circuit used would be similar to Fig. 5c, except for the insertion of a load resistance R_L in the plate circuit. If an electrodynamometer type milliammeter is used, it should be in series with the load resistor with its resistance included in the load. In choosing a load for power tubes, use the recommended load value for minimum distortion and maximum output. For voltage amplifiers use the average value used for such tubes. With power tubes you will get an output value for direct comparison with tube table values if you use a grid excitation slightly less than the C bias divided by 1.41. Voltage amplifier tubes can only be checked on a comparison basis. The power output in both cases will be $I^2_{AC} \times R_L$, where I_{AC} is the A.C. plate current.

Gas or Vacuum Tests: Even the best high vacuum tubes have gas (air) inside the envelope. The amount of gas has a con-

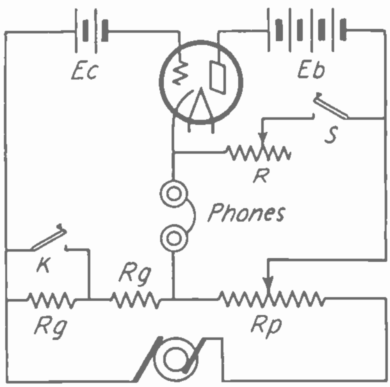


Fig. 7

siderable influence on the tube behavior and most tubes are highly evacuated to get uniform characteristics. Although this gas may be low enough to prevent eccentric performance, the presence of more than an acceptable amount of gas will affect the life of the tube, since the presence of an appreciable amount creates gas ions which are heavy, bombard the cathode and wear it out.

Tubes used in amplifying stages where a grid resistor input is employed must have a very low gas content, or the grid resistor must have a low ohmic value. This results in reduced power output and amplification. A.V.C. controlled tubes must have low gas content to prevent nullifying the A.V.C. action, usually indicated by a creeping up of volume. All tubes used in circuits where there is a high resistance input, must have a low gas content, otherwise the positive potential across the grid input resistor will decrease the C bias, raise the plate current and further wear out the emitter.

Knowing the amount of current flowing to or from the grid of a tube will help us to interpret what is going on in the tube, as well as provide us with a measure of the residual gas in the tube. Grid current may arise from the following causes:

1. Presence of gas in the tube resulting in a gas current.

2. Net positive bias on the grid resulting in a grid convection current.

3. Secondary emission from the grid resulting in a secondary emission current.

4. Conductive leakage between grid and other electrodes resulting in a leakage current.

As it is possible that the grid currents just mentioned may flow to or from the grid let us consider the exact directions of flow. Since we always connect our meter outside the tube, we will refer to the direction of flow of the current outside the tube. For example, current flowing away from the grid into the outside circuit will be called "current away from the grid." * Current flowing into the grid from the outside circuit will be called "current to the grid." These directions are indicated in Fig. 8, where we have also shown the proper connections for the grid current meter in each of the first three cases. The plus and minus signs indicate the polarity markings on the meter.

We can eliminate the fourth item very quickly by pointing out the fact that in modern tubes there is practically no leakage current. Whenever there is a leakage current in a tube, this is sure evidence that the tube is not worth using. The current is due to the establishment of a conductive path between the grid and plate, or between the grid and cathode, or between plate and cathode, by the deposit of dirt or some chemical on the press (the solid glass part that holds the leads and supports the electrodes) of the tube inside the glass envelope. In general, if there is a leakage current at all, it can be detected even when the tube is cold, by applying a voltage from a battery between the grid and plate and noting whether current flows by means of a sensitive microammeter or galvanometer. However, since leakage currents are quite rare we will not consider them further.

We should mention at this point that leakage resistance between the cathode and heater is considered serious in tubes used

* Remember that electrons flow in the opposite direction.

in A.V.C. circuits or in circuits where the cathode must be electrically isolated from the filament circuit. For this reason modern heater type tubes use a special ceramic heat conducting electrical insulator between heater and cathode. Several tube and counter checkers incorporate a cathode leakage test. Such test must be made with the cathode hot.

An ohmmeter may be connected between the cathode and filament if the exact amount of leakage resistance is desired. In a practical tester an indication of leakage is sufficient. Referring to Fig. 6a, normally with the grid shift switch as shown, the plate current will be low. If the cathode to common return wire is open at *X*, the rectified current should drop to zero if there is no leakage between the cathode and filament. The smaller the leakage resistance the nearer will the needle return the original value.

When gas is present in a tube, if we place a voltage between

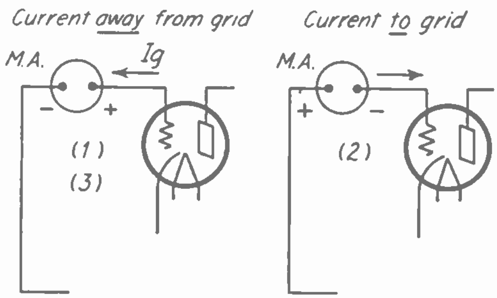


FIG. 8

the plate and cathode, the gas will be ionized. That is, the gas molecules are split into positive ions and electrons. The electrons are attracted to the plate by the positive charge of the B battery, and being extremely light in weight they travel very rapidly.

On the other hand, the positive ions of the gas are relatively heavy; being positive, they are attracted by the negative charge placed on the grid by the C battery. The motion of positive ions in a gas constitutes a flow of electric current in the same direction (opposite to direction of electron flow) so we have the equivalent of a current flowing to the grid inside the tube, or away from the grid outside the tube. Current meters are always marked so that the current enters at the + terminal and leaves at the — terminal and thus read up scale, so obviously we must connect the plus terminal of the meter to the grid in order to detect the gas current.

Now we will consider the grid convection current. If we reverse the C battery, making the grid positive, it is clear that the grid will act like the plate; it will attract to it electrons. It will "rob" the plate of some of the electrons coming from the cathode that ought to go to the plate.

Now, you must remember that the direction of flow of electrons is opposite to that of the flow of current. Electrons move to the grid (inside the tube) so we have the effect of positive current moving toward the grid (outside the tube), so the positive terminal of the meter is connected away from the grid, when we measure grid convection current.

Now we come to the last—the secondary emission current from the grid. Remember that the grid is placed *between* the plate and cathode, so that some of the electrons passing from the cathode to the plate, attracted there by the positive charge from the B battery, may strike the meshes of the grid. If, as happens under some conditions in screen grid tubes, these electrons strike the meshes of the grid with sufficient force, they may cause such a disturbance at the surface of the grid wire as to knock out of the wire, electrons which were held there by the negative charge of the C battery. These electrons may bounce around and finally end up at the plate where they should have gone in the first place.

But sometimes the electrons strike the grid so hard that more electrons are knocked out of the grid than travel to it from the cathode In other words, the net effect is that the grid *loses* electrons. This means a flow of electrons from the grid (inside the tube) or a flow of current away from the grid (outside the tube) which is our secondary emission current. The meter is connected when we measure the secondary emission current from the grid with + terminal to the grid. Note that this current is in the same direction as the gas current.

Let us sum up:

	(outside of tube)
Gas current	away from grid (—)
Secondary emission current..	away from grid (—)
Convection current	toward grid (+)

We have indicated a current toward the grid as positive and currents away from the grid negative. When we place a microammeter in the grid of a tube we measure the *sum* of these three currents, assuming that all three are present.

We cannot separate the two negative currents—i.e., the gas current and secondary emission current—because they flow in the same direction, but we can measure the gas current by itself by making the other two currents equal to zero. For example, suppose we gradually and steadily increase the grid (negative) bias supplied by the C battery. The plate current is cut down, which means that few electrons pass toward the grid on their way to the plate. As a consequence, since secondary emission current requires that electrons strike the grid, if the electron stream is cut to zero, the secondary emission current must also be cut to zero.

At the same time, since the grid is very negative it repels electrons which may travel toward it, so that the convection cur-

Weston Model 661 Portable Tube Checker extensively used by servicemen. Sufficient sockets are incorporated to reduce commonly used radio tubes to triodes and diodes.

Weston Model 674 Counter Tube Checker, employing a group of sockets for similar tubes, a combination switch gear and plate voltage selector and a filament voltage selector. This checker has an "english" reading scale and has incorporated a cathode leakage test.

rent is likewise cut to zero. So we have left only the gas current. As the bias is increased the gas current (providing there is gas in the tube) gradually increases to a maximum, whereupon further increase of bias produces no increase of gas current. The maximum gas current so obtained is a measure of the amount of gas in the tube. The greater the gas current the greater is the quantity of gas present.

However, there is another effect that is quite often neglected, but which is of considerable importance in modern screen grid tubes. We have mentioned above that in order to produce a convection current it is necessary for the grid to be positive in order to attract to itself electrons. This is not exactly true, for it is found that in some tubes, as, for example, the '27 and '24 tubes, a convection current (positive current) can flow as indicated in Fig. 9 even when there is a negative bias of 1 volt on the grid.

This is because we have, within the tube itself, a positive voltage on the grid which is called the contact potential.* In some tubes this contact potential may be as high as 1 volt, so that when we place a bias voltage of —1 on the grid, the net result may be zero. If the bias is reduced to —0.9 volt, we would then have a net grid potential of +1—0.9 or +0.1 volt, and a convection current would flow.

Figure 9 shows the grid current-grid voltage curve of a

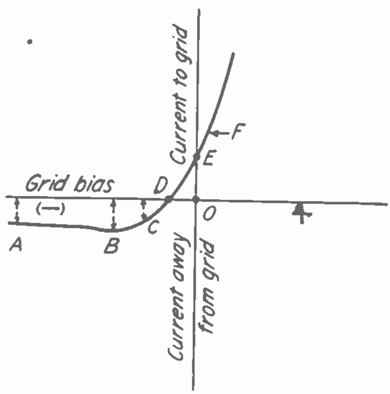


Fig. 9

gassy tube. With the negative grid bias large the current is away from the grid, and has a value of A and is the gas current. As we decrease the grid bias secondary emission current begins to flow because we are letting electrons pass from the cathode to the plate. This secondary emission current adds to the gas current, because it is in the same direction, producing the small "bump" at *B* (Fig. 9).

On further reducing the grid bias we begin to notice the effect of the contact potential of the tube. Furthermore, the grid is no longer sufficiently negative to attract all the gas ions. Consequently the current away from the grid decreases, as at *C*, until at *D* it is actually zero, although we still have the biasing voltage *DO* on the grid.

Of course, if we go further we are permitting the net grid

* For example the contact between the press lead and the grid will create a contact potential.

bias to become positive, so at the point D the current reverses, now flowing to the grid, and steadily increases as the net grid becomes more and more positive.

The presence of gas in power tubes is often identified by a haze (glow of ionization) between the cathode and plate. This, of course, is a case of excessive gas content. Except in mercury vapor tubes (rectifiers), the presence of a haze indicates a defective tube.

The gas content or for that matter the degree of vacuum, may be compared in a questionable tube by comparing it with a good tube in the circuit shown in Fig. 10a. The control grid alone is connected to the cathode with a milliammeter in series, with the grid at a +20 volt potential. This is sufficient to set up a space current, I_1, drawing enough electrons to the grid to create

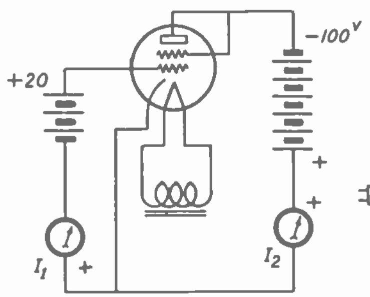


Fig. 10a

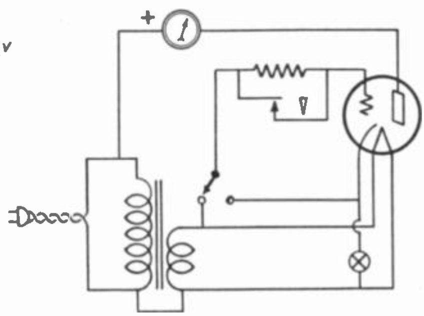


Fig. 10b

gas ionization. The plate and other electrodes are connected together and connected to the cathode through a microammeter, placing the plate at a —100 volt potential. The heavy + ions are attracted to the plate and we may measure the ionization current I_2 in the plate circuit. The value of $I_1 \div I_2$ is an indication of the gas content. The larger the value the better the vacuum or what is the same thing, the less the gas content. The acceptable ratio for a given tube can be determined by measuring a similar type high vacuum tube.

For practical service work it is merely necessary to indicate the presence of gas. A simple gas test will suffice. With a slight addition, the circuit shown in Fig. 6a may be made to indicate the presence of gas. If a one megohm resistor is placed in series with the grid, Fig. 10b, the presence of a gas current will create a drop in the resistor, the grid end being more positive than the end to the cathode. The negative bias is reduced and the plate current increases. In service tube testers the grid resistor is normally shorted by a toggle or push button switch. After the normal plate current is read using the maximum C bias, the resistor shorting switch is opened. A gas test of this type may easily be added to tube testers where the gas test is omitted. Figure 10b is a fundamental A.C. operated tube tester having all the important tests except short checking. The important tests for a heater tube are: short, mutual conductance, gas and cathode leakage tests.

Tube Capacity Measurements: The grid to plate, plate to cathode and grid to cathode electrode capacities play an important part in circuit design, especially with feed back, neutralization and high frequency amplification problems. Tube manufacturers give the average capacities, but in design it is important to include the set socket and wiring.

After a little thought you will realize that it would be impossible to connect the grid and plate into a capacity bridge and measure for example the C_{gp}, for you would have the C_{gk} in series with C_{kp} shunting it. This difficulty may be removed by using the bridge circuit shown in Fig. 11. A convenient ratio of R_2 to R_1 is chosen, R_2 may well be 100 times larger than R_1. C, a standard calibrated condenser, is adjusted for balance and then R for complete balance, again adjusting C if necessary. At balance.

$$C_{gp} = C\frac{R_2}{R_1}$$

The other tube capacities may be measured by placing that tube capacity in position *1* of Fig. 11.

ESSENTIALS OF A PRACTICAL TUBE CHECKER

Practical tube checkers are essential equipment and one should be available either at the shop service bench or sales counter. The one used at the sales counter should preferably be direct reading, that is, the needle should read *bad, good* or *gassy*. English reading tube checkers convince the customer. Because the salesman or store clerk is generally not capable of handling switching systems that require technical knowledge they should be easily operated. This is not necessary for the tester used at the shop bench or on a service call. At the bench, the serviceman may convince himself, even though a complicated "switching gear" is used, provided he has faith in the testing procedure. The same is true if the tube checker is taken on a service call, for then the doubtful tube may be demonstrated as defective to the customer by the signal generator-output meter comparison method.

Tube checkers are made in a large number of ways and it would be a long and really unnecessary procedure to discuss all types. Once the general scheme is mastered, it will be easy to learn how other systems work, if a diagram is provided with the device. In general, all tube checkers contain a simple short check, an emission test for diodes, and a grid-shift check. For simplicity all multigrid tubes are reduced to triodes by some internal or external connecting or switching system. A number of tube checkers will contain a cathode leakage and gas test. In order to grasp the general scheme of tube checkers, we will study the evolution of an obsolescent proof tester.

As all tubes are reduced to triodes or diodes we will start with the simplest of tubes. Figure 12 shows a filament and cathode heater type of triode and full wave diode, symbolically drawn. For the present we will assume that they all require the same filament voltage. A step-down socket power transformer

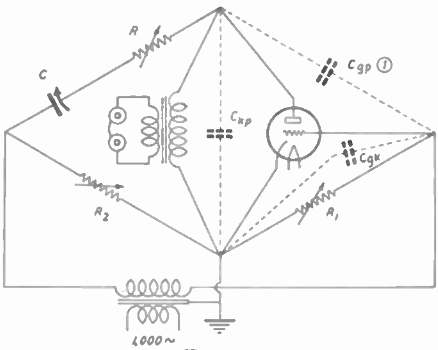


Fig. 11

is needed to get the required filament voltage. The secondary has as extension coil and its end terminal will be used to supply the C bias. Note that the plates of all tubes connect to one side of the power line. The secondary is so connected to the grid, that when a positive potential is fed to the plate a negative potential connects to the grid. When the plate is negative the grid is positive, but this will not defeat the method of connection for no plate current can flow if the plate is negative. Let us see how the circuit in Fig. 12 behaves.

Switch S_6 is first placed on the *short* position. If the plate is shorted to the cathode or to the grid, a current will flow through resistor R_4 and the pilot lamp. Resistor R_4 is chosen so that the current through the pilot lamp, if there is a short, is limited to a value to give normal brilliancy. Should the lamp light, we may assume shorted tube elements and the tube is defective. We would next place switch S_6 on the *regular* position. R_4 and the pilot lamp are no longer in the test circuit.

In this position the plate current is determined by the average plate and grid voltage. The plate voltage will be less than 110 volts, but the grid voltage may be made any value by choosing a suitable secondary tap. Usually it is a voltage that will give a sufficiently low plate current in tubes requiring a high bias. If the plate current is very low, push-button S_3 is pressed, releasing the shunt R_3 and increasing the sensitivity of the D.C. plate current meter *I* D.C. If the tube is a triode the reading of the meter is carefully noted and push-button S_1 is pressed. The last procedure changes the C bias to zero or a very low value. Naturally, as the plate voltage has not changed, the plate current will increase. The new reading of the meter *I* D.C. is noted and the difference in readings evaluated by subtraction. If S_3 is pressed for one reading it should be pressed for the second reading. Generally the shunt changes the meter from a 0–5 to 0–50 milliampere range. This current difference has no meaning unless you know what it should be for a good tube. This is the information you must get if you build your own tester, or the information supplied by the tube checker maker and by actually testing with a tube that has been verified as good by laboratory tube testing methods.

Although we may have established the fact that a triode has satisfactory emission control (acceptable g_m), our tests are not complete. Pressing S_2 introduces a one megohm resistor R_2 into the control grid circuit. From our study we know that gas is present if the plate meter reading increases in value. Leakage between cathode and heater is checked by pressing push-button S_5. Leakage exists if the meter reads. In both the gas and leakage tests S_3 may be pressed for greater sensitivity.

Checking rectifier tubes is somewhat simpler and consists of a plate to cathode short check, an emission test and a cathode leakage test. Place S_6 on *short* for an element short test; and press S_4 for a possible short in the second plate; place S_6 on *regular* for emission test, pressing S_3 if necessary; press S_4 for a second emission test for double diodes; and press S_5 for cathode leakage test if the rectifier is of that type.

Now let us consider a more practical tube checker for testing all four and five prong triode and diode tubes. Figure 13a illustrates a more practical checker. Only a four and five prong socket is used and diodes or triodes are placed in the socket corresponding to their number of prongs. All switches and push-buttons are identical in design and are used as described for Fig.

EVOLUTION OF AN OBSOLESCENT PROOF TUBE CHECKER

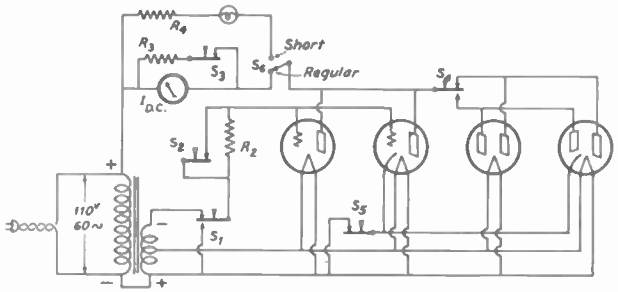


Fig. 12

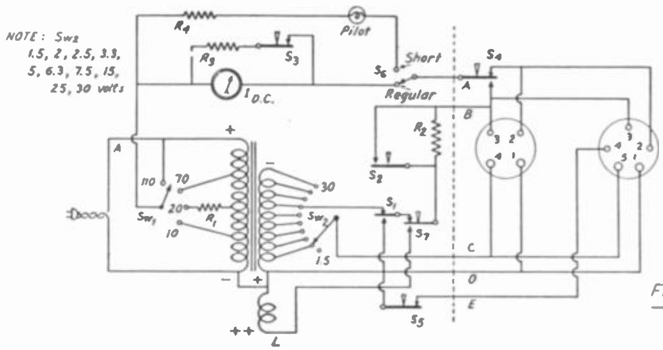


Fig. 13a

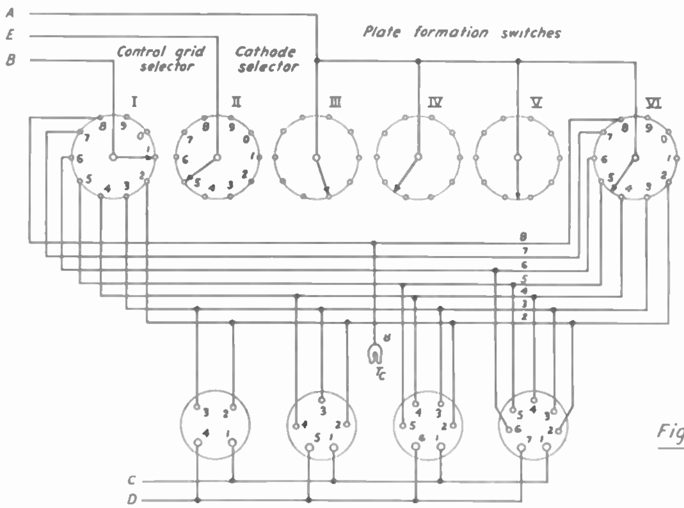


Fig 13b

12 except that push-button S_7 and coil L have been added to check class B tubes. Note that S_7 switches the grid from a high negative to a normal positive grid potential, a condition essential in testing class B tubes. In testing for shorts in triodes, press S_4 to determine if the grid is shorted to the cathode.

Diodes may be of the high vacuum type requiring a large plate voltage; gas filled (mercury vapor) requiring a low plate voltage or R.F. rectifiers (detectors) requiring very low plate voltage. To meet this need a variable voltage switch S_{w1} is needed and is connected as shown. Mercury vapor tubes may draw considerable current, so a limiting resistor R_1 (Fig. 13a) is included. If a high plate voltage is needed, line A from the power supply may be connected to some intermediate point of the primary, thus making the primary also act as a step-up auto-transformer. In the latter case it is wise to include a line rheostat (about 300 ohms) to take care of line voltage variation. A line A.C. voltmeter connected across the primary may be used to adjust the output of the transformer to a definite value regardless of the line voltage at the time of test.

Not all diodes and triodes work at the same filament voltage, so a variable secondary voltage is needed and provided by switch selector S_{w2}. Therefore, to test any four or five prong diode the information which should be given before testing a given tube in Fig. 13A is: position of S_{w1}, position of S_{w2}, allowable emission current, and whether S_3 should be pressed. For a triode the information that will differ is that instead of the allowable emission the allowable current change must be given.

Figure 13a has been drawn so that all supply voltages switching systems, and all test switches are on the left, except S_4. Observe that there are five leads, C and D the heater leads, B the control grid lead, E the cathode lead and A the plate lead. We know that all multigrid tubes must be reduced to triodes or pairs of triodes, if they are to be tested in a practical tube checker of this type. One way of doing this is to group tubes of similar internal and prong connection structures and provide a separate socket for them. The only difference will then be in the required plate and filament voltage and the allowable plate current change. A table of information is then provided. For example, a single socket will do for '00A, '01A, '10, '12A, '20, '26, '30, '31, '45, '50, '71A, X99,* 182B, 183, 864, 2A3; another socket for 2A5, '18, '41, '42, '43; another socket for '33, '47, 6A4, LA tubes; another

* To test a U99 tube, an electrode switching adapter will be required—NA-ALD No. 429.

socket for 80, 83, 82, 5Z3 tubes; etc. At each socket the plate would be connected to all grids except the control grid thus converting the tube inserted into that socket to a triode. In some cases tubes that do not have the same internal construction may be tested in one of the other groups, thus reducing the number of sockets required. The only trouble with such an arrangement, is that the appearance of a new tube may make it impossible to check it in a socket already provided. Such checkers provide spare socket holes for future adaptions. In spite of possible obsolescence, a system of this type is highly recommended for counter tube checkers as the problem of electrode switching is eliminated.

With only a four, five, six and combination small and large seven prong socket and a "switch gear" it is possible to test any tube as a diode or triode. This applies to present and future tubes provided the heater terminal position is not changed and eight and nine prong tubes are not made. Figure 13b is a suitable switch gear.

All sockets are numbered as per the latest R.M.A. or Weston standard, meaning that the table of tubes with prong (pin) numbers and the connected electrodes may be used as a guide. Number *8* is used for T_c, the top cap. The filament prong terminals are connected in parallel and to leads *C* and *D*. Six rotary switches having ten contacts each are required. Switches with ten contacts are used as they are easily obtained from wholesale mail order radio houses together with an etched plate giving the positions. Connections *2, 3, 4, 5, 6, 7* and *8* at the sockets are connected to corresponding positions on all six selector switches. Note that positions *1, 9,* and *10* are blank. Contact 9 may be used in the advent of an eight prong tube and *10* or *0* must be blank. Any selector can make contact to any electrode except heaters.

Switch I selects the control grid which goes to lead *B* of Fig. 13b; switch II selects the cathode which goes to lead *E*; switches III, IV, V and VI contact all other electrodes and as many as four of them may be connected together leading to line *A* as shown. Switch II is always placed on *O* for filament type tubes; switch I on *O* for diodes; switches IV, V and VI on *O* for triodes and diodes; switches V and VI are placed on *O* for tetrodes, etc. The general scheme is easily carried out by following an R.M.A. tube-numerical prong or socket identification chart. If you build such a tester it is best to construct a chart; if the checker is a commercial product the maker will provide such a chart. The following will illustrate the point:

Tube	PLACE										
	Sw_1	Sw_2	I	II	III	IV	V	VI	$I_{D.C.}$	Change in $I_{D.C.}$	Press S_3
26	110	1.5	3	0	2	0	0	0	—	---	√
56	110	2.5	3	4	2	0	0	0	—	---	√
22	110	3.3	8	0	2	3	0	0	—	---	√
24	110	2.5	8	4	2	3	0	0	—	---	√
47	110	2.5	3	0	2	4	0	0	—	---	
80	110	5.0	0	0	2-3	0	0	0	---	—	
81	110	7.5	0	0	2	0	0	0	---	—	
83	20	5.0	0	0	2-3	0	0	0	---	—	
25Z5	110	25.0	0	3 4	2 5	0	0	0	---	—	
55-T	110	2.5	8	5	2	0	0	0	—	---	√
55-D	10	2.5	0	5	3-4	0	0	0	---	—	√

This table shows how triodes ('26, '56) are tested, how tetrodes ('24) and pentodes ('47) are reduced to triodes, how both plates of double diodes ('80, 83, 25Z5) are tested for emission, and how double purpose tubes, for example, a duo diode-triode (55) are first tested as a triode (55-T) and then as a double diode (55-D). Other information given here is only hypothetical, as it is given to illustrate the point, although (—) indicates that this test is not essential, (---) indicates some value must be given and √ indicates that a sensitive current meter is necessary. The short test on this tester is not as thorough as the one shown in Fig. 1, as it cannot indicate shorts between electrodes tied together.

A noise test for tubes due to loose elements, irregular emission, poor internal or prong connections has been omitted from this practical tester. A noisy tube is easily identified in the chassis while the receiver is in operation. No noise test would be authentic unless it duplicated actual dynamic condition—realized by trying the questionable tube in a receiver.

No constructional detail is given as the tester described is purely for instruction purposes. However, sufficient information is given for an experienced serviceman to make or remodel a tube checker.

The switch gear described is similar to the one used in the Supreme Model 45 tube checker. Other manufacturers are willing to sacrifice the advantage of an obsolescent proof device and thereby simplify the switching systems.

TEST QUESTIONS

Be sure to number your Answer Sheet 42RH.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another set ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your Course, and the best possible lesson service.

1. What might cause grid current to flow even though the grid is properly biased?

2. Define mutual conductance.

3. In practical tube checkers what test is always made first?

4. What fundamental test is made to determine the serviceability of a rectifier tube?

5. What are the four important tests made in practical tube checkers when checking an indirectly heated cathode triode?

6. Draw a fundamental A.C. operated tube tester to test a '27 tube, which will make the important tests except the short check.

7. What value would the 0—0.5 ampere meter read if a screen grid filament tube ('22) were placed in the short checker shown in Fig. 1, and the control grid were shorted to the filament?

8. Explain briefly what would happen to the emission of a gassy tube if it were used in an audio amplifier stage, where the input coupling was of the resistance-capacitance type.

9. What is the purpose of the switching gear shown in Fig. 13b?

10. What three methods are used by servicemen to check tubes?

1. Secondary emission at the grid and gas ionization due to insufficient vacuum.

2. Mutual conductance (g_m) is the change in plate current divided by the change in grid voltage.

3. Check for shorted tube elements.

4. Emission test.

5. 1, Short test; 2, grid shift or mutual conductance test; 3, gas test; and 4, cathode leakage test.

6. See Fig. 10b.

7. $I = \frac{110}{250} = .44$ ampere or practically full scale reading.

8. Gas ionization would bombard the cathode, destroying the emitter, and the positive C bias produced by the input resistor would cause a large plate current, helping to destroy the emitter.

9. To permit the operator to change any multi-grid tube to a diode or triode, essential for a simple checker.

10. The tube checker, the grid shift test incorporated in set analyzers and the service oscillator-output meter comparison methods.

SERVICING SOUND REPRODUCERS AND PICKUPS

43RH

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

"You are just as big as the things you do, just as small as the things you leave undone. The size of your life is the scale of your thinking."—*Woodrow Wilson.*

"Resolve to be Self Independence thyself; and know, that he who finds himself, loses his misery." —*Coventry Kearsey Deighton Patmore.*

NATIONAL RADIO INSTITUTE

WASHINGTON, D. C.

1942 Edition

A LESSON TEXT OF THE N. R. I. COURSE
WHICH TRAINS YOU TO BECOME A
RADIOTRICIAN & TELETRICIAN
(REGISTERED U. S. PATENT OFFICE) (REGISTERED U. S. PATENT OFFICE)

NCP2M242 Printed in U. S. A.

Servicing Sound Reproducers and Pickups

INTRODUCTION

No one should attempt to repair or adjust a microphone, phonograph pickup, loudspeaker, in fact, any device until he is well versed in the theory and operation of the defective instrument. Not knowing the whys and wherefores of the inoperative device may easily lead to a worse defect, often making it unrepairable. Knowing the principle of operation, having acquired a reasonable amount of mechanical ability through experience and with the aid of the following instructions on the repair and maintenance of sound devices, you will be in a better position to service them intelligently.

As you acquire experience, repairing special devices will become a routine matter. However, new devices should be carefully analyzed before attempting repairs. The mechanism and the theory of operation should be carefully considered. Always make a practice of studying new reproducers as they appear on the market.

We will consider here only the service angle of sound pickup and reproducing devices. Elsewhere in the Course, you will study the theory of their operation.

MAGNETIC LOUDSPEAKER UNITS

In this class we should consider the magnetic unit where the diaphragm is directly actuated by magnetic attraction and repulsion, the unit where the action is transmitted to the diaphragm or cone by means of a lever mechanism. The phone, the iron diaphragm loudspeaker unit, the balanced armature magnetic unit, and the inductor dynamic unit should be considered in this classification.

The proper tests to be conducted on a magnetic unit are divided as follows:

Continuity test.
Resistance of windings.
Clearance between diaphragm (or armature) and poles.
Magnetic pull or strength.
Tests for grounds.
Testing cords.

Continuity Tests: An open in the unit may be traced to any portion of the electrical circuit. Any continuity device such as the battery and lamp, battery and phones or ohmmeter may be used. The battery and lamp is not recommended as it may send too much current through the unit, demagnetizing the permanent magnet or actually creating an open by melting the fine wires.

A flashlight battery and phone may be used if the sounds heard are carefully interpreted. In testing a winding of many thousands of turns, a slight click may be heard in the headphone and yet the winding may be broken. This is due to the high self-capacitance of the winding, and, in such a case, a click is heard only when first applying the pin tips to the winding under test. After the first capacitive charge of the winding, no further clicks will be heard. Experience will make it possible for you to determine whether a capacitive charge or good continuity is responsible for the click in the magnetic unit.

A reliable direct reading ohmmeter is a common service instrument and should preferably be used in continuity testing. Not only can continuity be established but the resistance of windings simultaneously checked.

By the simple continuity test the winding or windings of the magnetic unit can easily be checked for broken wires. In the bi-polar type of unit there are two windings, and the continuity test will show which winding is defective. Also, in the balanced armature type of unit there are two windings, one on each side of the armature, and the test will readily show the defective winding.

If a winding is found to be opened, it does not necessarily indicate that it is beyond repair or that it must be sent back to the manufacturer for re-winding the bobbin or for a new bobbin. The fine wire used on a bobbin of a magnetic unit is generally attached to a heavy end lead, which is brought out and soldered to the terminals. By carefully taking out the bobbin, the open may be found to be in the output end lead, and repaired properly with a great deal of satisfaction to yourself and real "Service" to your client. However, if the open is in the middle of the bobbin, or the inside lead, then the bobbin will have to be unwound, the break repaired, and the same wire re-wound on the bobbin; or the unit returned to the manufacturer for complete repair.

Lack of continuity in magnetic units may be due to the following causes:

1. Open in one of the conductors in the cord.

This open may be in a poorly soldered connection of one of the conductors at the free end in the metal pin tips, or at the terminal end of the unit, or in the cord proper.

2. Poor or unsoldered connection at the terminals of the reproducing unit.

The leads from the bobbins of the magnetic unit terminate in soldered insulated binding posts. These leads sometimes become broken or unsoldered at these terminals.

3. Opens in the bobbin winding.

Since the bobbin winding consists of many thousands of turns, its wire size is very small, the diameter of which may be from only .002 to .004 of an inch. These fine wires often break, due to expansion and contraction from the effects of external atmospheric conditions. Crystallization and electrolysis* from the humidity of the surrounding atmosphere many times cause opens in bobbins. Electrolysis is particularly noticed at the soldered connection of the fine wire to the heavier end lead. In the early days of magnetic unit design and manufacture, soldered flux paste containing acid was used, and improper use of this flux caused bad breaks from electrolysis directly at the soldered connection of the end lead. Opens due to electrolysis are readily recognized by the green residue left at the break. This is why opens in bobbins of fine wires predominate in locations where the humidity is high, such as in the tropics, or in locations where a great amount of salt is in the air, such as on ships, and cities along the coastal fronts. Bobbins of such fine wires should be thoroughly impregnated in order to withstand any reaction from the surrounding atmosphere. Also, soldering paste containing acid should never be used in making connections of fine wires. Resin core solder is the only solder to use. This is not difficult when the surfaces are clean and the enamel on the wire properly removed.

The proper procedure in making a continuity test on a magnetic unit is to begin at the free end or pin tip end of the cord, and then, by a careful process of elimination, the open can be located.

Resistance of Windings is best measured with a reliable multirange ohmmeter. A D.C. Wheatstone bridge may be used. The resistance of the winding determines whether the winding

---

* Electrolysis is battery action where the copper is one electrode, iron, lead or tin the other in this case; the water vapor in the air with the acid flux at the contact is the electrolyte. The copper is usually eaten away in this localized action.

is in good condition. The correct value of the resistance can be obtained only from the manufacturer or testing a perfect duplicate. If the resistance is found to be appreciably lower than the value specified by the manufacturer, then it is an indication that some of the turns in the winding are short circuited, resulting in poor efficiency of the magnetic unit. The two windings of a bi-polar or balanced armature type of unit should measure equal resistance. If one winding has lower resistance than the other, it shows a defective winding and will cause an unbalancing of the magnetic pull upon the diaphragm or armature, resulting in poor performance of the unit. The resistance of the bi-polar type of magnetic units generally ranges from 1,000 to 1,500 ohms per unit, and 400 to 800 ohms per unit for balanced armature types.

Improper resistance of magnetic units is due to:

1. High resistance or extremely low resistance due to defective cord.

A high resistance, due to the cord, may be caused by a high resistance soldered connection in the cord conductors, or a partial open due to broken strands. The resistance measured under these conditions may range from several thousand ohms to many megohms.

Sometimes when measuring the resistance of such units a value of a fraction of an ohm or a few ohms is obtained. This is caused by some kind of a short circuit between the conductors of the cord, or the grounding of the conductors to the case.

2. High resistance due to improper soldering at the terminals in the unit of the reproducing unit.

3. High or low resistance due to defective bobbins.

High resistance in a bobbin is caused by a high resistance electrical contact in the bobbin due to a soldered connection, partially open from electrolysis, or oxidation in a spliced joint. A high resistance from a poor soldered connection is many times caused by a so-called "resin soldered connection." Improper use of resin core solder makes a "resin" joint instead of a good metallic electrical contact, causing a high resistance.

A low resistance bobbin is a good indication of shorted turns. Sometimes a whole layer, or several layers, may be shorted out, causing a weak response and poor performance of the unit. Shorted turns can only be accurately determined by measuring the inductance of the unit as a whole, or the bobbins individually. This is best done by using a suitable A.C. Inductance Bridge. If such inductance measurements are made, it is best that the diaphragm or cone be removed from the unit, for inductance measurements are made more difficult by these moving parts. Inductance measurements are generally made on an alternating current frequency of 800 to 1,000 cycles per second, and will vary from a fraction of a henry to several henries. As in the case of resistance, the inductance of the two bobbins of a bi-polar or balanced armature types of units should be the same. The inductance of magnetic units varies with the A.C. current, the amount of D.C. passing through the unit, and many other factors, so great care must be taken in making inductance measurements in order that the conditions are correct before definite conclusions can be drawn.

Improper clearance between diaphragm or armature and the poles of the magnetic unit may be evident by a rattle or a metallic vibrating sound when the unit is connected to an A.F. source. Also in testing, there may be no response, and yet in testing for continuity and resistance the unit is found to be entirely satisfactory. However, upon examination of the unit, the trouble may be found to be in the clearance between the diaphragm and poles of the bi-polar type of unit, or between the armature and poles of the balanced armature type. Rattles or metallic noises in magnetic units are primarily caused by the diaphragm or armature hitting the pole pieces. This may be caused by a number of things: dirt accumulating between diaphragm and pole pieces, rusting of the armature or pole pieces, poor seating of the diaphragm, fatigue* of diaphragm or armature, fatigue of spring or loose connecting rod in balanced armature type of units, loose laminations in pole pieces, or small defects in the design of the unit. The fatiguing of any parts freezes (permanently fastens) the diaphragm or armature against the pole pieces, resulting in no response. All the above defects can generally be remedied by carefully noting the particular trouble and repairing or replacing the defective part.

The magnetic strength of the permanent magnets is one of the most important factors in the performance of magnetic units. Weak magnets will mean a weak magnetic pull on the diaphragm or armature, resulting in weak reproducer response. In the bi-polar type of phone or magnetic horn units, the strength of the permanent magnets can be quite easily determined by taking the cap off the unit and noticing the strength at the pole tips by the pull on the magnetic diaphragm when the diaphragm is

* When steel or wire loses its spring action, it is said to have fatigue.

released from the poles. It will be found that permanent magnets of good strength hold the magnetic diaphragm against the pole pieces quite firmly, and it will take an appreciable pressure to release the diaphragm from the poles.

A spring balance (weighing scale), having a scale from 0 to 10 pounds, can be used in conjunction with a small disc of soft iron for testing the strength of magnets. The disc should be absolutely flat and should have a small stud fitted with a hole, attached to the center of one of the faces of the disc. The disc should be about one inch in diameter and 1/16 inch thick.

Place the disc centrally over both pole pieces of the unit to be tested. Loop a piece of stout string through the stud of the disc and attach it to the hook of the spring balance as shown in Fig. 1. Exert a steady pull carefully along a line perpendicular to the face of the disc until the magnet lets go.

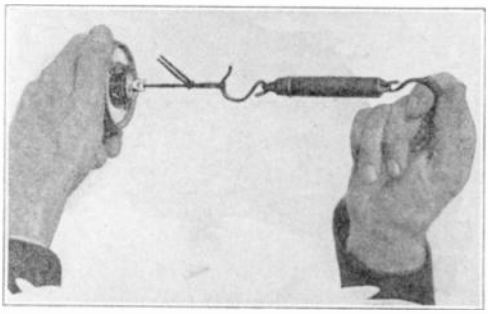


FIG. 1

The exact force required to separate the disc from the magnet will vary with each type of unit under test but average values show that a pull of 2 pounds and more is required for most phone magnets, a pull of 4 pounds and more is required for the horn type of loudspeaker, while 7 pounds and more will be required for the cone type of speaker magnet before the disc can be pulled away. The proper force can always be found by first testing a unit which is known to be in good condition, then comparing it with the unit which is suspected of having a weak magnet. However, the most accurate way to check the strength of permanent magnets is visually by means of a meter as shown in Figs. 2 and 3.

The meter is a sensitive milliammeter such as a Weston D'Arsonval type, but with the permanent magnet removed. Special soft iron pole pieces are made to fit the type of magnet to be tested. A current of known value is allowed to pass through the winding of the meter. A permanent magnet of standard strength is placed on the pole pieces of the meter and the deflection of the needle is observed. The standard magnet is now replaced with the magnet to be tested while the same current flows through the moving coil of the meter. By checking the second reading against the first, the strength of the permanent magnet under test is determined. In Fig. 2 is shown the schematic drawing of a meter with pole pieces attached to test the bi-polar type of magnetic units. For this test the permanent magnets do not have to be removed from the speaker unit, as the magnetic strength can be tested at the tips of the pole pieces as shown. Fig. 3 shows the arrangement of pole pieces on the meter for testing large permanent magnets as found in the best balanced

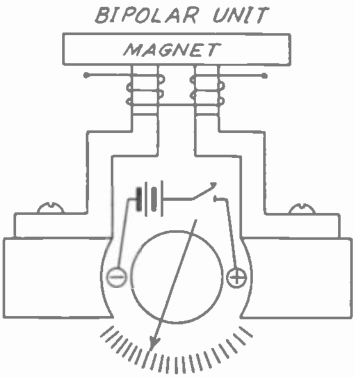


FIG. 2

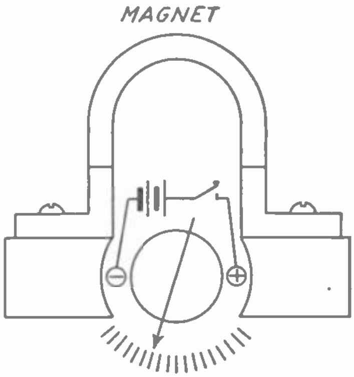


FIG. 3

armature type of magnetic units. In this case, the permanent magnets have to be removed from the speaker unit. However, it is generally found that the smaller permanent magnets, as found in bi-polar units, give the most trouble, as the larger horseshoe magnets in balanced armature units are better designed and hold their magnetism indefinitely. Also in practice, if all other tests on the reproducer unit prove satisfactory and the loudspeaker is still weak, it can be quite definitely concluded that the permanent magnets are weak. Causes of weak magnets are generally: bad overloading of the unit, and the subjection of the unit to an alternating current source such as putting it across a 110 volt A.C. supply.

The permanent magnets must fit firmly and squarely against the soft iron pole pieces. There must be no air gap between the magnets and pole pieces, otherwise the magnetic pull upon the diaphragm or armature will be weak. Weak magnetism at the soft iron pole tips may be caused by poor mechanical assembly of the permanent magnet on the pole pieces.

In some types of bi-polar reproducing units, weak magnetism at the tips of the pole pieces may be due to a magnetic short circuit of the reluctance gap. After the unit has been tested for opens, shorts, grounds, clearance and general physical condition, a quick test of its sensitivity may decide whether the magnets need strengthening. Merely connect the loudspeaker phone tip terminals to an 0 to 1 A.C. milliammeter or low range 1,000 ohm per volt A.C. voltmeter. By yelling into the cone, horn or diaphragm or by snapping the armature or vibrating system, an indication will be obtained roughly proportional to the sensitivity of the unit.

Many servicemen test the magnetic system of a unit by touching the poles with a steel screw-driver. The attraction obtained gives a rough indication of the magnetic strength.

If weak magnets are found in a magnetic unit, the only remedy is to have the unit properly remagnetized. This is not accomplished by any ordinary means, and must be done by the manufacturer, or one fully equipped with the proper remagnetizing machine. The principle of the magnetizing machine is shown in Fig. 4.

This is a special, powerful electromagnet. The coils *A* and *B* on this machine may have an outside diameter from 8″ to 10″, and are generally wound with very heavy insulated No. 12 to No. 14 B. & S. gauge wire. The coils are energized from a 110 or 220 volt D.C. source, from which 10 to 15 amperes is drawn through the winding. The core of the electromagnet ranges from 2″ to 4″ in diameter. As shown in Fig. 4, the permanent magnet to be magnetized forms the "keeper" for the electromagnet, and it takes several seconds to magnetize the permanent magnet to saturation. Magnets can also be remagnetized by hanging them on a ½ inch diameter copper wire loop connected momentarily to about six 6 volt storage batteries in parallel. A 1,000 ampere switch should be used to make the momentary connection. The air gap of the permanent magnet should be closed by a soft steel keeper.

Grounds, cord shorts and leakage: The test for grounds consists of a method by which it can be determined whether there is any shorting of the winding to the magnetic core or metallic frame. This is readily accomplished by a method similar to the lamp continuity test, but generally it is best to use a high voltage source, such as 110 volts D.C., as the insulation between winding and metallic casing should be sufficient to withstand 110 volts D.C. There must not be any ground between the winding and casing, as this may short circuit the winding and cause the power tube to be overloaded. In testing for shorts, the cord must be considered, for it may not be inside the unit.

Cords on loudspeaker devices are a source of trouble, and these must not be overlooked. Look for a short or leak. Defective cords should be replaced as they are inexpensive.

REPAIR OF HORNS AND CONES

All loudspeakers, whether of the vibrating diaphragm, armature or the moving coil type, employ a horn or cone which moves a large body of air. Baffles are a further aid to low frequency reproduction when cones are used.

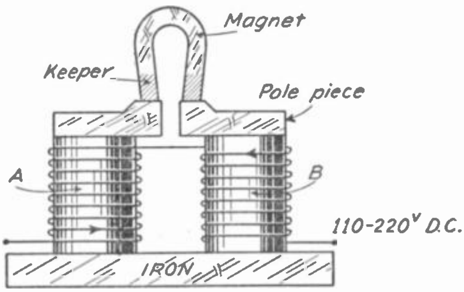


FIG. 4

Innumerable shapes and designs of horns are used. Usually they are made of papier mâché, fibre, plaster, wood, soft metal or processed cloth. Correctly designed horns will vary from one to several feet in length, depending on the low and high frequency range desired. Either the exponential or modified exponential horn is used. Horns should be supported so that vibrations cannot be transmitted to the supports—soft rubber contacts are desirable. The mouth and back of the moving unit should not be obstructed.

Should horns be damaged, the break should be cemented and the horn coated with an elastic waterproof varnish. Holes should be refilled with plastic wood. Outdoor horns, subject to corrosion or erosion, should be waterproofed periodically.

Horns are a coupling system between the air and the unit and a given unit and horn are designed to work together. Always use the unit recommended by the horn manufacturer.

Although cones used in the older type speakers might have been circular, elliptical or egg shaped, varying in size from 6 to 36 inches, the modern cone is generally circular in shape. The material of the cone is generally a paper having special acoustic properties. Alhambra (a trade name) or fibrous moisture-proof paper is used. Waterproof manila paper is often employed.

As the material of the cone is so fragile, and as the paper is usually very thin, it damages easily, and holes may be punctured in the cone. If the damage is not too great, the hole may be patched by carefully cementing a small piece of paper over it. By using a good Dupont or Ambroid paper cement, and care in patching, the damage can be fixed up and the cone will sound as good as new. A mutilated cone should be replaced with a new one. It may be purchased from the maker or any large wholesale mail order supply house.

The method of attaching the apex of the cone to the armature pin is very interesting, and is generally one of the great sources of troubles in magnetic cone reproducers. A metal or fibrous, star-shaped apex piece is generally glued with some kind of moisture-proof cement to the apex of the cone. The pin attached to the armature of the balanced-armature unit is threaded at the free end and is held to the apex of the cone by a small thread and nut arrangement. In setting the pin on the apex of the cone, the cone must not exert any pressure on the armature, which might cause the armature to become unbalanced between the poles of the balanced-armature unit. This is very important, for poor technique in setting the pin on the apex of the cone may cause such a pressure on the armature as to allow it to come near the pole pieces, causing rattles. The armature of a balanced-armature type of unit is best adjusted in the central position of the pole pieces by leaving the cone free, and after this proper adjustment has been made, then the cone should be carefully tightened to the armature pin without disturbing the balance of the armature.

Poor, weak or dead response from magnetic cone speakers is often due to the fatiguing of the cone at its apex. In this case it will be noticed that the apex of the cone has become weakened, especially around the metal apex piece. Mechanical weakening naturally means waste of sound energy, especially at the higher frequencies. The best remedy for this is to strengthen the center of the cone by means of a collodion solution.* This is a

* Some servicemen have found a mixture of one-half collodion and one-half banana oil more suited to their needs.

liquid solution which can be readily applied, and in drying it will stiffen the center apex of the cone and bring back the good performance of the unit. Application of collodion will also help in eliminating little buzzes or rattles due to the armature pin not being tightly fastened to the apex of the cone. If the seam in the cone works open, it should be recemented.

Servicemen differ in their opinion as to when a cone should be repaired or replaced. When it is possible to wait long enough, order a new cone from a supply house. They are inexpensive and will restore the machine to its initial tone quality. In rush jobs the repair should be made in the best possible manner. Here are a few additional hints.

If the leather edge becomes hardened, it may be softened by rubbing in Neetsfoot (trade name) leather oil.

Many speakers, particularly dynamic speakers, develop in time a cone rattle or blasting effect. The cone vibrating at high frequencies breaks down the stiffness of the paper, preventing reproduction of high frequencies. Application of several thin coats of rubber cement about an hour apart has helped restore good speaker operation.

The low frequency response in free edge cones may be improved by cutting away a portion of the free edge and cementing on a thin chamois leather floating ring. The floating edge should exert no pull on the apex and it should help centralize the cone. Be sure the cement is hard before testing or using the cone.

Troubles peculiar to moving coil speakers will be taken up in the next section.

MOVING COIL UNITS

Moving coil units differ principally in the method of supplying the magnetic flux. They may be of the electromagnet or permanent magnet type. In the first case the field coil may be connected in the power pack system, to a D.C. main or to a storage battery if the receiver is of that design, or to the output rectifying system of the set or to a copper oxide type rectifier. In the second type the field is always present because of the use of large, powerful, permanent magnets.

We are concerned in this text with the moving coil structure and the cone. The supply system may be tested in the usual power pack trouble shooting procedure. Permanent magnets may be tested as shown in the first portion of this text. To test magnetism in the electromagnetic dynamic loudspeaker apply a screw-driver to the core of the field and observe the pull before and after the receiver is turned on. If no change is observed, test the continuity of the field winding and its power supply.

The proper tests for moving coil reproducers are as follows:

1. Continuity test on field winding.
2. Resistance of field winding.
3. Continuity test on voice coil.
4. Resistance of voice coil.
5. Continuity test on output transformer.
6. Resistance of output transformer.
7. Test for grounds.
8. Test for rattles.
9. Test for bad resonant peaks.
10. Tests peculiar to self-excited reproducers.

An ohmmeter continuity test on the field windings will show whether the winding is open. The resistance of the field, which may vary from a few ohms to a few thousand ohms, may be checked against the value usually given in the service diagram. A variation of 10% is normal.

A great deal of difficulty is experienced in dynamic reproducers with opens in the moving voice coil. These are readily discovered by a continuity test. In many cases, however, it will be found that an output transformer is mounted on the frame of the speaker. In this case care must be taken that the voice coil is disconnected from the secondary of the output transformer before tests are made for continuity and resistance.

In the resistance test, the value of the resistance will show whether the winding is in good condition. Voice coil windings differ materially in design and range from one turn to several hundred turns. This resistance will be found to be from a fraction of an ohm to 50 ohms, and the proper value of the resistance can be obtained only from the manufacturer, or by comparing to a perfect speaker of identical construction.

If an output transformer is mounted upon the frame of the speaker, a continuity and resistance test on the primary and secondary winding will determine whether the windings are open or satisfactory. If the output transformer is a push-pull output transformer feeding from the output of push-pull power tubes, its primary winding consists of two windings in series, and the secondary is a single winding, as shown schematically in Fig. 5.

Although the primary is tapped at the electrical center, the resistance between the center and the end terminals will differ to some extent. The section using the turns near the magnetic core will have the least resistance. The resistance of the secondary winding will be very low, between 1 and 50 ohms. In output transformer design, the secondary winding is generally directly over the iron core and the primary winding over the secondary.

If the output transformer feeds from a single power tube, it will consist only of a single primary and single secondary winding.

Grounds in dynamic reproducers are much more detrimental to operation than in magnetic speakers on account of the higher voltages involved. In testing for grounds, careful tests must be made between field winding and core, voice coil winding and core, primary and secondary windings of output transformer and

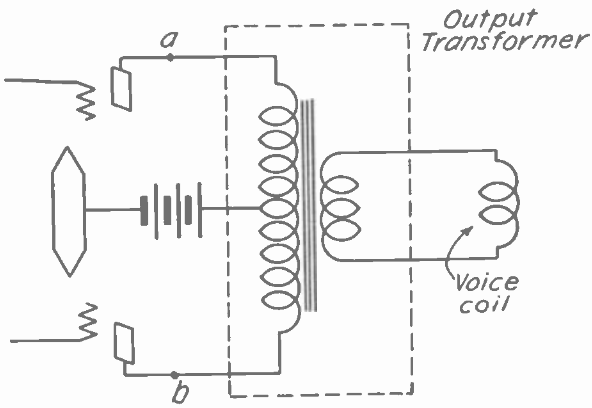


Fig. 5

core. There must be absolutely no ground between any winding and the core. Also, partial grounds, indicating low leakage between windings and core, must be eliminated, for this shows poor insulation or leakage between windings and core, which will result in a bad ground when the high voltages are applied. Partial grounds or leakages are best checked by means of a 10 megohm ohmmeter. In some output systems one terminal of the voice coil may be intentionally grounded. This ground should be temporarily opened. Always refer to the circuit diagram of the receiver for unusual speaker connections.

In testing for rattles, it is best that the dynamic reproducer be in operation on an audio amplifier. Rattles are best discovered by feeding a variable audio frequency current into the input of the audio amplifier and noting the sound response from the dynamic speaker. Any variable audio frequency oscillator may be used so long as its range is within the usual audio band and the oscillator is calibrated. Where an A.F. oscillator-amplifier is not a part of your testing equipment you must be guided by experience and critical observation of the moving parts. By varying the audio note, rattles peculiar to certain frequencies may be readily detected. In moving coil reproducers rattles are caused by the following:

A. Moving Voice Coil Rubbing Against Pole Pieces or Core of Magnet Structure.—This may be due to the voice coil losing its shape causing it to hit against the magnetic structure. Generally it is due to improper alignment of the voice coil resulting from an offset spider, or loose spider supports.

If the voice coil is caused to rub against the magnetic pole pieces, there is serious danger of the enamel on the voice coil wires scraping off and some of the turns being short-circuited. If such a condition exists, care must be taken to analyze the voice coil for shorted turns. This can be done by checking accurately the D.C. resistance and examining the voice coil wires under a magnifying glass. If the voice coil touches the pole pieces because of improper alignment of the external or internal spider, this can be remedied by realignment. The gap between the center core and the inside of the voice coil form generally ranges from .010 to .020 of an inch. Alignment can be made by inserting three cardboard or celluloid strips between the inside of the voice coil and the central iron core as shown in the internal spider system in Fig. 6. Loosen the centering screw where the internal spider is used or loosen the external spider screws in the other types, let the moving coil align itself and tighten the holding screws. If the moving coil does not recenter itself it will be necessary to loosen the retaining ring around the edge of the cone. Repeat the centering process and tighten all screws.

Iron filings and grit in the air gap may cause rattles. Blow out all foreign material with a hand bellows or with a fine nozzle attached to an air pump.

B. Loose Wire in Voice Coil Winding.—In manufacture, the voice coil winding is carefully impregnated or lacquered, but in some cases the wires become loose under the continual strain of the voice coil vibration. The rattle thus caused is a distinctive buzz, and a little experience will enable you to detect loose wires in the voice coil readily by this particular sound.

Loose wires on voice coils can be remedied by impregnating the voice coil with some kind of good lacquer or household cement. A good air-dry Dupont clear lacquer or acetone solution such as "ambroid" can be used. Care must be taken in applying this lacquer that it is put on thin, otherwise it will interfere with the movement of the voice coil by rubbing or sticking against the pole pieces. Some voice coils have a number of layers of winding on the voice coil form and a few wires in one of the inner layers may be loose, causing a buzz. This trouble is a little more difficult to remedy. This is best taken care of by several applications of the thinned-out impregnating solution over the spot on the voice coil under question, until the impregnation has had a chance to work through the other layers. A new cone with attached voice coil should be used in unrepairable cases.

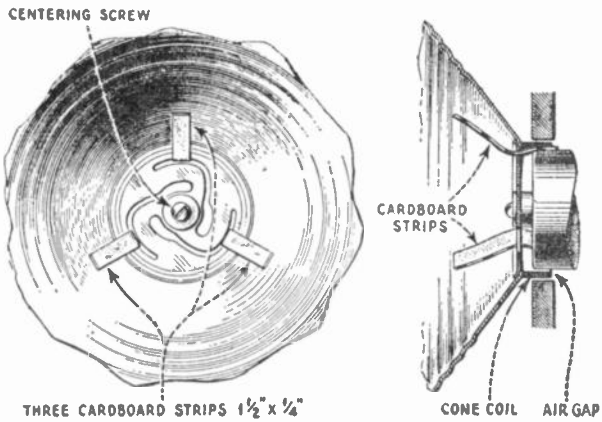


Fig. 6

C. Spider Rattles.—The various legs of the spider, external or internal, whether of metal or insulating material, have a definite natural period of vibration, and at times these parts fatigue, causing bad spider rattles. This kind of rattle is particularly annoying at large volumes, and gives rise to a high pitch buzz.

Spider rattles occur frequently on metallic spiders. These rattles can best be eliminated by slipping a thin rubber tubing or cotton sleeving over the legs of the spider supports, or gluing a thin piece of felt or leather over the parts of the spider leg causing the rattle. These materials will dampen any rattles without adding sufficient weight to impair the efficiency or frequency range of the moving voice coil form.

D. Cone Rattles.—Rattles may be due to the cone proper. If made of paper, the rattle may come from a partial opening or weakening of the glue in the seam. If flexibly mounted at the periphery (the outer edge), by leather or cloth material, the cone may set up a bad paper rattle at the periphery, due to a bad whipping of the paper at large vibrations. If the cone proper is held between metal supports, rattles may occur due to the periphery of the cone hitting the metal supports, unless separated by felt washers.

Rattles due to the whipping of the paper at the periphery occur at low frequencies near the natural resonance of the cone, due primarily to the flexible membrane of the cone support being too loose. There may also be an uneven tension around the periphery, straining the cone. This unevenness may be caused by the flexible member of the cone support hardening at spots, or the chamois, which is sometimes used, stiffening unevenly. The chamois can be made more flexible by rubbing with the fingers or by using some kind of leather dressing. If the cone is held too tightly at the support, the bolts should be loosened and the cone pressure released. A tightened cone caused by the hardening of the leather or chamois ring means a lack of good low-note reproduction, and the reproducer will sound "high-pitched."

Most reproducers are designed with a central spider which is fastened at its rim to the voice coil. If this spider cracks, which is not uncommon, high note distortion will usually result.

All dynamic reproducers have inherent acoustic resonant peaks, and these will readily be noticed when varying the variable audio frequency oscillator in testing for rattles. In well designed speakers, these resonant peaks are not very pronounced, and generally little trouble is experienced from this cause. The acoustic resonant frequency may be lowered by loading the moving coil tubing where it fastens to the cone with gum or other heavy sticky material.

TESTING CONDENSER REPRODUCERS

In testing condenser reproducers, care must be taken that the polarizing voltage be taken off the conducting plates of the speaker before any detailed tests are made on the unit. This polarizing voltage is of the order of several hundred volts, and this voltage is generally obtained from a rectifier tube.

About the only defect which can occur in the condenser type of reproducer is the puncturing of the thin aluminum film. This puncture may be mechanical or it may be an electrical breakdown caused by the high voltage from the rectifying tube.

A continuity test, with the polarizing voltage off, will determine whether the aluminum film is punctured or touching the aluminum casting. Condenser reproducers are generally made up of several small condenser reproducer units in parallel, so care must be taken in tests to determine which unit is defective.

No-voltage or improper polarizing voltage will cause poor performance of the condenser reproducer. This may be due to a poor or defective rectifying tube, or some defect in its associated circuit.

Most difficulties with the condenser reproducer are external to the unit proper, and tests on the associated circuits will locate the trouble.

When replacement condenser speaker sections cannot be obtained it would be wise to consider replacing the entire condenser speaker with a permanent magnetic type dynamic speaker. In ordering such a speaker, be sure to specify the output tubes used in the receiver so the correct matching transformer is sent. The condenser speaker and its voltage supply should be removed from the circuit, taking care that the other supply voltages remain intact. The coupling transformer of the new speaker is connected directly to the plate circuits of the output tubes.

EXTRA NOTES ON SPEAKER SERVICING

I. The Baffle should be made as large as possible. Some of the best cone reproducers are ruined by placing them in small cabinets or behind small baffles. Baffles are most effective in large sizes, and also when the baffle material is non-resonant and heavy. A strong two or three ply wood baffle, an inch to an inch and a half thick, is recommended. Some baffles, particularly in console cabinets, depend upon the material of the cabinet for the baffle effect; or a thin baffle board, one-quarter to one-half inch thick, is used. By putting in a strong, thick baffle board, extending to the sides, top and bottom of the speaker compartment, the low tones will be brought out and the reproduction will become fuller and more pleasing. This is why console cabinets became popular for broadcast receivers, not only because the receiver and speaker are self-contained, but the cabinet itself acts as a good baffle (even the sides, top and bottom of the cabinet) and better quality reproduction from the reproducer is attained.

II. Prevention of "Booming" and "Microphonic Howl" from Dynamic Reproducers.—The boom-boom reproduction of dynamic reproducers is caused by an excessive over-emphasis of the low frequencies. This is caused sometimes by deliberately "chopping off" the high frequencies in an audio system by means of a by-pass condenser in order that no high frequencies can be reproduced in the loudspeaker, so the speaker would be "rich in low notes." This is an acoustic illusion, and is a trick which has unfortunately been used by some well-known manufacturers to satisfy the public for "low note reproduction." By examining the audio system it will be found that a by-pass condenser has been employed somewhere in the system in shunt, and this can be taken out. The normal R.F. by-pass condenser from the plate to cathode or filament in the plate circuit of the detector should be .001 to .002 mfd. capacity. Some manufacturers have used as much as .005 to .006 mfd. to by-pass the higher audio frequencies. The lack of high frequencies "gives the effect" of better low notes and boomy quality results.

This kind of reproduction is also obtained by improper use of a reproducer in a self-contained cabinet, which is particularly true in small table model or mantel type speakers. These cabinets are small; the air column behind the speaker is closely confined and will sometimes over-emphasize the low frequencies. Generally, very little can be done to prevent boomy reproduction under such conditions. Relieving the air column pressure on the reproducer by eliminating the wooden back, or cutting an opening in the bottom of the cabinet, will help. Any radical change in the design of the cabinet should never be attempted without permission from the owner.

"Microphonics" is a phenomenon in a broadcast receiver, which is due primarily to the radio system of the receiver and not to the reproducer, although the loudspeaker will be blamed for it many times. The sound waves from the speaker will cause the cabinet to vibrate, and this mechanical vibration will be transferred back to the radio frequency and detector chassis frame, causing the brass, aluminum or steel plates of the tuning condenser to vibrate, or the vacuum tube elements to vibrate. These vibrations will cause a modulation of the incoming carrier wave, resulting in a continuous "howl" from the loudspeaker. The condenser plates or tube elements can also be made to vibrate acoustically through the air. In order to eliminate "microphonics," mechanical vibrations must be prevented from being set up by the sound waves from the speaker. This can be accomplished in several ways:

(a) The R.F. chassis frame is mounted on rubber, felt or mechanical springs, so that it will receive little mechanical vibra-

tion from the cabinet. It will be noticed that chassis in console cabinets are mounted in this way.

(b) If vibration of the tube elements is causing the "microphonics," the tubes should have flexibly mounted sockets or a heavy metal cap should be placed on the tube to prevent them from vibrating. Highly sensitive detector tubes will require special attention in this respect.

(c) The speaker should be mounted so that it will not transmit much vibration to the cabinet. A felt cone ring between the cabinet and speaker, and a heavy baffle board will help. Sometimes inverting the speaker will help.

(d) If the cabinet is thin and weak, its walls and shelf will vibrate readily, causing "microphonics." By strengthening these weak places with added wooden strips or supports, this trouble will be eliminated.

(e) When a receiver is completed, very little can be done for variable condensers having thin plates; they should be at least 1/32 of an inch, staked or soldered and supported rigidly at several places. Aluminum gang condensers are less apt to be microphonic than brass or steel plate condensers. See *(a)* when microphonic action exists.

III. Precaution Against Using Dynamic Speaker Against a Wall.—The reproducer is designed to work with a certain receiver and in a certain cabinet. By placing it against the wall, the air pressure against the back of the speaker may change its characteristics entirely, and reproduction will be less pleasing.

IV. Use of Auxiliary Speaker for Tone Emphasis.—The acoustic result of two speakers together may be better than either one singly. This was particularly true when the first cone reproducers were produced. The cone speaker brought out the low frequencies, and the horn speaker brought out the high frequencies. By combining the two, the resultant reproduction was quite satisfying. A small cone and a large cone together will have similar effects. Three speakers of different characteristics can sometimes be used together to give better results.

Where two or more speakers are used simultaneously and their sound outputs are in the same general direction, it is important that the diaphragms or cones be in phase. As most speakers are supplied from a common source this means that the cones should move "in" and "out" together. Phasing is accomplished by connecting all voice coils or speaker terminals together in the accepted manner and momentarily connecting to a 4.5 volt battery. As the connection to the battery is made, watch the motion of the cone. If some move "in" as others move "out," reverse the speaker connections, or in the case of some dynamic speakers reverse the field coils so that all moving systems move "in" and out together.

V. Impedance Correction by Proper Matching of Impedances.—It is well understood that associated circuits with vacuum tube systems will give best results only when the impedances of such systems are matched.

This is very important in loudspeaker systems. Dynamic reproducers have voice coils, the impedances * of which may range from a few ohms to 50 ohms, depending on the number of turns. This voice coil impedance must match the secondary of the output transformer associated with the power output tube, or maximum power undistorted output will not be obtained. A voice coil having an impedance of 20 ohms cannot be used with a step-down output transformer designed to work into a voice coil impedance of only 4 ohms.

The impedance of the voice coil of a dynamic reproducer is a variable factor, since the amplitude of vibration of the voice coil is not constant over the entire audio frequency range. However, it is substantially constant over a considerable portion of the frequency range between 200 and 2,000 cycles. Above 2,000 cycles the impedance increases with frequency, and below 200 cycles the impedance increases to the point of natural resonance of the diaphragm and then rapidly decreases with frequencies lower than the fundamental. For impedance matching purposes, the voice coil impedance is generally measured at between 200 and 400 cycles.

It is extremely important that the output transformer match the impedance of the voice coil.

In buying a replacement speaker it is not necessary to specify the correct turn ratio of the coupling transformer. If the maker and the model number of the receiver are specified, a suitable speaker will ordinarily be sent by a reliable supply house. It is also wise to specify the tubes used in the output stage, the arrangement, (single, push-pull, two in parallel, etc.) the operating voltages. These factors determine the correct speaker input impedance. The field resistance of the defective speaker should be given.

VI. Rattles in Speakers Not Due to Speakers.—Oftentimes

* For service work you may assume that the impedance of a voice coil is 1.5 times its D.C. resistance, which you can measure with a low range ohmmeter.

complaints will be received of rattles occurring in speakers, and the trouble will not be in the speaker but in the electrical system preceding the speaker.

(a) If push-pull power tubes are used, one tube may not match properly with the other, causing unbalancing, and a rattle is heard in the reproducer.

Power tube overloading is caused by having the volume control of the receiver turned up too high, and overloading the grid of the power tube.

Output power tubes deteriorate readily, and distortion results at lower power output. Changing the power tube will readily determine this.

(b) Any overloading of detector or audio tubes causes distortion, and a rattle will be heard in the speaker. An overloading of any tube causes the grid circuit of the tube to take current, and this always results in a distortion rattle.

(c) Overloading and distortion of amplifying tubes may readily be caused by improper voltages on the tubes, due to a breakdown of some part of the circuit.

SERVICING MICROPHONES

Microphones play an important part in home recording, public address and call systems. Many servicemen are called on to maintain or service such systems. Here again we will limit ourselves to caring for and servicing these sound pickups.

Microphones used in home recording systems are quite rugged and will stand normal rough handling. Needless to say, continual abuse will soon render the device useless. Double button microphones used in public address systems are very delicate instruments and must be handled with care. They should not be exposed to moisture, and, when not in use should be kept in a glass jar having a ground glass stopper. In the bottom is placed a handful of sal-soda. This will absorb any moisture that may have accumulated on the microphone.

In transporting the microphone, carefully wrap it in cotton batting or felt to prevent it from being jarred. Condenser microphones, as you know, have a thin plate separated from its fixed plate by a distance of one or two thousandths of an inch. A sharp jar may cause the two plates to become short-circuited.

Never attempt to take a microphone apart for repairs as this is a highly specialized job. Dirt may accumulate on the speaking surface, causing noise when in use. Don't try to blow it off. Use a small camel's hairbrush to clean the diaphragm and exercise great care, otherwise the diaphragm may be bent out of shape.

Carbon Microphones: These instruments require a small D.C. current of the order of 10 milliamperes. The current which is measured by inserting a milliammeter in the circuit should not exceed the recommended value, as tiny electric arcs will develop, causing the carbon granules to get red hot and stick together. When the cohering takes place, the buttons of the microphone must be refilled by a specialist having the proper facilities.

Quite often it will be observed that the currents in double button microphones are unequal. If this difference is greater than 30%, distortion is bound to exist. An unbalance may occur only when the microphone is not in use, and equal when in use. This is not a defect. Unbalance in microphones may eventually lead to burning of the granules.

When a microphone becomes moist, it should be dried out as previously explained. Or it may be placed near a lighted electric bulb or in warm sunshine. Should the carbon become packed but not burned together, the granules may be loosened by holding and rotating the microphone in one hand with the diaphragm parallel to floor and gently tapping the edge of the microphone with the other hand. Never tap the ends of the microphone or the bridge nor attempt this adjustment when current flows through the microphone.

Condenser Microphones: We must not overlook the fact that the microphone amplifier is a integral part of this pickup. Troubles are often traceable to a defective amplifier.

Condenser microphone diaphragms are extremely thin and special care must be taken to see that it is not dented or forced out of shape.

The condenser unit is usually filled with an inert gas and the entire basic unit (not the case) impregnated with a wax compound to exclude moisture and prevent gas leakage. Excessive moisture may penetrate the sealing compound and cause a variable leakage current. This will result in a scratching sputtering noise. Failure to dry out the moisture, by enclosing the unit in a jar with sal-soda, may eventually allow the high voltage to break down the unit, giving rise to a "spitting" noise. The remedy is to allow the unit to dry out in the drying jar for a long period of time and at a warm temperature.

Defects in the amplifier should be watched. A defective tube, broken down insulation in the microphone amplifier or the cable, or a bad connection in any part of the pickup system will give rise to noise. Usually the trouble is due to an open ground connection. It is essential that the condenser microphone frame and the —F amplifier tube terminal be grounded by a lead through the cable. The ground wire from the microphone to the amplifier often opens at the microphone frame.

Quite often an A.C. hum is heard in the sound output. Usually this is traced to inductive pickup from an adjacent A.C. line. Move the cable cord to various locations. If the hum persists the trouble is probably the result of an open in the ground connection to the shield of the cable.

SERVICING PHONOGRAPH PICKUPS *

Servicing combination radio-phonographs and electric phonographs is unquestionably a service that the radio technician should be ready for. The amplifier system is treated as you would any vacuum tube amplifier. However, the serviceman should have an intimate knowledge of phonograph pickups and the electrical motor.

In spite of its small size and apparent simplicity, the pickup unit has its weakness, which, after it has given very satisfactory service for some time, will eventually show up and will require attention.

Before operating with screw-drivers and pliers, be sure that proper tests have been conducted in the amplifier to prove to your own satisfaction that the amplifier is free from defects and that the sound reproduction is normal.

Distortion may exist due to worn out needles, worn out records, not using electrically produced records, excessive tension on the tone arm or armature, loose needle, loose parts *within pickup unit*, defective internal damping. Noise may appear because of a loose needle, loose armature or poor connections. The sound output may be erratic because of excessive weight on the record or a non-uniform rotating motor. No reproduction will result if the armature freezes or gets out of adjustment, or any part of its electrical circuit opens or shorts.

Distortion is an often complaint. In a few isolated cases, the cause for distorted reproduction is due to nothing but the use of old and worn out records. Many customers seem to forget the very important fact that, in order to do justice to the electrical pickup unit, it is necessary to use none other than electrically cut records. Records salvaged from the old phonograph

---

* Partially abstracted from an article in Radio-Craft.

simply will not do. After records have been in use a long time, they usually collect a certain amount of dust and grit in the grooves; this dirt, added to the fact that the grooves are probably worn by the needle passing through them a number of times, distorts the signal picked up from the record. It is desirable, therefore, to first check this item carefully, and the best and quickest test is to play your own perfect record, which should be carried along especially for such purposes. This record will serve another very important and practical purpose, namely to prove to your customer's own satisfaction, after having completed a repair job on the pickup unit, that your work has been properly done and to preclude any possible argument to the contrary.

The first thing to do, in servicing a pickup unit, is to check the speed of the turntable. If a speed indicator is not available, the speed can be checked by placing a strip of paper under the edge of a record so it will just project beyond the edge of the turntable. Play the record in its usual manner, then place your finger where the paper will strike it, and then count the revolutions made by the turntable for one minute. Be sure to have the pickup unit in its normal playing position, so that the retarded action of the needle on the record will be taken into consideration while the revolutions are being counted. Standard records turn at 78 revolutions per minute. On later phonograph combinations, there are two speeds provided; one for the standard record speed, and a slower speed of 33⅓ revolutions per minute for the long-playing records. The speed control mechanism is provided with a control lever to give either of these two speeds. It might be well to mention the fact that the needles for the long-playing records are specially designed for use only on these records and cannot be used on the standard records. Quite often the speed adjustment alone will not remedy the distortion.

It is generally possible, by listening carefully to the sound coming from the speaker, to localize the source of the distortion. First, ascertain whether or not the high and the low notes are being heard, if conspicuous by their absence, it is generally due to the armature of the pickup being off center.

If there is a rattle on certain notes and blasting on the low notes, the trouble may be generally traced to worn out, or deteriorated, rubber damping blocks.

If a vibrating and crackling noise is heard while the record is being played, it may be mainly due to the fact that the base of the pickup, near where the needle is inserted, is magnetic, and attracts small particles of iron.

Sharp, cracking sounds, not unlike static discharges, very often may be traced to loose connections in the pickup unit.

Weak magnets will also cause low reception and distortion; although it is not probable that you will meet with this condition.

In all present-day pickup units it has been found necessary to use some sort of damping on the vibrating armature. Naturally, everything has a natural period of vibration, and if this vibration of the armature is not damped in some way, the armature will hit the pole pieces and thus cause distortion. The exact methods used to overcome this tendency to vibrate varies, to some extent, in the different makes of pickup units. In general, this damping is accomplished by mounting pieces of soft rubber tightly between the pivot supports, as well as placing a rubber damping block between the pole pieces. Thus, the armature is left free to move between the pole pieces, but is damped by the rubber mounting at its pivot. If the pickup is used infrequently, the rubber damping blocks and rubber pivot supports become hard and unpliable and are worthless as dampers.

Hardening of the rubber blocks may throw the armature off center. If the pickup unit is repeatedly left to rest on the needle or on top of the record, instead of letting it hang free on its proper support after each record has been played, the armature naturally gets off center.

If the aural test indicates that the armature is improperly centered, then this part must be adjusted. The sequence of disassembling the necessary parts for making this adjustment will differ according to the various types and models. However, certain general requisites apply to all pickup units. Remove the outer cover case by removing the cover screws and the needle holder screw. Mark the magnet pole pieces and the magnet with a red crayon pencil, so that when they are replaced, they will be in their original position. Remove the magnet, and place a piece of soft iron across the poles. Failure to observe this precaution will result in a loss of magnetomotive force which will impair the sensitivity of the pickup unit. Loosen the two round-headed screws in the armature adjusting plate with a small screwdriver. The small piece of metal holding the damping block should now be moved until the armature is properly centered between the pole pieces. The armature should be held in the exact center of the magnetic field—exactly halfway between the magnet blocks. Judging the center by eye is, in many cases, sufficiently accurate for this adjustment. When certain that the armature is properly centered, replace all parts of the pickup assembly. It should be noted here that, in a good many cases, on certain models, it will not be necessary to remove the magnet and pole pieces to make this adjustment.

If the armature is found to be rusty, a replacement is recommended; but if a new part cannot be obtained quickly, a temporary repair can be performed by scraping off all the rust and rubbing all surfaces with very fine emery cloth. (Do not coat the surfaces with oil to keep it from rusting again, as oil has a deteriorating effect on the rubber dampers.)

To test the armature for correct centering, the cover plate should be replaced and the instrument turned on; then, while playing a record with the volume control turned on full, lift the pickup unit from the record and move the finger across the needle point, both to the right and to the left. The same sound should now be heard in the speaker, regardless of the direction in which the finger is moved. If the sound is not the same, but weak on one side and strong on the other, then determine which side gives you the weakest reception. If the sound is weakest when moving the finger to the right, the left adjustment screw should be loosened and the rubber pivot support, or adjusting plate, forced over nearer to the armature. If the sound is weaker when moving the finger to the left, the right hand screw should be loosened and the rubber pivot support, or the adjusting plate, forced nearer the armature. It is advisable always to make the above-mentioned test first, after the turntable speed has been checked and adjusted, before any attempts are made to replace the rubber padding, as in a good many cases this is the only adjustment necessary.

If our test indicates that the trouble is due to faults in the rubber dampers, then these pads should be carefully inspected.

If badly deteriorated or hard, they should be replaced. The old rubber should first be completely removed by scraping the parts clean with a knife. Specially made rubber pads may be procured from the manufacturer of the particular pickup unit that you are working on. If such a set of rubber pads are hard to obtain, any first-class, good, live rubber—such as part of an automobile inner tube—will do very nicely for the damping block between the pole pieces, and the thin portion of a baby's rubber nipple may be used by cutting out two strips to act as rubber pivot supports. The exact size of the rubber pads required may easily be determined by carefully noting the size of the old rubber pads and then you can make exact duplicates.

The same general rules for disassembling the pickup unit, as previously described for the armature adjustment, should be followed when replacing the rubber dampers. After the magnet, pole pieces, coil, and the armature have been disassembled, all metal parts should be cleaned free from all accumulations of dust and grit; place the new rubber pivot supports in their proper place; and reassemble the pole pieces, the coil, and the new rubber damping block between the pole pieces. Now center the armature and tighten up the screws in the adjusting plate. The next step requires some sort of a clamping device, such as a small vise or a "C" clamp. After the assembly has been replaced on the pickup arm, and you are sure that the magnet poles are against the proper pole pieces, the assembly should be replaced in the clamping device for the proper tightening of the pole pieces.

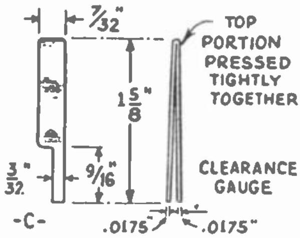


FIG. 7

The proper amount of pressure to be applied depends on the type of unit you are working on When working on RCA, G.E. and RCA Victor pickup units, the use of a clearance tool will aid greatly in making proper adjustments of the pole pieces. This gauge may be constructed of metal by making one as per the detail shown in Fig. 7. The cut-out portion slips over the coil and the two legs slip in between the pole pieces. After the pole pieces have been clamped together, the bolts holding these pieces should be tightened up. Then remove the pickup arm from the clamping device and take out the gauge. The pickup is now reassembled and the cover plate replaced. Before this is done, make sure that the magnet clamp is in its proper place. If the magnet clamp is not in its proper place, it may force the front cover to one side. If this should happen, it will, in all probability, touch the needle-holder screw, and this, in turn, will produce a rattling noise in the speaker.

In removing the pickup assembly from the motorboard, you may be tempted to loosen the two pivoted set screws which are located on each side of the pickup arm just above the top of the base. The advice is: "Don't do it!" The proper method is to disconnect the two output wires under the motorboard, then remove the wood screw holding the base in place, and lift the whole assembly off the board. The reason for doing it this way is to avoid tampering with the set screws which are held in place inside of the arm with lock nuts. While working on this part of the unit, the lubrication between the pickup arm and the base should be checked over. If the bearing surfaces appear to be dry, a small amount of vaseline should be applied so as to insure free motion of the arm.

Particles of iron, found at the base of the pickup unit can be removed with a toothpick, hand bellows, or still better, with a vacuum cleaner.

The radio-phonograph transfer switch should always be inspected, and the contacts kept clean, although there is nothing to be gained by excessive filing and cleaning. In some cases, it might be found necessary to bend the spring contacts to insure better compression, since any imperfect contact will materially interfere with good record reproduction.

Very little trouble has been encountered with the motors. In most cases when the motor has a tendency to stall or lose power, all that is necessary is to apply a little oil to the bearings.

The coils and leads of the pickup can be tested for shorts and opens with an ohmmeter following the routine outlined for magnetic units.

TEST QUESTIONS

Be sure to number your Answer Sheet with the *number* appearing on the front cover underneath the title of this text.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another set ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your Course, and the best possible lesson service.

1. What disadvantage does an aural continuity test have on windings with many turns of wire?
2. What tests would you make, if, applying a steel screw-driver to the iron core of an electromagnetic type dynamic speaker, no change in pull is observed before and after the set is turned on?
3. In what three ways could you stop "microphonics" in sets brought in for servicing?
4. Give four causes of rattles in moving coil cone speakers.
5. What information would you supply when ordering a replacement speaker for a receiver whose model number is not known?
6. What is the purpose of the sal-soda placed in the glass container used for storing microphones?
7. Explain briefly the armature center test on magnetic phono pickups.
8. In what two ways does hum usually get into a microphone pickup system?
9. What two defects may exist if the rubber dampers in a phono pickup harden?
10. Explain briefly the centering process for moving coil reproducers having an internal spider support.

1. A click may be heard due to self capacitance, even if the winding is open.

2. Test the continuity of the field winding and if found in good condition test the power supply of the field winding.

3. 1. Mount the chassis on rubber, felt or mechanical springs; 2. place a heavy metal cap on the tube set into vibration; 3. use either a heavy dead baffle or a felt ring between the baffle and the cone retaining ring.

4. 1. Moving voice coil rubbing against pole piece or core; 2. loose wire on voice coil; 3. defective spider; 4. defective cone.

5. Give the output tubes used, the arrangement and type of circuit, the operating voltages and the field resistance of the defective speaker.

6. To remove the moisture and keep the microphones dry.

7. With pickup connected to an active amplifier rub the needle to the right and left. The noise in both directions should be equal.

8. An open ground connection to the shield of the cable, or having the microphone cable too near an A.C. line.

9. Mechanical resonance will be accentuated and the armature may be thrown off center.

10. Loosen center screw, insert three thin cardboard strips between the core and moving coil and tighten center screw. Loosen cone edge retaining ring if necessary.

HOW TO RECOGNIZE, LOCATE and REMEDY INTERNAL RECEIVER NOISE, and INTERMITTENT RECEPTION

44RH

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

HOW TO SUCCEED

Be studious in your profession, and you will be learned. Be industrious and you will be rich. Be sober and temperate, and you will be healthy. At least you will, by such conduct, stand the best chance for success.

BENJAMIN FRANKLIN.

1942 Edition

A LESSON TEXT OF THE N. R. I. COURSE
WHICH TRAINS YOU TO BECOME A
RADIOTRICIAN & TELETRICIAN
(REGISTERED U. S. PATENT OFFICE) (REGISTERED U. S. PATENT OFFICE)

NCP2M542

Printed in U. S. A.

Internal Receiver Noise

INTRODUCTION

A large number of service calls are due to the development of some noise in the receiver. The set owner wants the *popping*, or the *frying*, or the *hissing*, or the *rattling*, or the *whistling* taken out. Then, too, the set owner may complain that the set plays and cuts off and plays again, or cuts off and doesn't play until some part is adjusted or touched, or cuts off and refuses to play until the set remains inoperative for some time. The last type of trouble is referred to as intermittent reception and is the most intangible sort of service work that a serviceman may encounter. Both types of trouble will be discussed in this lesson, but internal receiver noise and whistles will be considered first.

INTERNAL OR EXTERNAL RECEIVER NOISE? The noise observed may have its origin outside the receiver—that is, it may be coming in through the aerial and ground pickup system, or over the power lines. External receiver noise will be treated elsewhere in the service course.

The first thing a serviceman must do when starting out to repair a noisy receiver, is to determine whether the noise is internal or external.

If the receiver is battery operated it is a comparatively simple matter to determine whether the noise is internal or external. To determine this the antenna is disconnected from the receiver, as is also the ground. Then the antenna and ground binding posts are short circuited by running a small length of wire from one to the other. With the volume control turned on full, no noise will be heard if the source is external to the receiver. On the other hand, if the noise is still heard, it is definitely proven that there is a defect in the chassis or power supply. This test, however, is applicable only in the case of well-shielded battery receivers. Modern sets are all properly shielded, but the test is not conclusive when made on older types of unshielded battery receivers.

In the case of A. C. operated receivers, noise may be coming in over the power line, in which case, even though the antenna and ground are disconnected and shorted, external noises will get through. The only way a definite check can be made on noises entering the receiver through the power line is by the use of a line filter.

A typical line filter is shown in Fig. 1. While the filter may not serve to eliminate all noises coming in over the line, if there are any noises of this sort it should reduce them considerably. If the filter eliminates the noise or reduces it considerably, it can be definitely assumed that it is coming in over the line. It would be wise to reconnect the antenna and ground to see if some noise is not coming by way of the pickup system. An increase in noise indicates that it gets in by both routes. If, however, with the aerial and ground connection shorted and with a line filter between the A. C. outlet and the receiver, the noise still persists, a receiver defect is indicated.

Should you feel that the noise is a receiver defect and appears only when a signal is fed to the receiver, test by connecting to the receiver input a well shielded modulated oscillator. This test should be made after you test for external or internal noise origin.

CLASSIFYING INTERNAL NOISE: We may classify or identify the various kinds of noises according to their characteristic sounds. This is an important factor in our effect to cause analysis. We may classify noise as to nature of the source, whether it is mechanical or electrical.

You should be able to recognize the various sounds that are referred to as noise. We have: *1.* Scratching, clicking, crackling, rattling and grating noises, generally due to a defective part or connection; *2.* Whistling or swishing noises, generally traced to oscillation and regeneration in the circuits; *3.* Ringing noises, gradually increasing in intensity. They are called microphonic noises and are traced to poor design, loose parts, defective tubes or to too much volume; *4.* Hum, which will be considered elsewhere in the course, generally due to defective parts, poor original chassis layout, faulty design, poor tubes or bad connections.

From the standpoint of isolating the origin of an internal noise, the classification of whether noise is mechanical or electrical is important. Mechanical origin of noise is quickly determined.

MECHANICAL NOISE

Isolating Mechanical Noise: Not all receiver noises reach the ear through the loudspeaker. All noises that are electrical in origin, of course, do, but mechanical noises may enter the ear directly from their source. For example, the laminations in the power transformer may have worked loose and may vibrate. Cabinet doors may develop rattles. Various parts of the receiver and the cabinet may have what is known as acoustic resonance, and when a loud note comes through the loudspeaker at a particular frequency a sympathetic vibration will be set up, resulting in sound (noise). Sometimes the core laminations of an audio transformer are caused to vibrate and act as a very weak speaker unit; in this case the broadcasts will be heard even with the speaker disconnected.

A simple test can be made to determine whether the disturbing noise comes from the speaker or not. If a dynamic speaker is used, the secondary of the output transformer is disconnected from the voice coil and a good wire resistance unit of the same value as the A. C. resistance of the voice coil is shunted across the secondary, as shown in Fig. 2. If a magnetic speaker is used,

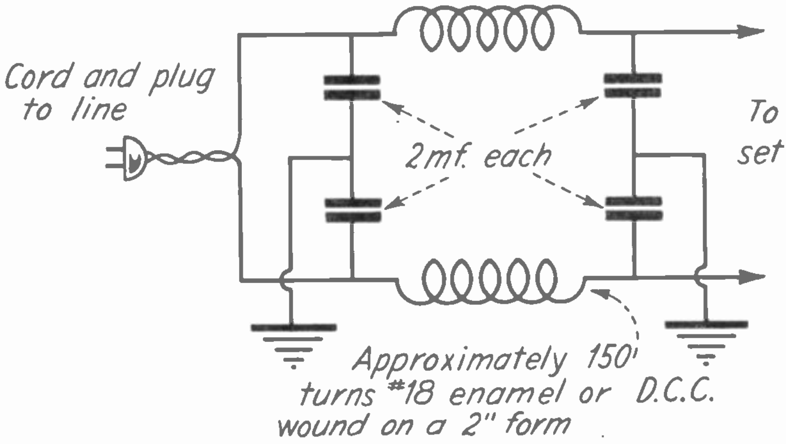


FIG. 1

the armature coil is disconnected and a shunt resistance is connected in its place. In the case of a dynamic speaker, the resistance may be from 6 to 30 ohms. In the case of a magnetic speaker, the average resistance is 4,000 ohms. There is no need of being exact in regard to the value of the resistance used in this test.

If the noise is still present with a resistance substituted for the magnetic unit or moving coil, we can be sure that the defect is mechanical, and that the sound is coming from the transformer laminations or some vibrating part. However, if there is no noise, test the speaker, in a manner to be explained shortly.

Microphonic Tube Noise: A very troublesome type of howling noise is caused by what are called "microphonic" tubes. These noises are most frequently low pitched ringing noises, which, when started, gradually increase in intensity. A microphonic tube is one which has loose elements—that is, the filament or generally one of the grids is not mounted very rigidly on its supports. As a result any mechanical vibration which reaches the tube causes the loose elements to vibrate. The distance between the elements varies, modulating the signal by varying the plate current in that tube. This changing plate current is amplified through the set and the speaker emits a howl.

There are two major causes for setting up tube vibration. First, sound waves coming directly from the speaker, which is technically called "acoustic coupling." Second the sound from the speaker causes the cabinet to vibrate and the cabinet vibrations are mechanically transmitted to the receiver chassis and then to the tube.

The detector is the most sensitive and the most likely to cause trouble. Placing your hand firmly on the detector tube will generally stop the howl, as the vibration is damped. In the older sets the detector tube was mounted on spring sockets or sponge rubber supports, which acted as a cushion or shock absorber. This is not as a rule necessary with present day tubes, because in the modern tube the elements are attached at the top to a mica disc which is supported by the glass dome. Modern tubes are designed to be non-microphonic.

The following remedies will generally be found satisfactory:

1. Change detector tube. A new tube need not necessarily be used if similar type tubes are used elsewhere on the chassis. Simply interchange tubes until a satisfactory tube is found for use in the detector socket. Although a tube may be microphonic when used as a detector, it will generally be satisfactory when used in an R. F. or A. F. stage.

2. In the very old table model sets using an external speaker, placing the speaker a short distance away from the set will often eliminate the howl. Turning the speaker in a different position may also help.

3. Use of the damper. "Tube damper" is the name of a heavy weight designed to fit over a tube. It is called a damper because it damps out or prevents the tube vibration. One of these weights placed on the microphonic detector tube helps to eliminate microphonic howls. In the case of tubes surrounded by a metallic shield the inside of the shield may be stuffed with asbestos wool. Try a modern tube of the same type.

Although a microphonic detector tube causes the most trouble, we should not overlook the first audio which also is sensitive to picked-up noise. Therefore, after correcting the effects due a microphonic detector tube and the noise is still apparent, correct possible trouble in the first audio stage.

Mechanical Rattles: Rattling noises that are by the process of elimination definitely shown not to exist in the speaker, as a rule are due to loose chassis parts. Any loose parts in the receiver or cabinet such as loose screws, nuts or hardware, if not securely mounted, may be set into vibration by the loudspeaker when operating. Noises thus developed are clicking, rattling, and

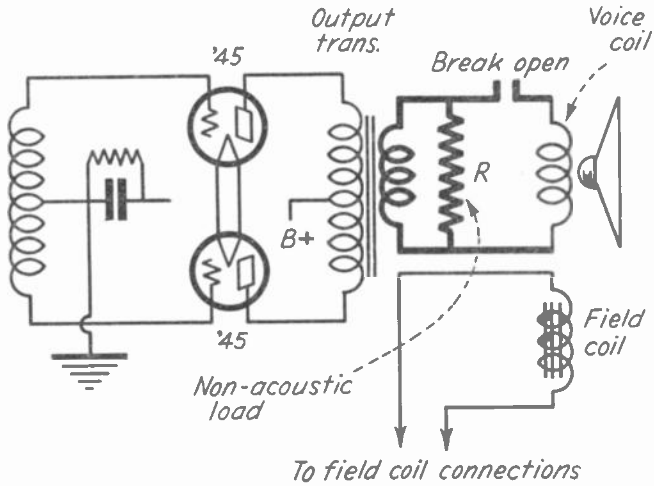


FIG. 2

metallic noises. The remedy, of course, is to go over the set and tighten all loose parts.

Mechanical A. C. Hum: A humming noise, if heard with the loudspeaker disconnected, may be due to vibration of the iron laminations in the power transformer, choke coils or audio transformers. The laminations may not be clamped tightly enough or a coil might be loose on its core. Tighten the clamps on the transformer or choke, wedge the transformer or choke coil tightly by means of bakelite spacers or thin pieces of dry wood driven in between the coil and the iron core. A study of the mechanical structure of the part will reveal the best possible way of correcting the defect. Quite often coating the ends of the lamination with a sticky non hardening varnish will stop this trouble. If the transformer is in a water tight case and the part does not overheat, pouring in insulation pitch may correct the disagreeable humming noise.

Mechanical Resonance: Noises which are directly caused in one way or another by the sound waves eminating from the loudspeaker are particularly prominent in sets where the loudspeaker is mounted in the same cabinet with the set. They are continuous ringing or moaning noises gradually increasing in intensity.

With a loudspeaker in operation, the sound vibrations set up mechanical vibrations which are transmitted to all parts of the set. For example, when the sound vibrations strike the tubes, microphonic noises are developed as previously explained. Sound vibrations similarly affect other parts of the receiver. This is readily proved in console sets by lightly touching the walls of the cabinet with the finger tips. The walls of the cabinet act like diaphragms. The greater the intensity of sound delivered by the speaker the more the cabinet will vibrate. But the magnitude of the wall vibrations is influenced by one other factor; namely, acoustic resonance. Every speaker we know has a "resonant" frequency—that is, it responds more to certain frequencies than to others. They are in effect "favorite" frequencies. Any part of the console is also capable of vibrating at its "natural" frequency —the frequency at which it vibrates most readily. When a frequency emitted by a speaker corresponds with the natural frequency of, let us say, the cabinet wall, a violent vibration of the wall takes place. This vibration is, of course, transmitted to all parts of the radio set, and may cause a microphonic howl.

In a number of modern receivers the chassis is made so that it floats on springs or sponge rubber. If such a support is included in the chassis which you are trouble shooting for this type of noise be sure that it is free to float. If freeing the chassis does not eliminate mechanical resonance, it may be possible that the rubber has hardened. Try new ones. If the set you are working on does not have this feature, unbolt the chassis and set it on sponge rubber. Be sure to keep the cabinet at least 2 to 4 inches away from the wall. The back of a console should be open.

Where a cabinet wall vibrates excessively, it has been found that, by lining the cabinet walls with celotex, or other acoustic sound absorbing material, the resonant frequency of the cabinet can be reduced or its amplitude of vibration reduced.

While we are on the subject of vibrating objects, it can be mentioned that the serviceman should look for loose ornaments, glass or wooden panels near the console speaker. Sympathetic vibrations may be set up external to the machine.

If the variable condenser plates vibrate, a howl is sure to be heard. Condenser plates have natural frequencies at which they vibrate most readily. When condenser plates vibrate the capacity changes periodically and the circuit is thrown in and out of resonance. The frequency at which this detuning takes place is the frequency at which the condenser plates vibrate. The variation in capacity has the same effect as if the radio wave were modulated at the vibration frequency. If these frequencies correspond with loudspeaker resonance peaks, the plates will vibrate more vigorously.

The same is true of inductance shields. The shields are subject to vibration if they are not rigidly mounted. When a coil shield vibrates, its position relative to the coil changes, and therefore, the inductance value of the coil changes. This causes detuning at the frequency of vibration, and a howl is set up. If the vibration frequency is the same as the natural frequency of the shield, the howl is intensified.

While the remedy in these cases may be obvious, it is not always easy to apply. Of course, shields should be fastened as rigidly as possible to the chassis. The original design is frequently at fault in that the shield material is too thin and subject to vibration. Thick shields are less apt to cause such trouble.

In the case of the condenser the vibrating plates are generally the rotor plates because they are not as rigidly mounted as the stator plates. Where it is possible, mounting the condenser on rubber or mounting the entire chassis on rubber feet will remedy the trouble, since the rubber acts as a shock absorber taking up the vibrations. Finally, mounting the speaker on rubber feet, and using celotex or some other sound absorbing material as a baffle will also assist in eliminating the howl.

ELECTRICAL DEFECTS CREATE NOISE

Electrical Origin of Noise: Any defect in the electrical circuit may give rise to steady or irregular crackling, scratching, grating, hissing and frying noises. They may be due to improper wiring connections, broken down insulation, poor tube prong contacts, shorted trimmers and variable condensers, defective tubes, defective variable and fixed resistors, defective coils and condensers, defective speakers, or run down batteries. We may hear whistles and hissing due to oscillation or regeneration in any

R. F., I. F. or A. F. stage. How can we recognize and repair such defects?

Electrical Connections: Defective connections or contacts are noise generators. This is usually readily detected by moving the leads to see if they are loose and noting whether the noise increases or decreases. Don't ever be afraid to pull on a connection if you suspect it of being defective. It is far better to have broken the connection entirely and to resolder it than to take any chances of having a rosin joint and an intermittent contact. The presence of a large amount of rosin around a soldered joint is almost a sure indication of an improper connection.

The presence of a green discoloration at a joint is a definite

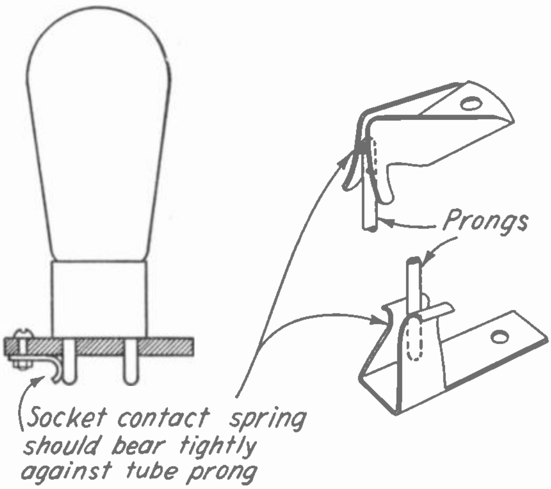


FIG. 3

sign of corrosion and indicates a possible source of noise. The only thing to do in this case is to resolder these joints after they have been perfectly cleaned. A poorly soldered joint will result in noisy reception in any radio circuit. This is because it causes irregular variations of current which are amplified and appear in the loudspeaker reproduction as disturbing noises.

Defective Socket springs are a sure source of noise. Some servicemen get into the habit of looking for this sort of trouble first, and by wiggling the tubes around in their sockets while the set is playing.

Socket spring contacts are made of rigid material which should spring back against the tube prongs when the tube is inserted in the socket. This material is usually a phosphor-bronze metal, nickel or cadmium plated. Socket contacts are really springs which exert pressure on the tube prongs at all times. Such springs may make good contact when new and then later develop poor contact for various reasons. The application of heat from a soldering iron to the spring may cause it to lose its temper and "its springiness." Heat softens the metal and continual pushing and pulling the tube out of its socket may result in giving the socket springs a permanent set away from the tube prongs with the result that intermittent contact is made or none at all.

If you bend a spring, it pushes back against the bending

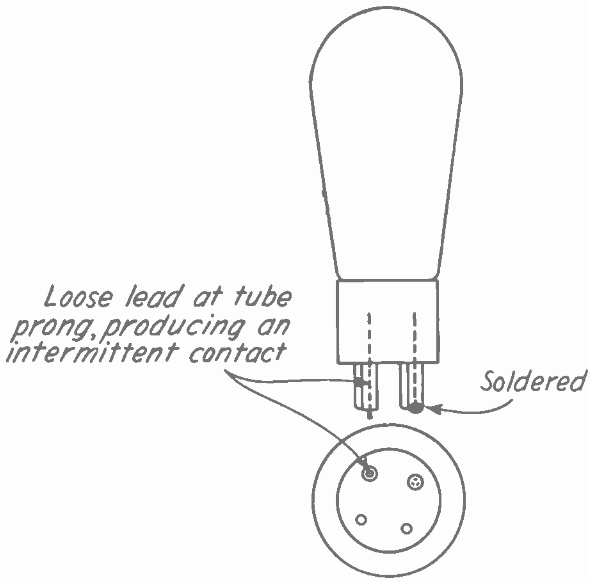


Fig. 4

force. This back pressure makes the contact. On the other hand, if you bend a piece of soft metal, it stays bent. This is what happens when the spring contact is soft. Bending the spring towards the tube prong till contact is made as shown in Fig. 3 will usually correct the trouble. However, if the spring is really bad or very soft, replacement of the socket is the best remedy.

Defective Tubes: If noise is traced to a tube and if examination of the socket spring contacts shows that there is a good contact between springs and tube prongs, the tube may be internally defective. Remove the tube and examine the tube prongs to see if there is a loose wire in the prong. Continual removing of the tube from the socket for various reasons may have caused the small amount of solder on a tube prong to have worked loose or dropped out. A drop of solder at this point will remedy this trouble, as shown in Fig. 4.

Even if the tube prong contacts are satisfactory, the trouble may be internal in which case a new tube is needed. Loose tube elements will cause noise. Frequently, a tube test will show up this defect. Tap the tube lightly with the fingers. No irregular noises should emanate from the speaker. A slight ringing noise may be noticed, but this is normal. If tapping a particular tube results in a crackling or sputtering noise, it is a sure sign that the tube is defective, or has internal loose elements or has a loose contact.

Defective Insulation: A frequent cause of a sputtering, hissing and frying noise is defective insulation. If an incomplete breakdown occurs between two points, noise results. Poor insulation in a power transformer may cause flash-overs and sparks. A frequent source of trouble is the bakelite terminal strip which generally carries all the metal terminals. The terminal strip should be thoroughly cleaned and dried. If leakage or breakdown has taken place, a part of the strip may have become carbonized or charred. This part should be scraped away with a knife. Dirt between posts may absorb water and at high potentials cause the same trouble. Dirt then, if present, should be removed. Breakdowns and leakage often become visible in the form of sparks which can be observed while the set operates in dim surroundings. In this way the offending part may be located. Power transformers, choke coils and filter condensers should be checked very closely since they are in the high voltage circuits. The rectifier tube socket should also be carefully examined for signs of leakage and possible breakdown.

Lead wires carrying high voltages, if close to wires at low voltage may result in trouble. If the insulation between them is punctured, there will be sparking between them and naturally noise will appear. This is especially true in hot, damp weather, and in humid areas where moisture condenses on the insulation. The only remedy in such cases is to use wire with the best of insulation, waxed and moisture proof (spaghetti,) and to separate wires and terminals at high and low voltages.* Where sets must

* Sparks and insulation breakdowns are determined by voltage difference. One wire may be at a high positive voltage, while the other may be at ground or at a high negative potential.

be operated in damp localities such as along the sea coast, it is sometimes desirable to remove R. F. coils, choke coils and other small parts and soak them in hot paraffin. Should the coils become moist, bake them in a ventilated oven, before dipping in hot paraffin. This will drive off the moisture.

Failure of wire insulation may be caused mechanically. For example, if a high voltage carring wire is caught underneath a metal clamp, the insulation may be broken mechanically. The wire may be partially grounded, causing an intermittent electric breakdown. Examination of the wiring will do considerable to locate such causes of noise.

Variable Condenser Plates: The variable condenser some-

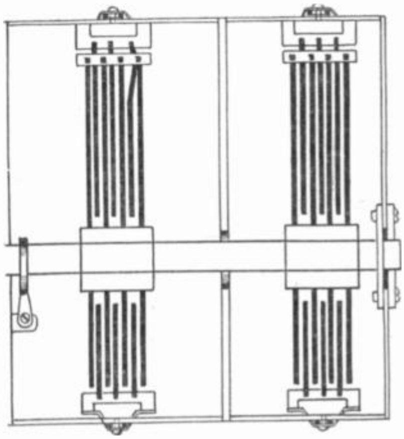


FIG. 5

times is the cause of clicking noises, especially as it is rotated. If the clicking noises occur at some definite dial setting, it is probably due to the condenser plates being bent out of line. As the position of the rotor plates are varied, the bent plates short against adjacent stator plates and a clicking noise is heard. Figure 5 illustrates such a condition. The bent plates should be straightened out and the condenser lined up to clear neighboring plates. After condensers are mechanically realigned, the stages should be electrically realigned.

In practically all receivers which have been operating a year or more, dust will have collected along the surfaces of the condenser plates. In time sufficient dust collects to make contact between the stator and the rotor plates as they are rotated. This dirt having a high resistance, short circuits the plates and a scratching type of noise is heard as the receiver is tuned. The remedy, of course, is to clean the condenser plates. This is best done with an ordinary tobacco pipe cleaner. Rub the cleaner over the entire surface area of both rotor and stator plates. Be sure to remove all dust and particles present. The use of air under pressure for this purpose is quite advisable, if a supply of compressed air is available. Many servicemen have at their workshop a hand bellows for cleaning purposes.

A number of variable condensers have been made where the plates of the condenser have been copper or cadmium plated. The plating often peels, resulting in noise as the main station selector dial is turned. A temporary cure, is to disconnect the condenser from the receiver and apply a 300 to 500 volts A.C. or D.C. source to the two condenser terminals. Be sure to use a series resistor to limit the maximum current flow. If the trouble persists use a new replacement condenser, with heavy aluminum plates. Such a procedure will only be possible if the dial is not calibrated in kilocycles or meters, as you are bound to upset the calibration. Do not try a replacement in superheterodyne receivers, as you are bound to have serious trouble in tracking.

A pressure contact between the rotor shaft and the condenser frame is the only electrical contact provided in most ganged variable condensers. If you find that noise traced to a variable condenser is not due to shorted plates, suspect this moving contact. Attach a pigtail connection. Drill the shaft and solder into the hole a flat flexible braid wire. Starting with the variable condenser open, or closed, wind up the braid and solder or clamp the other end of the braid to the condenser frame.

A Defective Gassy Tube will often give an undesirable *hiss*.* This is particularly true if the tube actually glows. Test the plate and grid voltages. If they are not normal correct the defect causing it before trying a new tube. If the new tube works, try the old tube. Never try to adjust the voltages so a gassy tube may be used. Never try a new tube before checking the supply for abnormally high plate and low grid voltages.

Variable Resistors or potentiometers used as volume, tone

* Do not confuse this with the hiss found in supersensitive receivers. As the tubes most likely to be gassy will be in the detector and A.F. system, you can check natural circuit and tube hiss (thermal agitation and tube shot effect) by shorting the input of the first or second R.F. stages. Hiss following this test is probably due to a gassy tube. Regeneration always accentuates hiss.

and minimum sensitivity controls very often become defective because they are constantly adjusted. They also may give rise to undesirable noise. Such defects are quickly identified by operating the receiver. If the defect is not a mechanical one that is easily remedied by soldering, bending contacts to get a better electrical connection or separating loose wires, it is far wiser to discard the control for a new one. Defects in the carbon strip of non-wire wound resistors cannot be successfully repaired. A new control should be used or if it is possible to obtain a new resistance element it should be installed. Don't try to "doctor" the resistance strip with a pencil or carbon smear, as such repairs are not permanent.

Resistors are frequently the cause of noise. It is not rare to find a noisy wire wound resistor. Because the kind of wire used in resistors is not easily soldered to, poor terminal contacts often occur. In some cases the manufacturer has only used pressure or clamp terminal contacts. High resistance wire wound resistors are made with a fine wire which breaks easily. A spark connection at the break gives rise to unusually severe noise.

Carbon and metallized resistors of even reliable make may have poor cap connections (point where the resistor unit makes contact with a moulded cap). Recent improvements in construction have naturally reduced such a possibility, yet you should be on the lookout for poor cap connections.

Test resistors with an ohmmeter and twist caps gently or press hard on terminal contacts for erratic needle readings.

Because of the granular construction of moulded carbon resistors, heavy current may cause uneven distribution resistance resulting in erratic current flow, in turn, giving rise to a hissing output. Usually this will be accompanied by a condenser or circuit breakdown which causes excessive current to flow through the resistor. It is assumed that the set maker had no original intention of overloading the resistor.

Bypass and Filter condensers may be the source of noise. Particularly suspect the type that is in a case. The internal leads may make poor terminal connections. A condenser that has been internally punctured may have an arc between the foil plates. Grimy, dirty condensers may be leaky on voltage rises. Often a moulded condenser is riveted to the chassis, the rivet connected to one side of the condenser (low potential terminal). If the rivet works loose, noise will be heard. Wet electrolytic condensers if operated beyond the safe voltage may sizzle, the noise coming direct or through the circuits. If a condenser looks like a possible source of noise, first be sure that it is mechanically perfect, that the circuit voltages are correct. Then try a new condenser. The condenser, unless defective, should hold a charge, have no unreasonable leakage, and should be able to handle peak voltage. This you can only determine by direct test, not by guess.

*Coils and Transformers,** in fact any electrical component of a receiver may produce noise, if their terminal leads or wires, if the wire used in the device, opens so that only a poor or arc connection exists. An ohmmeter test will show internal defects by its inability to hold its resistance reading.

Poor wire joints caused by electrolysis may even produce noise due to the voltages produced at the joint, modulated by vibration. Poor coil and transformer insulation may often be charred or carbonized and give rise to unwanted noise.

The speaker is another source of noise, and any one with some experience in repairing receivers can recognize most speaker noises without making complicated tests. If you are doubtful of whether or not the noise is due to a speaker defect, substitute a speaker known to be in good condition for the suspected speaker. This will immediately tell you whether or not the speaker regularly used with the receiver is defective. If you are employed by a dealer or distributor of receivers, you will find it convenient to have an extra speaker of the type used with the receivers you service most.† If a substitute speaker is not available, you may connect a head set to the secondary of the output transformer, listening for possible noise in the sections ahead.

Those noises which are due to the speaker proper are, in general, mechanical in origin, and therefore consist of rattles, clicks and scratches. Most troubles can be detected by a keen visual inspection. Any mechanical moving part of the speaker should be examined for rigidity and alignment with reference to other parts of the speaker. The two main types of speakers in use are the balanced armature and moving coil units driving either a cone or a column of air through a horn.

In another lesson complete instruction on the repair of

---

* In another text special tests on condensers, coils and resistors are taken up. Here we are only concerned with the fact that they may be a source of noise, how they may produce noise and the obvious service remedies.

† The makers of the Philco receiver, supply their distributors with a master speaker arranged so that the field resistance and inductance, and the proper speaker impedance can be adjusted for all types of their receivers.

speakers is given. This should be reviewed, keeping in mind defects and breaks which lead to receiver noise. We should mention here that in inspecting a speaker, look for loose parts, poorly soldered joints, loose nuts and screws, improper centering of armature of moving coil, dirt in air gap, bent driving pins, wet paper, fatigued diaphragms, locked armatures, loose turns on the voice coil, charred or defective insulation, open field coils and weak permanent magnets. Don't forget that, unless the speaker you use in tracing noise is perfect, and is a satisfactory electrical replacement for the defective one, it is a useless instrument for the detection of noise.

Battery Operated Receivers: The battery power supply is often a source of noise. The terminals corrode and poor internal or external connections develop. Moving the receiver around may have resulted in the development of poor external connections. The battery leads should be braided or tied together if possible, and kept free from contact with any moving object so that there is never any strain put on the battery connections and there is no chance for the insulation to be cut through by rubbing against a sharp object.

If a storage battery is found with corroded terminals, clean them thoroughly with a toothbrush and ordinary ammonia, but be careful not to spatter any on the house furnishings or in your eyes. If the battery clips are found to be corroded, clean them in the same way. Then apply with a small stiff bristle paint brush a thick coat of pure white vaseline to prevent future corrosion.

Run down B batteries are also frequent sources of sputtering and crackling noises. Each 45 volt B battery should be renewed when the voltage under load falls below 37 volts.

Often it is a single cell in a B battery that is a source of trouble. If this is the case, the voltage of the B battery when operating under full load will drop off. A voltage measurement of the battery when it is not delivering power is not an accurate check, as defective cells recover to a certain extent when not working. Always test a B battery with a high resistance voltmeter with the receiver in operation or with an equivalent resistance connected across the battery. If there is a shorted cell in the battery, its voltage will drop off 1.5 volts for each defective cell. The drop may be even more than this, due to the defective cell acting as a high resistance. Replacement of the B battery is the only remedy.

Storage batteries may be tested in the same way if there is no hydrometer handy. If the voltage of an ordinary 6 volt storage battery drops off as much as 1.5 or 2 volts, it either needs recharging or a cell is defective. A freshly charged A battery may cause some of the older type battery sets to oscillate at first when the volume is turned on full, as the battery may deliver slightly more than 2 volts per cell. Explain this to the customer telling him to keep the volume at a point where oscillation does not occur until the battery looses its excessive charge.

NOISE DUE TO REGENERATION AND OSCILLATION

Noises which are characteristic of some form of feed-back and oscillation generally manifest themselves as high pitched whistle, squeal, howl, and "put-put" noises, the latter commonly called motor-boating. Feed-back or regeneration may occur in one form or another, in almost every set. It occurs whenever the

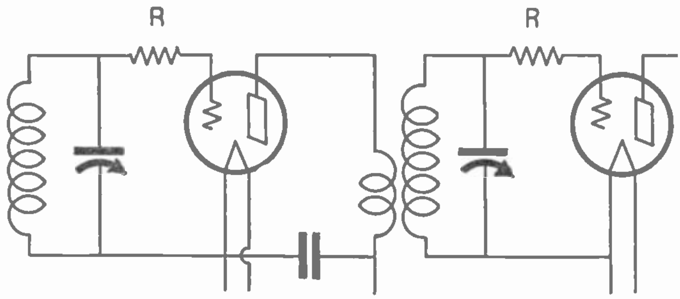


FIG. 6

plate circuit of a tube is accidentally coupled to its control grid, and whenever the output of an amplifier is coupled to any part of the amplifier ahead of it. This is especially true in screen grid sets.

When the set oscillates at radio frequency a characteristic squeal or whistle is heard. The pitch of this whistle changes, going up and down in scale, as the variable tuning condenser is rotated slightly from the point at which the squeal is heard.

Receivers which employ feed-back and oscillation neutralizers may squeal or whistle if the neutralizing adjustment has been jarred or tampered with. Replacing tubes may cause the original neutralization adjustment to be ineffective. Open grids in the R. F. section, defective or inadequate grid suppressors often give rise to squealing. These facts you are acquainted with, but you should remember that neutralizers are used only in

R. F. and I. F. stages where triode tubes are employed. Triode amplifiers are generally to be found in the older receivers. This does not mean that screen grid and pentode tube stages will not oscillate, but it is generally due to shift in grid and plate wires, or an open shielding, or an open condenser, or excessive plate or screen voltages, or initial poor design.

When you have finally traced the squeal to a feed back not

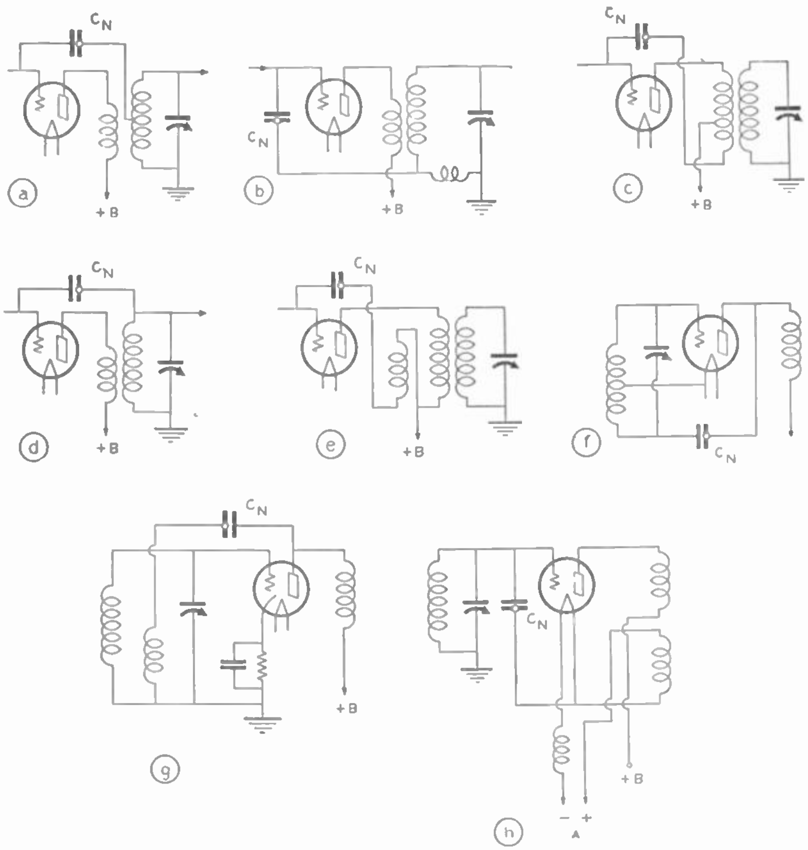


FIG. 7

due to an imperfect ground, excessive supply voltage, imperfect shielding, open by-pass condensers, or misplaced plate and grid wire, and no scheme of neutralization is used then suppress the squeal by placing a resistor in the grid circuits as shown in Fig. 6. It is generally inadvisable to add neutralizing circuits although the scheme shown in Fig. 7d may be tried. Grid suppressors varying from 100 to 1,000 ohms may be tried, connected in series with the control grid connection in each case using the smallest value necessary to destroy the objectionable feedback.

Feedback from the plate to the grid circuit was eliminated in a large number of the old receivers, by a counter-fed voltage. Figures 7a to 7b show some of the circuits used. These circuits are used in either filament or heater type triode tube circuits, never in tetrode and pentode tube circuits. The theory of adjusting an R. F. stage is as follows: With the filament circuit of the tube open, tube inactive, the signal may be passed into the next stage either through the grid-plate capacity of the tube or through the coupling circuit associated with C_n, the neutralizing condenser. As the two signals fed through are in opposition to each other neutralizing is realized when C_n is adjusted so no signal is passed on.

In Radio circuits where filaments are in parallel merely opening the filament circuit of the tube whose stage is to be neutralized is necessary to make the tube inactive. Use a universal socket adapter with an insulation peg in the filament lead or slip a soda fountain straw over one of the filament prongs. In series filament circuits, as used in some receivers, the filament is opened at x in Fig. 8 and the external filament circuit is completed with a resistor R equal to the rated tube filament voltage drop divided by the rated tube filament current. Other schemes have been suggested as operating the tube at high grid cut-off bias, or opening the plate circuit without disturbing the plate supply to cathode by-pass condenser, point y in Fig. 8.

The usual procedure in neutralizing the circuits shown in Figs. 7a to 7h is as follows:

1. Tune the receiver to a modulated signal generator adjusted to about 1000 kc. A local station may be used.
2. Make the tube ineffective as an amplifier in the way just described. Tube filament will not light or heat. Start with the R. F. or I. F. stage nearest the receiver input that employs a neutralizing circuit. Always use the tube to be left in the receiver. Therefore, first test the tube for mutual conductance.
3. Using the appropriate neutralizing tool adjust C_n, the neutralizing condenser, midway between the adjustments where an aural output signal is heard. If removing the tool upsets the adjustment, compensate so that no signal is obtained when the tool is withdrawn.
4. Restore the normal connection of the tube so that it will amplify.

5. Repeat the procedure for each R. F. and I. F. tube provided with a neutralizing adjustment.

If, after neutralizing the set, the oscillation noises still continue, it indicates that there are some other forms of feedback coupling present.

In general, if oscillation is present in the radio frequency stages, the following may be the cause—this may be true even of modern screen grid and R. F. pentode tube systems.

1. *Poor or No Grounds.* Receivers may oscillate if a poor external ground is connected to the receiver. In fact short wave regenerative receivers often work better when the main ground is disconnected.

Various parts of the receiver are grounded for example: one end of grid coils and resistors, cathodes, C bias resistors, variable

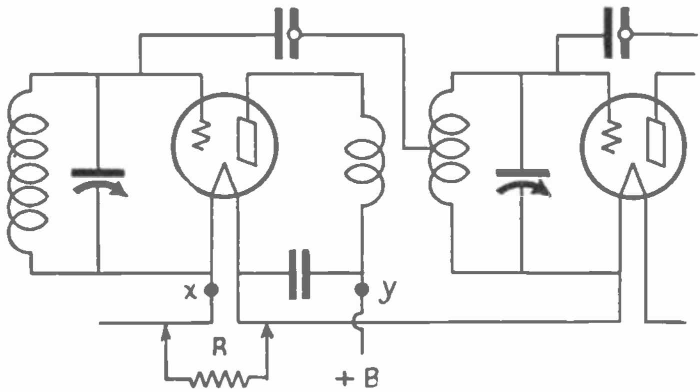


FIG. 8

and fixed condensers, shields, etc. Should a poor ground connection exist at some point in the receiver, the signal current may be forced to take another path to ground, often coupling with another stage to set-up regeneration and oscillation.

In broadcast receivers it is customary to use the chassis frame as the common ground connector. For low R. F. frequencies the impedance of signal paths through the chassis is so low that even if various stages have a common coupling through the frame, the voltage drop existing is too small to cause serious feedback. Should a ground connection at some part open or even become a high resistance joint, the signal will take another ground path, with the resultant feedback. The remedy is to go over the chassis for poor coil, condenser, resistor and shield ground connections.

Short wave receivers often employ special ground wires from the various circuit components, connected together at the ground binding post or some common point in the chassis. Unless these ground wires are carefully laid out, feedback is likely to occur. Look for misplaced or open ground lead wires.

2. *Too much gain* or amplification will also cause excessive regeneration or oscillation. There is a definite limit to the amount of amplification which every set is capable of giving, and still be stable. This limit is primarily set by the amount and nature of the shielding—the layout of the lead wires, and the constants of the circuit. The better the shielding in a given set the more amplification we can get out of it along with stability. But there is a definite limit to this amplification which is set by the designer of the receiver. Now if there are any conditions which tend to increase this amplification, feedback and oscillation will occur, with resultant noises. The amplification of an R. F. stage increases with the plate voltage and also with the screen grid voltage applied to the tubes. Check these voltages to see if they are excessive.

3. *Imperfect shielding.* The object of shielding is to prevent coupling from one coil to another, or from one condenser to another. Reliable makes of receivers are supposed to have satisfactory shielding. The trouble frequently arises when the shields are not securely in place. For example, the shield over a coil may not be clamped tight to its bottom plate leaving an opening or crack. This crack is sufficient to allow the magnetic field to leak out and enter another stage and so cause oscillations with resulting squeals. Shields may not be properly grounded. The shielding should, therefore, be examined to make sure that it is in good condition.

4. *Open by-pass condenser.* In some receivers, for the sake of economy, the tubes may be operated from a single bias resistor shunted by a condenser. The screen grids and plates connect to a common supply terminal shunted to ground by a single condenser. See Fig. 9. Should one of these condensers open, coupling from one stage to another may cause regeneration or oscillation. In general any open by-pass condenser in any type of circuit may cause undesirable interstage coupling attended by squeals and whistles. Even if the condenser is intact, its by-pass action may be inadequate. Try a condenser with a larger capacity or use resistor-capacitor filters. Open or inadequate by-pass condensers give rise to a howl or squeal that may be heard without tuning the receiver.

5. *Haphazard wiring* of the plate and grid leads may result in coupling, causing oscillation. If the grid and plate leads in the radio frequency circuits are wired very closely together or run parallel to one another, voltages are induced from one circuit into the other causing regeneration. These should be separated and placed as far apart as practicable so that these couplings are eliminated. In most cases it is best to have the plate leads nearest the chassis.

AUDIO FREQUENCY REGENERATION

Whistling noises, squeaks, put-puts and howls may be developed in the audio frequency amplifier independent of the radio frequency amplifier. The following causes for this trouble with the remedies should be carefully studied.

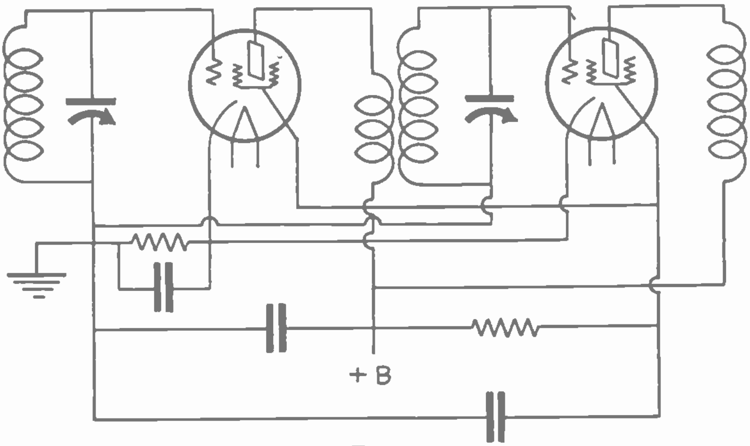


Fig. 9

1. Coupling between speaker leads and detector grid circuits. If the speaker leads, A. C. line leads or plate leads from the audio frequency tubes are close to any part of the detector grid circuit, such as a grid resistor, grid condenser, grid lead wires or near the detector tube itself, a squeal may be heard. The remedy, of course, is to remove these leads as far from the detector circuit as possible.

2. An open plate circuit in the detector may also cause howling. This may be an open in the primary of the transformer located in the plate circuit of the detector, or an open plate circuit between the power pack and the audio transformer, or an open power supply bypass condenser in the plate circuit.

This particular trouble is easily verified by checking the plate-chassis voltage. If this voltage does not exist check the plate supply. If this is found intact the plate coil or resistor is open. Complete the connection or replace the defective part. If the howl is still present, the detector tube may be defective and should be tested. However, if the tube and transformer are O. K. but there is no plate supply voltage, check the power supply by tracing all connections and make the necessary corrections.

3. Open grid circuits in any part of the audio amplifier will cause a low pitch squealing or howling noise. An open secondary of an audio transformer, an open grid input resistor or an incomplete grid return may be causing the trouble. This condition is generally indicated by an absence of grid bias voltage on the audio frequency tubes. Where a high resistance path is normally provided for applying the grid bias, an open grid circuit is best checked by measuring the cathode-chassis voltage and the plate current.

4. Open by-pass condensers or insufficient by-pass condenser capacity in the plate or grid bias circuits of the audio frequency tubes will cause the same noises. This is generally the cause of motor-boating. When motor-boating and hum are heard it may be due to inadequate power pack filtering particularly the filter output condenser. Check plate-cathode by-pass condensers, increase their value or use a capacitor-resistor filter, the resistor being of low value (5,000 to 20,000 ohms).

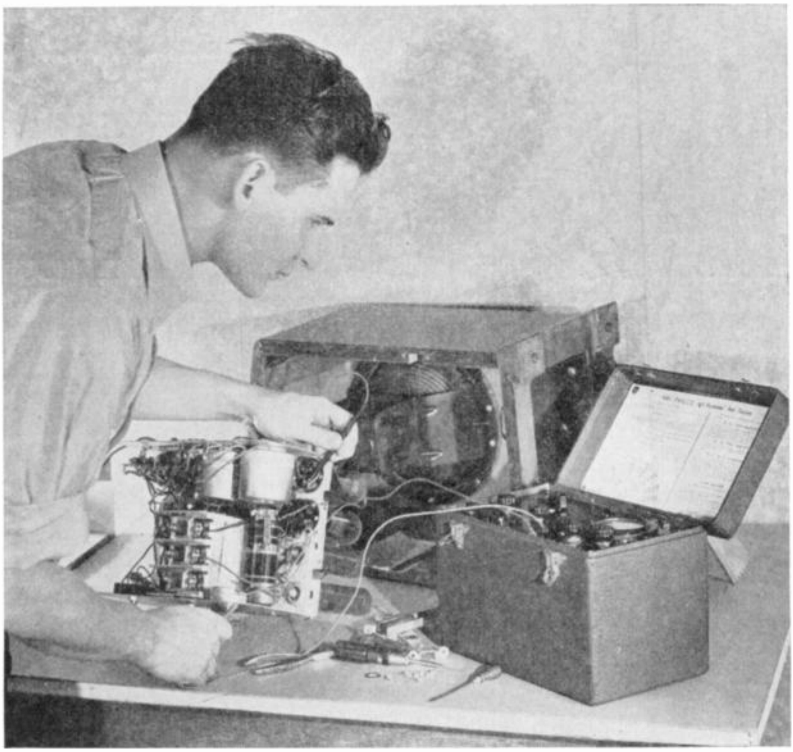
INTERNAL RECEIVER NOISE ISOLATION

From what has been said so far in this text, we should have a clear insight as to the causes of internal receiver noise and feedback squeals and their remedy. For the serviceman the most important initial step is the isolation of the defective stage or, if possible at once, the exact defect. A systematic procedure yields the quickest results. Here is a suggested procedure.

1. First determine if the noise is external or internal as previously explained. With experience you will be able to detect feedback oscillation and tube or regeneration hiss. Remember that squeals can be radiated from a neighbor's receiver. Regeneration that is produced when tuning a receiver to some station is produced within the receiver under test. You now know that the noise is at the receiver.

2. Check for surface defects and test for mechanical noise in the manner previously explained. Are there any loose parts on

the chassis, in the cabinet, near the receiver that will cause resonant vibration? Are tube or coil shields open, creating feedback? Is the detector or first A. F. tube microphonic? Does the speaker cord come anywhere near a tube to cause feedback? Are any of the tubes poorly held in their sockets? Are the control grid caps firmly in place and do not make contact to the tube shield?



Working on an open chassis

3. Effect to cause reasoning has an important place in noise and feedback isolation. Does the noise or rattle sound as if it originates in the speaker? Does the howl sound like an open grid? Does the squeal sound as if it is due to ineffective neutralization? Is the noise the result of tuning the dial or making a normal receiver adjustment? Does jarring the chassis give the noise? What you hear may have a lot to do in telling you the location of the defect. This can only come from experience. When an effect

leads you to a possible cause of trouble always check the source before extensive repairs.

4. Failing to locate the defect while the chassis is in the cabinet and by now being reasonably sure that the defect is internal, remove the chassis from the cabinet. Place the receiver on one end, supporting it if necessary, and remove the bottom chassis plate if one is used. The bottom of the chassis and all the wiring must be in full view. You should be able to turn the power switch on, get at the top of the chassis—that is, get at any part while the set is in operation or turned off. Again go over the underside of the chassis for surface defects. Are there any poor soldered joints, any corroded joints, are the coil shields firmly in place, are the socket prong contacts making firm pin contact, can you see loose contacts, does the insulation look charred or worn away? Turn the set on and preferably in dim lighted surroundings, look for sparks or arcs. Only after an extensive visual check proceed to a systematic noise isolating procedure.

5. *Stage by Stage Elimination Test.* Starting with the output stage short the input circuit, grid to grid short in a push-pull or push-push stage, grid to chassis short in single tube output stages. This removes the effects of the previous stages. If the noise which at this point is easily recognized, is heard, the trouble is in the output stage, tube or tubes, output coupler or the power supply. Be sure to check the electrical voltages and currents. If the main voltage supply is producing the noise, a plate-chassis supply voltage measurement will show a decided tendency to vary erratically—the needle will jump around. Try shorting the input of the preceding stage. An increase in noise definitely indicates a defect in the supply.

If the output stage check does not isolate the defect, proceed to short the input of the first A. F. stage or detector whichever couples to the output stage. If noise now comes in, it is due to a defect in this stage or its power supply connection. Check the circuit carefully for defective parts. Proceed this way through the detector, I. F. section, oscillator, pretuner until the source of trouble is definitely located in a particular stage.

In the R. F. stage where the trouble has been traced to the variable condenser, short the input of each of these R. F. stages so you can detect in which section of the gang condenser the defect exists.

Another stage isolation procedure would be to insert a headset (phone) or a milliammeter in each stage proceeding from the antenna input to the receiver output. Headphones connected in series with the defective circuit will reproduce the noise. Noise in the stage will cause the meter needle to flicker. A universal socket adapter is a valuable quick aid for such tests.

The most frequent source of noise within an isolated stage is due to varying resistors, intermittent or poor contacts or opens. An ohmmeter is the essential device in noise isolation. Poor connections or contacts are observed by a flickering needle reading. Variable resistors are tested in the same way, except the ohmmeter should show a smooth increase or decrease in reading. Always shake the part that is being tested for noisy connections.

Tubes may block intermittently due to open supply circuits, particularly the grid supply leads. Voltage readings should show normal applied electrode voltages.

Intermittent Reception

When the customer's complaint is that the set plays for a short time and then cuts off, only to repeat this performance, you have a trouble shooting problem that is referred to as intermittent reception. There are various types of intermittent reception, namely:

1. Set plays, cuts off and plays, at regular intervals.
2. Set plays, cuts off and doesn't play until the set is jarred. Mechanical disturbance.
3. Set plays, cuts off and doesn't play until the main power switch is turned off and on, or a control grid cap is touched, or some tube is pulled out of the socket, or turning off and on some light or electrical device on the same power line as the set. Electrical disturbance.

Frankly the isolation of the defect causing intermittent reception is the most intangible, most elusive sort of job that a serviceman may tackle.

If the set cuts off and plays, cuts off and plays at a definite time rate, you will invariably find the trouble due to a thermostatic electrical connection. In general, you will find it in a circuit which carries current. Thermostatic joints are those which make contact intermittently due to heat expansion of dissimilar material, for example, solder and copper. When the receiver, tubes or any part or any connection is at room temperature the connection is complete. When the temperature rises, dissimilar expansion opens the connection. If the temperature rise is due to heat produced at the joint, the cut-off will be of short time duration. If the temperature rise is due to the average heat of the chassis, the cut-off will be of longer duration. In the first case we probably have a break in a supply current carrying joint, and in the second case probably a signal carrying joint.

Tubes are often to blame for intermittent reception. If any of the welds between the elements and the support to the lead conductor should open or short because of expansion, the amplifying action of the tube is destroyed and the set cuts off. As soon as the tube cools off the connection is restored, or the short opens and the set plays. The set may not cut off entirely, merely fade to a low sound level.

Resistors or coils carrying current may open up after carrying current for a short while. Any contact connection is subject to thermostatic action. One serviceman in an attempt to associate the time of cut-off with the probable cause of a thermostatic joint gives the following table:

Period	*Probable Cause*
0 – 3 minutes	Defective tube, supply current carrying joint.
3 – 5 minutes	Resistors that are slow to heat up, particularly types with large heat radiation surfaces.
	Series filament resistors in universal D.C. and battery sets.
Over 5 minutes	Transformers, coil, or joints that are affected by the surrounding temperature or carry only weak currents.

In some cases the joint after opening up will stay open, because the joint has no spring to return the lead that moved away. Such connections may remain open until the set is mechanically jarred. You may track this down by a stage by stage elimination procedure, being extremely careful to prevent mechanical jarring.

Where the set is restored to operation by an electrical disturbance (try a mechanical disturbance first), reception may be restored because the electrical surge results in an arc connection. Look for sparks in the chassis. Noise will probably accompany the restoration of performance. An open circuit connection, like an open grid resistor or coil, may still permit the receiver to work until some electrode, particularly the control grid, develops a charge sufficient to block the operation of the stage. Any slight electrical disturbance will unblock the stage, restoring operation. In superheterodyne circuits the local oscillator may block and thus stop operation. Any electrical disturbance may reestablish oscillation.

If intermittent fading is observed, then you may have an open by-pass condenser. Intermittent rises in volume may be caused in the same way. Be sure that antenna and ground system is intact. Shake the aerial and ground leads, listening for noise, or better still connect a signal generator to the input after the fading appears. Thermostatic joints in coupling condensers invariably destroy reception and defects here may easily be confused with resistor and coil opens. Only a replacement condenser will check such defects.

A systematic procedure for isolating the defect of intermittent reception is recommended.

1. Start with a search of possible surface defects, including an inspection for a defective pickup system.

2. By an effect to cause reasoning you may be able to tell what and perhaps where the trouble may be.

3. Check tubes. Put in a new set of tubes and leave them play for a time greater than the cut-off period. Then replace the old tubes one at a time, each tube tested for a reasonable period.

4. Open chassis. Look for sparks and arcs. Look for corroded or resin joints. Check condensers for opens by shunting them with ones known to be in good condition. Be sure in the latter case that you make this substitution while the set has cut off.

5. Try a stage isolation procedure. In A.V.C. sets using a visual indicator, watch the indicator before and after cut-off takes place. In other circuits place a plate milliammeter in each stage. Where the number of meters are limited you will have to check one stage at a time. A change in any supply circuit will generally show up as a change in plate current in the defective stage. Defects in signal circuits which do not carry an electrode current or complete a voltage connection can only be checked with a vacuum tube voltmeter.

You may start with the signal generator connected to the detector and leave the set on for a reasonable period. If the cut-off does not appear, advance the signal generator to the input of the previous stage. When reception is restored by the least touch or electrical disturbance, a stage elimination test is about the most reasonable procedure to take.

6. After the defective stage is found, inspect every circuit

component. You may have to change every part in the circuit. Do so one at a time.

7. When you feel that the defect has been repaired, play the receiver for at least three to four hours over the cut-off period, before approving the job.

Keep a record of all defects for future reference. Be sure to record the make and type of receiver. Weaknesses in certain designs may result in intermittent reception. If you consult the service manager of the local distributor of the receiver you are working on, he may give you some valuable clues to the possible trouble.

It may take you ten minutes or ten days to correct an intermittent defect. Most of the time will be lost in waiting for the receiver to cut off. So always do such jobs along with other bench repair jobs. Intermittent reception defects traced to internal defects are best located at the bench and to one side so as not to interfere with your regular work. Be sure that the chassis is open, and on end so that you see and can get at every part. Don't get discouraged, the best service technicians realize that a defect of this kind has no mercy on their patience.

TEST QUESTIONS

Be sure to number your Answer Sheet with *the number* appearing on the front cover underneath the title of this text.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your Course, and the best possible lesson service.

1. Where would you look for noise if upon connecting a headset to the secondary of the output transformer after making a test for mechanical noise, the noise disappeared?
2. What sounds indicate an open grid in the A.F. amplifier?
3. How would you cure motor-boating traced to an A.F. stage?
4. An expert Radio-Trician cured a severe rattle noise by moving the radio to some other position in the room. Moving the cabinet away from the wall in the first position did not stop the rattle. What defect did he find?
5. What kind of noise would indicate the possibility of dust between variable condenser plates?
6. Where would you expect to find the trouble, if intermittent reception reoccurred in intervals of 2 minutes?
7. What effects might be observed if a thermostatic joint existed at the terminals of a by-pass condenser?
8. What is the purpose of the test in which the aerial and ground post of the receiver are shorted, and a line filter is temporarily inserted in the supply leads?
9. How would you test for poor tube socket contacts, when the chassis is in the cabinet?
10. How would you test for a poor contact in a coil?

Noise and Intermittent Reception. No. 44 RH

1. In the loudspeaker system.

2. Low pitched squeals and howls.

3. Check the by-pass condenser. Increase its value if necessary. In severe cases insert a plate resistor-capacitor filter.

4. Some loose parts in the room caused to vibrate by the sound emitted from the loudspeaker.

5. A scratching noise appearing when the tuning dial is rotated.

6. Thermostatic joint in a defective tube or a joint carrying a supply current.

7. Intermittent fading or increases in volume.

8. To ascertain whether the noise is of internal or external origin.

9. Wiggle the tube and listen for noise.

10. Measure its resistance with an ohmmeter and look for needle flicker. Shake the coil.

RECEIVER HUM

45RH

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

DO YOU REMEMBER NAMES?

The secret of Jim Farley's success as a politician?—He can call 50,000 people correctly by their first names. The average man is more interested in his own name than in all the other names on earth put together; remember that name and you pay him a very effective compliment, but forget it or misspell it and you are instantly at a disadvantage.

One of the simplest ways of gaining good will and making people feel important is by remembering names, yet how many of us do it? We are introduced to a stranger, chat for a few minutes, and ten to one we can't even remember his name when we say goodbye.

The technique of Napoleon III of France, who boasted he could remember the name of every person he met, can be used to advantage by anyone, even today. If he did not hear a name distinctly, he politely asked that it be repeated; if it was an unusual name, he would request that it be spelled out. During a conversation, he repeated the name at every opportunity and tried to associate it with peculiarities of the man's features. If the man were some one of importance, Napoleon would, when alone, write the name on a piece of paper, concentrate on it for a few minutes, then tear up the paper.

How well do you remember names?

J. E. SMITH.

NATIONAL RADIO INSTITUTE

WASHINGTON, D.C.

1942 Edition

A LESSON TEXT OF THE N. R. I. COURSE WHICH TRAINS YOU TO BECOME A

RADIOTRICIAN & TELETRICIAN

(REGISTERED U. S. PATENT OFFICE) (REGISTERED U. S. PATENT OFFICE)

NCP2M142 Printed in U. S. A.

Receiver Hum

ORIGIN OF HUM

Hum is a common trouble that the service man will constantly be required to eliminate. It is evasive and hard to trace down. Rarely indeed can a service man take his set analyzer and by making the usual routine measurements locate hum, especially in an A.C. operated receiver. A thoughtful and systematic procedure must be followed. In many cases, it is necessary to make many investigations and measurements before hum is finally located and overcome. In this book we will cover important sources of hum thoroughly, so that anyone versed in

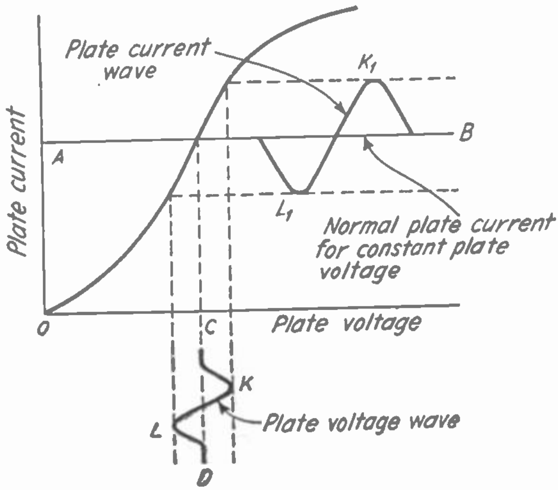


Fig. 1

radio servicing can locate the source of hum and make the necessary corrections.

Hum may be caused by any low frequency variation in the voltage supplies of any vacuum tube stage of an A.C. receiver, when the variation is due to improper connection to the A.C. supply or to inadequate filtering in the power pack. If this variation or "hum ripple" exists in an audio or the detector stage (second detector in superheterodyne receivers), the hum will appear in the speaker output whether or not the set is tuned to a station. However, a hum ripple introduced into an R.F., I.F., first detector or oscillator stage will not get through to the speaker unless it is modulated on an incoming carrier or the beat frequency, or unless it sets up self-oscillation and forms its own carrier.

Figs. 1 and 2 are shown to refresh your memory on the action of tubes as amplifiers. Fig. 1 shows the variation in plate current due to plate voltage variation, while Fig. 2 shows the effect of a C voltage variation. Similar curves could be drawn for changes in screen grid, filament and suppressor grid voltages, the only difference being in the degree of change.

In the detector or A.F. system, any supply variation at a hum frequency will be amplified and relayed by the associated equipment and will therefore be heard even if the R.F. system is not tuned to a station.

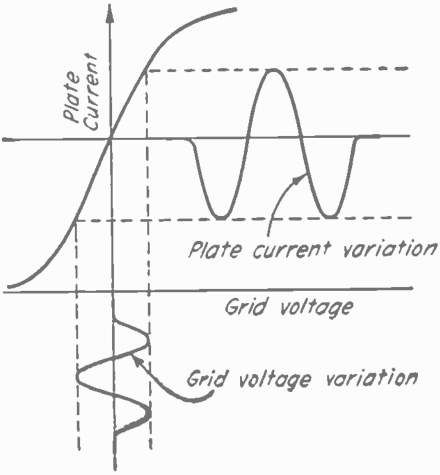


Fig. 2

If the variation takes place in an R.F. or I.F. stage, and the amplifier tube operates *absolutely* on the straight portion of its operating characteristics (acts in a linear fashion), the corresponding variation in the plate current will be wiped out by the tuned section. Unfortunately, the characteristics of any practical amplifier stage are far from straight. Because of this, the incoming carrier or beat frequency will be modulated by the undesired variation. When the R.F. or I.F. system is well designed,* it will take a large variation in the operating voltages

* R.F. and I.F. systems are always designed to have a low factor of cross-modulation and modulation distortion. When such distortion is reduced to a negligible amount, hum modulation in the high frequency sections of the receiver will be negligible. The use of variable mu tubes ('35, '51, '58) reduces such distortion and hum modulation as well.

to cause the introduction of hum (hum modulation). Hum modulation may automatically take place in tubes like the '24 or '57 having normally a low C bias cut-off, when they are fed with a strong carrier signal.

Because the high frequency system of a receiver is built to have tremendous gain, every precaution is taken in the elimination of supply variations, for a high input signal may cause hum modulation in the input stages and a low input signal may be hum modulated in the last R.F. stages. As a service man, you will be required to be on the lookout for defects which will introduce hum modulation.

Any defect which will cause the high frequency stages to oscillate will also allow the variations in supply voltages to in-

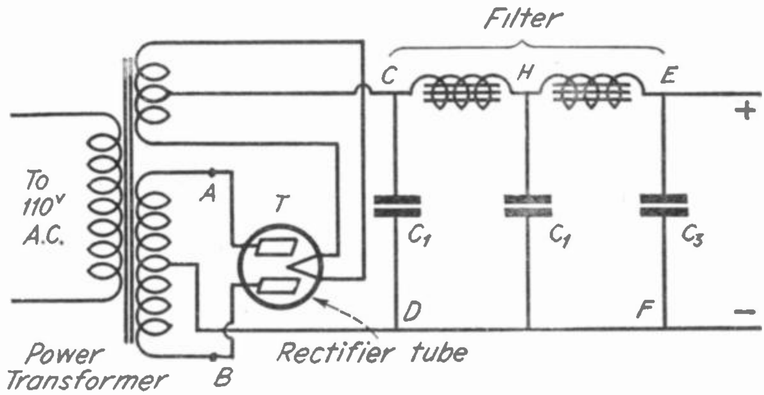


FIG. 3

troduce hum modulation. This condition is natural in the oscillator of the superheterodyne and the supply voltages must be adequately filtered to remove hum modulation. A good radio receiver designer takes all possible precautions in the prevention of hum in all stages of the receiver, and it is your duty to keep defects from marring the original design qualities.

In A.C. operated receivers, voltage and current are supplied to the tubes in two ways. To supply the filaments, A.C. current is taken directly from the line and applied through a step-down transformer. To supply the D.C. potentials the line voltage is stepped up and then it is rectified and filtered by the power pack of the receiver.

The alternating current applied to the filament is one source of hum, for as the alternating current varies, it follows that the temperature of the filament must also vary. This is particularly true of tubes with thin filaments, having little or no thermal lag. This, of course, affects the electron stream from the filament to the plate and it will vary in unison with the variations in temperature.

This is particularly true of tubes in which the filaments are electron emitters such as the '26, '71A, '45, '47 and '50. It is less noticeable in the case of tubes whose cathodes are indirectly heated, such as the '24, '27, '35 and '56. If correct voltages are applied to a '26 tube, the hum may not be of sufficient magnitude to be troublesome. However, if incorrect voltages are applied or if the tube filament deteriorates through long use, hum will result.

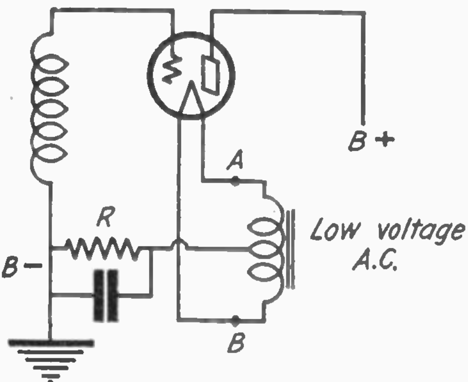


Fig. 4

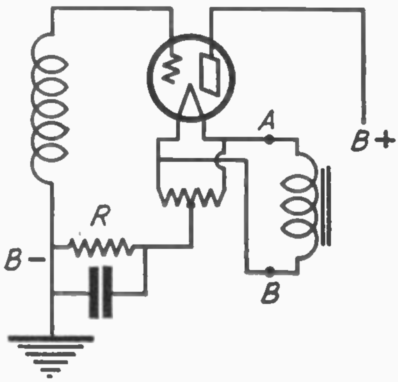


Fig. 5

These circuits are typical of the output A.F. stages in modern receivers. They have been used in the R.F. and intermediate A.F. stages of old receivers.

The plate and grid voltages of the A.C. tubes are supplied by an alternating current rectifier and filter as shown in Fig. 3. The voltage from such a source is never the pure unvarying voltage that can be obtained from batteries, but has, in addition to the regular rectified voltage, small variations super-imposed on it. These variations correspond to a 120 cycle frequency in the case of an '80 type rectifier and a 60 cycle frequency in the case of an '81 rectifier. The variations, although small, may result in hum if they are present in the grid bias, screen grid, or plate voltage supply.

In battery operated receivers hum is generally absent unless the battery supply is replaced by A and B eliminators. Then the receiver is A.C. operated and we have the same problems as in receivers employing power packs—it is impossible to filter out all the "ripples" in the rectified A.C. and there are small variations in filament, plate and bias voltages.

Hum voltages may also be introduced into tube circuits by magnetic induction. The strong alternating magnetic field of a power transformer may reach out and influence other parts of a receiver, for example, the audio frequency transformers. If the audio transformer is so placed that the magnetic field from the power transformer links with it, there will be a small voltage induced in the audio transformer which will be amplified, resulting in a hum. This is often true even though both transformers are well shielded. In many cases, the lead wires to the audio transformers pick up enough magnetic energy from the power pack to cause a hum output.

Electrostatic induction is another cause of hum. About the rectifier tubes there exists a strong electrostatic field due to the high voltage alternating current applied to this tube. This field may influence parts of the receiver, such as the detector tube or its circuit. The circuits or parts so influenced pick up electrostatic voltages which are amplified.

In most manufactured receivers, hum has been guarded against by careful shielding and placement of parts, but you can readily see how any abnormality in the receiver may result in slight hum voltages which through amplification, quickly reach large magnitudes.

HUM IN A.C. FILAMENT TUBES

The filaments of A.C. tubes are supplied with raw alternating current. In order that hum in receivers be kept down to a minimum, the filament circuits must be connected to the signal-carrying circuits in such a way that the A.C. ripple is balanced out of the amplifying circuit. (It must be remembered that the filament or cathode is the common return for all circuits.) Figs. 4 and 5 show the connections to an A.C. filament type tube and the method employed in obtaining the grid bias. This method is common for all direct heater type tubes such as the '26 in R.F. stages or the direct heater power tubes such as the '45, '47 or '50. The filament voltage is supplied through a low voltage step-down transformer. The plate current flows through a resistor connected between B negative and the center tap of the low voltage secondary as in Fig. 4 or the center of a resistor placed across this supply secondary as in Fig. 5.

In some circuits, the center tap connection may be made through an adjustable resistor connected directly across the winding, and the bias resistor is, of course, connected to the center tap. In any case, the center point must be a true electrical balanced center, for if any alternating voltage from the filament is applied to the grid of the tube, it will be amplified and appear as a loud hum. Notice that the grid is connected to the A.C. filament by means of the grid bias resistor. When point *A* is positive, point *B* is negative. This is fundamental in any A.C. circuit. If the biasing resistor *R* is connected to either point *A* or *B*, the grid will receive in addition to the bias voltage, a strong A.C. voltage which will cause hum. Somewhere between the positive point *A* and the negative point *B*, there is a *balanced neutral point*, where the A.C. voltage between *A* and *B* changes from positive to negative. If the grid resistor is connected to this point, no A.C. voltage will be applied to the grid—consequently no hum voltage will be amplified. This point is the electrical center of the circuit. The two halves of the transformer filament winding must be perfectly balanced if the center tapped winding method is used. If a hum adjuster is used, this neutral point may be found by adjusting the resistance to the point which gives minimum hum. In the same way, all other transformer windings for any tubes require this balance for minimum hum. Anything that tends to upset this balance, no matter what it is or in what circuit, will cause hum.

HUM DUE TO RECTIFIER TUBES

We will now consider hum which can be traced to the rectifier tube in the power pack. Hum from this circuit is in many cases caused by a defective tube or connection.

In the '80 type rectifier, there are two plates. Each plate rectifies one-half of the alternating current wave and the complete action results in full-wave rectification. If one plate or circuit is open, only one-half of a wave is rectified, and we get a 60 cycle ripple instead of one of 120 c.p.s. The filter system designed for a full-wave rectifier is not as efficient as one designed for half-wave rectification. Therefore, if one of the plate circuits becomes open, a loud hum results, because the filter system is not designed to filter out 60 cycles. An open of this type might occur in the tube prong where the lead wire from the plate is not properly soldered to the prong. A drop of solder will, of course, correct this. Look for a defect in the tube, or a bad socket grip on the tube prongs.

If the filter system following a full-wave rectifier is of the brute force type, unbalanced rectification up to a certain degree will not produce noticeable hum. But if insufficient filtering is used or just enough to reduce hum to an acceptable amount, any unbalance is likely to lead to increased hum. The use of a tuned filter is bound to result in serious hum when the two halves of the rectified waves are unequal. This is because the resonant filter is tuned to twice the frequency of the power line. Unbalance results in harmonics which are only partially filtered. The greater the unbalance, the greater the possibility of hum.

Unbalanced rectification may result from mechanically unsymmetrical elements in a full-wave rectifier tube, an internal or external open between the plate and filament of one rectifier section, or an internal or external leak between one plate and the filament.* Examine the tube socket. It should be free of dirt, dust and sticky oil. If high voltage has broken down the wire insulation or charred or carbonized the socket in spots, a new socket should be used and the wire insulation replaced. The tube should be checked for unequal rectification and open elements. It must be assumed that some unbalance can be tolerated.

Where two half-wave rectifiers are used in a full-wave manner, the possibility of having unequal rectification is greater. Low emission on one tube, gas in one tube are possible sources of trouble.

When a full-wave rectifier becomes gassy, usually indicated by a pink or blue haze or glow around the tube elements, the rectified current is so much distorted that the filter will be unable to properly filter out the ripples. A heavy current will flow in the choke coils, cutting down their effective inductance and in that way introduces hum. Any gas in the tube will give rise to so-called "gas oscillation" which may be radiated to the signal system of the receiver. In this way hum may be introduced. A gassy tube may cause the input filter condenser to break down, destroying the filter system or the power transformer. On the other hand, a leaky input filter condenser may make the rectifier gassy. Before replacing the gassy tube, be sure that there are no defective parts which will make the new tube gassy. A quick test for a shorted filter condenser is obtained by connecting an ohmmeter between the chassis and a filament socket terminal of the rectifier.

---

* A short between the elements will destroy the tube.

Mercury vapor tubes depend on ionization for their operation. They glow continuously. Special precautions are taken to remove noise due to the ionization action, usually recognized as a fuzzy or ragged hum. The tube should be enclosed in a tube shield, the latter having many holes to allow sufficient circulation of air. These tubes must not overheat. It is usual to insert a 1 to 6 millihenry R.F. choke in the plate leads, close to the plate electrodes. As a further aid in reducing hum, a 0.1 mfd. high voltage buffer condenser may be connected from plate to cathode or filament. The power transformer should have an electrostatic shield or a line filter to prevent outgoing hum radiation. All primary and secondary leads should be twisted. Never remove the line fuse always built into apparatus using a mercury

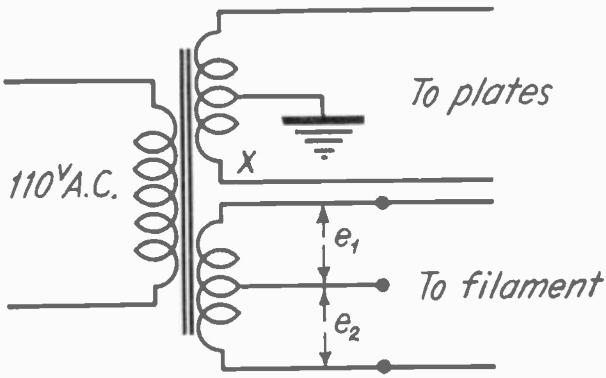


FIG. 6

vapor rectifier. If the fuse is of correct value and blows repeatedly, the rectifier is being overloaded. Bear all these facts in mind when servicing such systems.

HUM TRACED TO POWER TRANSFORMERS

The power transformer is supposed to deliver two equal A.C. voltages to the two plates of a full-wave rectifier. A great many of the causes for unbalanced voltages may be traced directly to the power transformer. A number of the common ones will be considered here.

An open high voltage secondary winding as shown in Fig. 6 at X will result in unbalanced voltages. No voltage reaches the lower plate of the rectifier and it acts like a half-wave rectifier. A partial short may exist across one half-section of the secondary or part of the circuit. In this case that plate circuit receives less voltage and the voltages applied to the two plates of the rectifier are unequal. This invariably results in hum. An A.C. voltmeter would show the absence of voltage on one plate or unequal voltages on both plates if it were connected between the center tap of the transformer and the plate of the rectifier. If the windings are shorted, it would be evidenced by the overheating of the transformer. If the open is at the terminal leads, it may be corrected by soldering. However, if it is internal or the short is internal, the transformer should be replaced.

The same conditions of an open or partial short may exist in any of the low voltage windings which have center taps for balancing purposes. Center taps are to be found at the rectifier filament winding and at the secondaries supplying filament

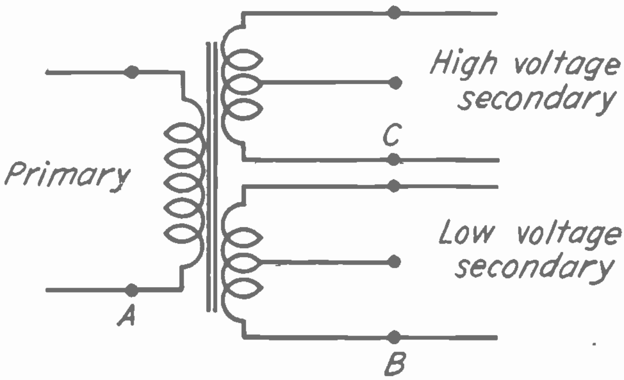


FIG. 7

power as shown in Fig. 6. The voltages on each side of the taps must be equal. The same tests for unbalance apply here as for the high voltage winding except that a low voltage A.C. voltmeter should be used.

Poorly soldered joints are a frequent source of hum. Sometimes resoldering a joint will clear up the hum. The resistance of a poorly soldered joint at one end of a transformer winding may be sufficient to cause unbalanced voltages. All terminals should be carefully examined to see that they are not corroded or poorly soldered.

If there is an electrical leak between windings, hum may result. This is due to poor insulation between windings or a break-down of the compound in which the transformer is embedded. With the transformer disconnected from the receiver, a continuity test, or better still, a megger test between any two windings will show up a leaky condition. Test between *A* and *C*, *C* and *B*, and *A* and *B* as indicated in Fig. 7, for extremely high resistance. The resistance between windings should be very large.

When the center tap of the high voltage secondary connects to the low potential side of the filter which is at ground potential, the absence of a direct ground connection results in hum. An imperfect grounding may also cause hum.

Unless it was the designer's original intention, the presence of a ground at one of the filament circuits will invariably result in hum. This does not refer to the center tap grounding. The reason for this is that either the filament circuit is unbalanced by this ground or a grid bias voltage may be shorted out. Fig. 8 shows a number of different filament circuits used in

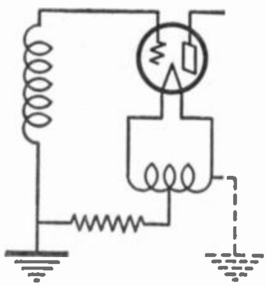


Fig. 8a

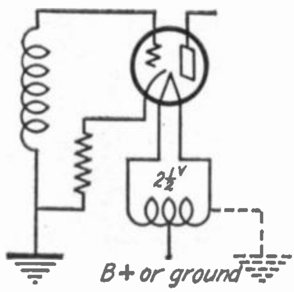


Fig. 8b

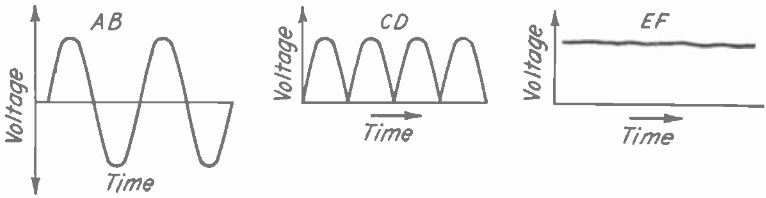
A.C. operated sets and how the presence of a ground upsets conditions. The grounding of any circuit connected to the filament winding will also result in hum, as for example, grounding of the pilot lamp. When the center tap of the filament winding is intentionally grounded, as is sometimes the case with the '27 or '24 type tubes, if either side of the filament winding is grounded, the heaters will be robbed of current. A circuit or continuity test will locate this ground.

If the transformer laminations are not tightly clamped, they will vibrate in unison with the alternations of the magnetic field. If the coil is loose on the core, it will also vibrate. The remedy is to clamp the laminations tightly and wedge the coil on the core by means of an insulating spacer or wedge between the core and coil. As a rule, such mechanical interference will be heard if the rectifier tube is temporarily removed.

HUM TRACED TO THE FILTER SYSTEM

The filter system has for its function the smoothing out of the pulsating direct current which comes from the rectifier. Fig. 9a shows the shape of the alternating current wave which is applied to the rectifier tube. Fig. 9b shows the appearance of the wave after it comes out of the rectifier tube. It is direct current, but not smooth. The function of the filter is to take this wave and smooth it out so it looks like Fig. 9c. The choke coils and condensers in the filter do this work. Any defect, therefore, in these component parts will result in poor filtering and, therefore, hum. The following are some of the major possible causes of trouble from this source.

A:—Depending upon the type of filter system used there will generally be two or three condensers. If any of these are open a loud hum will be heard. In addition, if the first or input condenser, C_1 in Fig. 3 is open, the output voltage will be con-



(a) (b) (c)

Fig. 9

siderably reduced. If the last filter condenser C_3 is open, motor-boating, R.F. oscillation or hum may occur.

One good way to test for open condensers is to connect an external condenser of 2 mfd. capacity across points *DC*, *HD* and *ED* as indicated by Fig. 3 while the receiver is operating. If hum disappears, it is a reasonable sign that a condenser in the filter is open or too small.

B:—A condenser which has low insulation resistance will cause imperfect filtering. A good condenser of 1 mfd. has a resistance of about 100 - 500 megohms. Higher capacities have lower total insulation resistance, thus a 2 mfd. condenser has 50 - 250 megohms resistance, etc. Very poor insulation will be shown up by the continuity test. Discharging a good condenser will give a "fat" spark, whereas if the condenser is leaky the spark will be weak. A measurement on a resistance ohmmeter or megger connected across the condenser will also show up bad leakage. The condenser should be entirely disconnected from the circuit when making this measurement. A leaky condenser cannot be repaired, it must be replaced.

C:—If either of the choke coils is shorted, it cannot perform its duty and hum will result. This will also show up as a slight increase in output voltage. The choke should be disconnected from the circuit and checked for resistance or the voltage across the choke measured. (In the latter case, be sure that no parallel device such as a condenser is shorted.) A short is sometimes caused by strands of wire touching the terminals of the choke. Visual observation will show this up.

D:—Choke coils are frequently made with a small air gap as shown in Fig. 10. If this is not properly adjusted, the inductance may be too low and hum will result. The simplest way

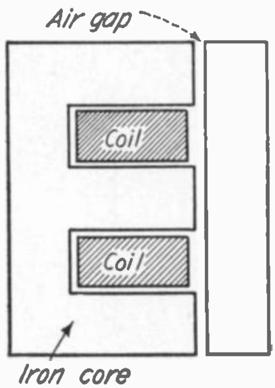


FIG. 10

to find the proper gap is by trial. Start with no gap, that is, clamp the laminations together so as to close up the gap completely and listen to the hum. Then take various thicknesses of paper, up to about .010 in. or .020 in. and place them in the gap, one after the other, making sure to tighten up laminations each time and listen to the hum for each gap adjustment. Choose that gap opening which gives least hum. Of course, an output meter in place of the loudspeaker may be used as a hum indicator.

E:—Hum may be due to insufficient condenser capacity in the filter. Trying additional external condensers at various points along the filter may reduce hum. This applies also to by-pass condensers. However, in some cases, the addition of extra condensers to the by-pass circuits may increase hum due to regeneration.

F:—Where the chokes are shunted by a small condenser, it is reasonable to assume that parallel resonance is used to block out the major hum ripple. Should this condenser open or short, a loud hum will be heard. Assuming that the frequency of the ripple does not materially change from normal, any jarring of the inductance may throw the filter out of resonance. In this case, readjusting the inductance of the choke by varying the air gap, or varying the shunt capacity will eliminate hum.

NEUTRALIZING HUM

Most filters in present-day use are of the "brute force" type. This type of filter delivers a substantially ripple-free current to

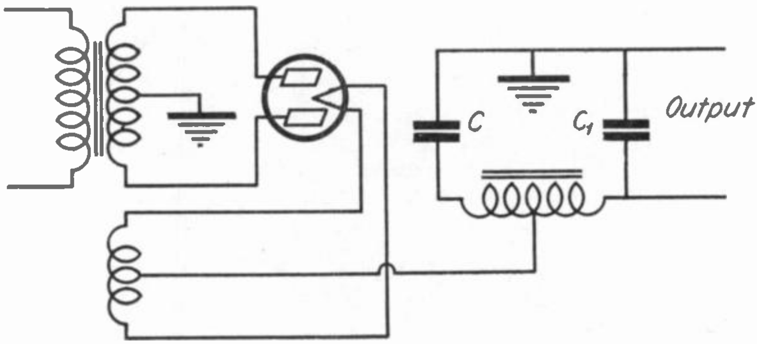


FIG. 11

the voltage divider. There has appeared a number of filter systems which have as their purpose good filtering with the use of minimum equipment. The resonant filter is one type extensively used. However, if they become unbalanced, a loud hum will develop and it will be more noticeable than that due to a slight unbalance in filters utilizing the "brute force" type of filter.

Fig. 11 shows a Meissner filter. It has been utilized in the General Electric, Westinghouse, Graybar, Gulbransen, R.C.A., Kolster, Edison and other receivers. If condenser *C* in Fig. 11 is the least bit leaky, a large hum will develop; whereas, there might be a slow leak in a similarly placed condenser of the "brute force" type as in Fig. 3 with little hum. If hum develops in any "Meissner circuit" watch for this condition. All connections must be very good because the slightest ground, short circuit or leak will cause hum.

The purpose of condenser C and that section of the choke nearest C is to form a series resonant filter shunted across the rectified supply. Anything that will upset resonance will increase hum.

Receivers which use the '26 type of tube in R.F. and first audio stages are very likely to show considerable hum due to the direct filament type electron emitter and hum of this type is very difficult to overcome without adding extra apparatus to the circuit.

Hum very frequently originates in the first audio stage. In many cases it has been balanced out of a receiver completely by introducing a neutralizing hum voltage in this section of the circuit. Fig. 12 shows a first audio circuit so adapted. This system can be effectively applied, no matter what type of first audio tube is used. It is adaptable to resistance coupled stages as well.

"B" voltage is obtained from the regular power source, "C" voltage is obtained by the voltage drop across R_1. A condenser C_1 is connected across R_1, so as to provide a low impedance path for the signal voltages. C_3 is an ordinary by-pass condenser of the kind used in all A.C. receivers to prevent the signal from passing through the supply source.

If R and C_2 of Fig. 12 are of proper values, hum will entirely disappear without disturbing the normal amplification of the receiver. In most cases the amplification will be improved because the signal current will have another path through C_2 and R.

As C_1 and R_1 are included in the grid circuit of the tube, the A.C. ripple voltage will be produced in the grid circuit having a magnitude, phase, and wave form determined by C_2, R, C_1, R_1. When R and C_2 are of correct value any hum in the circuit is completely balanced out. What happens in this circuit is that the A.C. voltage is taken from the plate circuit and fed back to the grid circuit. This bucks the hum signal in the grid circuit and we have satisfactory reception where formerly we had a bad hum.

The exact value of R and C_2 must be determined by experiment. R should be a good variable resistance having a range of from 0 - 50,000 ohms. For C_2 use fixed condensers having a range between .1 and 2 mfd. Connect them in the circuit as shown and vary R throughout its range. If the hum does not disappear, use a condenser of different capacity and again adjust R. If the hum is of the modulation type, a signal should be tuned in while the adjustment is made.

STAGE BY STAGE ELIMINATION OF HUM

The hum which is present will generally originate in one of the three major groups: (1) the power supply unit and filter, (2) the radio set, (3) the speaker. Often more than one of these is responsible. A step by step elimination process will frequently help to localize the source of trouble, similar to a method described in connection with stage by stage localization of noise. In this case, it is best to follow this procedure:

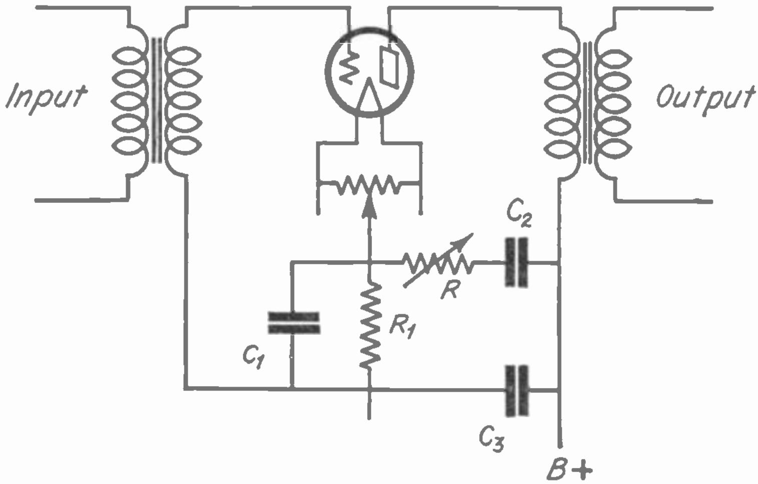


FIG. 12

1. Check the speaker first in accordance with instructions given later on "Speaker Hum."

2. Check the power supply system as already described in the section on "Hum Traced to the Power Supply."

3. Check the receiver proper by going from stage to stage as follows:

Short circuit the grid of the power tube to ground. If hum is present, it is coming in on the power stage and this stage should be carefully examined, checking points as will be explained later. If hum is not present the power stage is O.K. and the hum is originating in a preceding stage. Remove the short circuit from the power stage grid and short circuit the first A.F. stage grid. If the hum is heard, the trouble is in the first A.F. stage which should be gone over carefully. If hum is not heard, the first A.F. stage is O.K. and the trouble is in another stage. Remove the short from the first A.F. grid and short the detector grid. Proceed in this way until the circuit causing the trouble is found.

If hum is heard only when the set is tuned to a station, it is reasonable to assume that it is a modulated hum and a defect is to be expected in the R.F. system.

Be careful at all times when making connections and changes to open the power line switch so as to avoid any danger of shock. If a special part is to be examined, it should be disconnected from the circuit and the power switch opened when change is being made.

THE SOURCE OF HUM IN A STAGE

By substituting a pure D.C. source it is possible to tell where in a particular stage the hum is, that is, whether in the filament, grid, plate, screen grid or cathode circuit.*

Suppose a certain receiver develops a hum and we want to know definitely from which part of the circuit the hum originates. We proceed to use a D.C., preferably from a battery, in place of the source of current in the receiver of each individual tube circuit. By the stage by stage method, let us say hum was located in the output circuit. Disconnect the A.C. filament supply to the output tubes and operate the filaments from a storage battery in conjunction with the proper regulating resistance.

If the hum is due to the filament supply, it will now be made evident by humless reception. If hum is still present further tests are required. Short the grid bias resistor and connect a "C" battery into the grid return circuit, equal to the bias furnished by the biasing resistor. Next connect a series variable high resistance in the plate circuit to reduce the plate voltage to the regular value. (When the grid bias resistor is removed from the circuit the plate voltage rises and will be equal to the original plate voltage, plus the grid voltage.) If the hum is

---

* If from experience it is known that a certain type and make of receiver will normally give humless reception, when hum shows up the most practical scheme is to look for defective parts. The procedure given in the present section is very valuable in the design or assembly of radio receivers, or the elimination of hum in receivers which you know from experience do not give humless reception. When the exact source is found, then a more effective part may be used or one of the hum neutralizing methods may be employed.

originating in the grid circuit, it will now be eliminated. If not, we must now check the B supply.

A voltage from B batteries is now connected in place of the regular power pack voltage and a resistance is connected between the disconnected B– and B+ of the power pack of the receiver to consume current that would have been taken by the tube under test. This is done to prevent a rise of voltage throughout the receiver due to the removal of the load put on the power pack by the output tubes. The value of this resistance

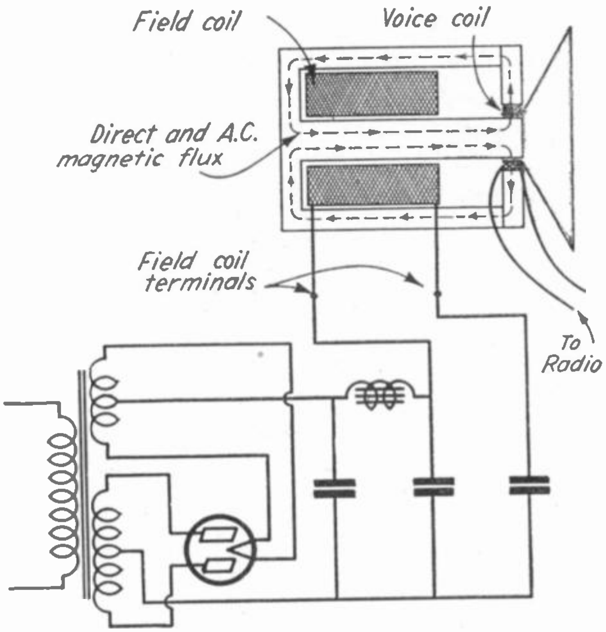


Fig. 13

can be obtained by measuring the plate current and voltage with suitable meters. R of course will be equal to $\frac{E}{I}$

If batteries to supply the new plate voltage are not available, a hum free B eliminator or the B section of a good power pack may be used. However, if possible, use batteries as they will not create the slightest hum.

The stage by stage elimination might indicate that hum is in the first audio stage. Proceed to connect batteries in place of the potentials ordinarily supplied by the receiver. Be sure that the filament resistance is of the proper value when using it to reduce the voltage of the storage battery. Suppose the first audio tube is of the '26 type which requires for its filament 1.5 volts and 1.05 amperes. If the storage battery is of the 6 volt type, the resistance necessary to reduce the voltage to the proper value is found from the equation:

$R = \frac{E - e}{I}$ where R = resistance
E = voltage of battery
e = voltage at which tube must operate
I = current

In this case:

$$R = \frac{6 - 1.5}{1.05} = \frac{4.5}{1.05} = 4.28 \text{ ohms}$$

The ordinary rheostat will not continuously carry this current so be sure to obtain one of the proper current capacity.

Hum is most likely to be introduced in the first audio stage so a careful analysis should be made of this stage. Battery voltages should be used for filament, grid, and plate circuits and a resistance should be used to consume the current that would ordinarily be drawn by the tube from the power pack of the receiver as described for the last audio stage.

Many service men prefer to trace hum by supplying battery sources for the operation of the entire receiver. The A.C. filament supply is disconnected from the receiver and the filament voltage supplied from a storage battery. If hum is still present reconnect the filament supply and replace the rectifier and filter system of the power pack with a battery. This proves conclusively whether or not the rectifier system is the origin of the hum. Hum should be absent. Then the stage by stage method may be used to trace the exact locality.

If you are tracing a modulation hum, you should employ a signal generator, preferably without A.F. modulation, connected to the input of the receiver. Now every stage except the R.F. stage under test should be operated by batteries. If hum appears, it is due to modulation in the stage operated from the A.C. supply.

In a manufactured receiver hum is most likely due to circuit defects, because the engineers of the manufacturers have more than likely eliminated the original normal hum by design. Therefore, from your analysis you will have determined precisely from which circuit the hum originated and almost invariably it will be due to a circuit or part defect rather than a design defect.

THE HUM IN THE DYNAMIC SPEAKER

The dynamic speaker is capable of introducing a considerable amount of hum in a radio set of its own accord. The reason for this will be apparent when we consider the circuit of the dynamic speaker as shown in Fig. 13. The dynamic speaker consists of a large magnetic field coil, which is excited by direct current supplied either by the rectified current from the power supply unit of the radio set, or by rectified current from a special speaker rectifier. In either case the current through the field coil is not a pure direct current, but contains a certain amount of alternating current. Consequently, the magnetic field in the air gap of the dynamic speaker is not a pure direct current magnetic field, but also contains a small amount of alternating magnetic lines. The moving coil of the dynamic speaker is situated

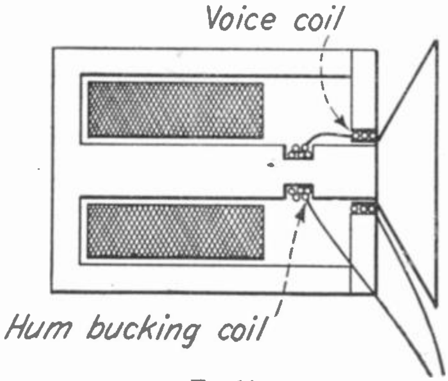


FIG. 14

in this air gap, and therefore, is influenced by the magnetic lines of the field coil. The alternating magnetic lines introduce a voltage into the moving coil and the result is a hum.

Another reason why the dynamic speaker sometimes introduces hum is that the output transformer of the dynamic speaker may be mounted in such a way that the alternating field from the power transformer, associated with the power pack or from the special rectifier system for the speaker, links with it. Consequently an alternating voltage will be induced in the output transformer which may be heard as hum.

To determine whether the speaker is contributing hum directly it is merely necessary to excite the speaker by means of its regular source with the primary of the matching transformer shorted so as to eliminate receiver hum. The hum that is heard now in the speaker is due to the speaker itself or the output transformer. The next plan is to excite the field winding of the dynamic speaker with pure D.C. and determine if the hum is reduced.

A number of methods have been utilized for correcting speaker hum. In general, if the speaker is a finished product of a manufacturer, it will be difficult to incorporate the changes necessary to reduce hum. However, the methods employed are as follows:

A:—Fig. 14 shows the use of a hum bucking coil in detail. A groove is cut into the pole piece of the electromagnet close to the end near the moving coil. In this groove there are wound

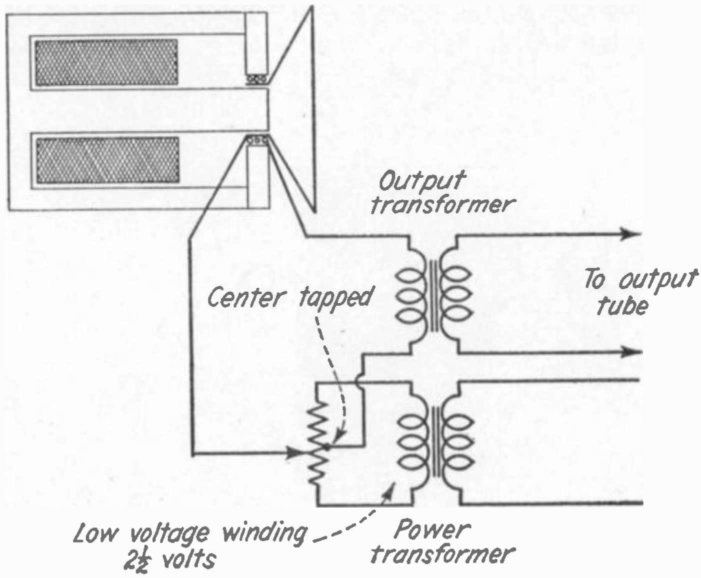


Fig. 15

a few turns of cotton covered wire in a direction opposite to the moving coil winding. This coil is connected in series with the voice coil and the output coil of the output transformer. When connected in one direction the hum is considerably reduced and when connected in the other direction, no change is noticed. The principle involved here is that the hum coil also has induced in it a hum voltage like the voice coil, but by connecting it in the proper direction, these two hum voltages balance out, resulting in a reduction of hum.

B:—The second method employed also involves the principle of balancing out hum. It is illustrated in Fig. 15. A potentiometer with a fixed center tap is connected across one of the low voltage windings in the power transformer and a portion of the voltage across this potentiometer is applied to the voice coil of the dynamic speaker. In this way a small alternating voltage is introduced in the voice coil. By moving the slider up and down along the potentiometer, its voltage may be varied until the right value is found for balancing out the hum which is present in the speaker. With one terminal connected to the center of the potentiometer, it is possible to move the slide toward either side of the center of the potentiometer, and in this way we can get A.C. voltages of the proper phase to balance out the speaker hum voltage. This method may be applied to any dynamic speaker. If a center-tapped potentiometer is not available, solder a lead to the lower center position of the resistance coil in a standard potentiometer.

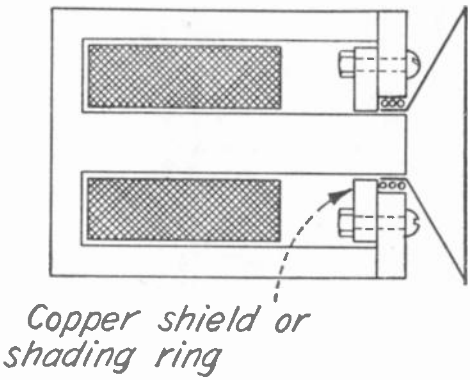


FIG. 16

C:—The third method commonly employed by manufacturers is to place a heavy copper shield between the moving coil and the field coil. This heavy copper shield is shown in Fig. 16. Its effect is to shield the voice coil from the alternating currents in the field coil, by setting up in the field magnetic circuit a flux opposite to the A.C. flux produced by the ripple current in the field coil. The shading ring has little effect on the voice coil currents.

A defective rectifier supplying voltage to the speaker field will cause considerably greater hum than that normally present. This is due to the fact that the defective rectifier no longer rectifies properly, and a larger amount of alternating current voltage is applied to the speaker field than is normally the case.

Replacement of this rectifier, whether it is a tube, or a copper oxide type, is the only remedy.

Imperfect rectification due to other causes will also cause speaker hum. For example, a badly unbalanced secondary of the rectifier transformer giving different voltages on each side of the center tap, will cause hum. A dry electrolytic condenser as shown connected in Fig. 17 will greatly reduce hum.

A mechanical hum may be contributed by the dynamic speaker, due to vibration of the laminations in the speaker power transformer. Clamping the laminations tightly, and wedging the coil on the core securely, are the only remedies for this.

As a last resort, speaker hum may be removed by moving

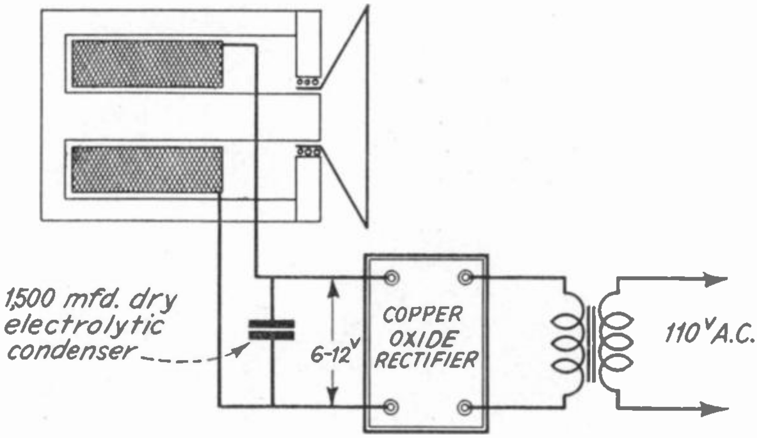


Fig. 17

the speaker back from the baffle (½ to 2 inches). This has the tendency of destroying low frequency response and likewise hum reproduction.

TUBE HUM

The tube is frequently at fault when hum is involved. Defective tubes or improper operation of tubes may cause hum. Under the section on "Filter Systems" we discussed hum caused by the rectifier tube. This section will be devoted to other tubes in the set.

A.C. tubes in general, and the '26 type tube in particular, must have proper voltages applied to them for minimum hum. Fig. 18 shows how the hum from a '26 type tube varies with plate current. This shows that for least hum, tubes should be operated at a specific plate current. This means that a definite grid bias and plate voltage must be used. These values are given by the set maker. Circuits should be checked to see that tubes are operating at rated voltages.

Absence of bias in any tube will generally cause hum. An open grid circuit makes the tube more sensitive to electrostatic induction from the rectifier tube. Sometimes it may result in oscillation which will usually accentuate the hum. Absence of grid bias may be due to any of the following causes:

1. Open grid bias resistor. A continuity test will show this.
2. Open R.F. secondary.
3. Open A.F. secondary.
4. Open grid leads.

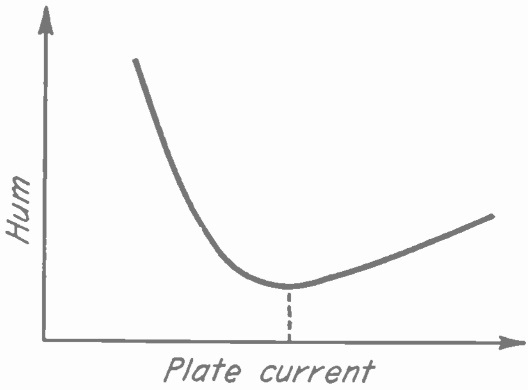


Fig. 18

5. Defective bias resistor or by-pass condenser.
6. Open plate return.

Circuit tests and visual observation will show up these faults. Where the fault is internal, the unit should be replaced. But if the open is at the terminals, it may be repaired.

The major common defects in tubes that cause hum are:

1. Gassy tubes. This is evidenced by a blue glow and haze, due to gas present in the tube or a leaky tube. The tube should be replaced after checking to see that the operating voltages are right.

2. Heater leads shorting to cathode. In the '24, '27, '35 and '51 types of tubes of some makes, the heater leads may lean over and touch the cathodes. This results in shorting out the tube bias and causes hum. A new tube should be tried.

3. Microphonic tubes. Such tubes have loose elements in-

side and are sensitive to vibrations and other disturbances. Such a tube may actually exaggerate any hum present. The best remedy here is to interchange it with some other tube in the set or use a new tube.

4. Sensitive detector tube. Some tubes have exceedingly high sensitivity as detectors. They may not make better than average R.F. amplifier tubes, but they have good detector sensitivity. As a result they are more sensitive to electrostatic pick-up of A.C. voltages which may be carried by neighboring circuits. Here, as in the case of the microphonic tube, the best thing to do is to interchange the detector tube with some other tube in the set if less hum at the sacrifice of sensitivity is desired.

HUM DUE TO REGENERATION

A receiving set in a regenerative or oscillating state is always more sensitive to any kind of disturbance than one which is stable. This is due to the fact that the sensitivity of the receiver increases as regeneration increases. For example, it is well known that a single tube regenerative set is very difficult to operate on A.C. on account of its tendency to exaggerate any A.C. ripple which may be present.

Regeneration may occur in both the audio and radio circuits. In all cases, the causes and remedies for the regeneration are the same as those given in the text on "Internal Noise." As far as hum is concerned, it should be remembered that if the hum arises in the audio stages, it is present irrespective of the presence of the R.F. carrier.

However, this is not always the case where the radio frequency stages are concerned. A condition may arise here which we termed "hum modulation." If the hum arises in the radio frequency tubes and no carrier is present, the hum may not be heard. This is because the R.F. stages do not amplify audio frequency signals, and hum is an audio signal. However, if a carrier is present, the hum in the R.F. tubes modulates the carrier and this is amplified and detected in the usual manner. This is the reason for hum making its appearance when a carrier is tuned in, and being absent between stations. To make sure that this hum heard when a station is tuned in, is due to the set, it is necessary to tune in to a number of stations. If the hum is present on all the stations, it is safe to assume that the hum is due to R.F. modulation and the causes for the hum should be checked in accordance with the instructions in this book.* If it occurs only on one station, we must be sure that hum modulation is not introduced by causing the first tube to work on its curved characteristic. This may be due to a strong local signal. The only remedy is to use a variable mu tube or insert a wave trap in the antenna circuit to reduce the signal strength of the interfering signal.

1. Neutralization of the receiver.

2. Filter circuit.

3. The A.F. transformer secondary may be improperly connected. Try reversing connections.

4. If modulation hum is present, you can isolate it in a particular stage or stages by using an R.F. signal generator Beginning at the R.F. stage, preceding the detector, couple the signal generator to the input of this stage. Now remove the tube ahead of this one so that no signal can be amplified through the circuit from the antenna system. If hum is now present, it is being introduced in the R.F. stage preceding the detector. If not present, it is due to another R.F. stage or stages and you should continue to couple the signal generator to each R.F. stage until the hum is localized in a particular stage. It is understood, of course, that the signal generator is of the R.F. type and unmodulated.

5. An open in the C bias filter condenser may give rise to oscillation or increased ripple feed from plate to grid. Check condenser for an open.

HUM ORIGINATING IN WIRING

Careless or inadequate wiring in a radio set is a frequent source of hum. The reason for this is that a great many wires in the receiver carry alternating current or filtered current. These wires pass other electric circuits. Around the wires carrying A.C. or D.C. with a ripple component, there will be a magnetic field and an electrostatic field, which may be picked up by other sensitive parts of the set, or which may induce voltages in various parts of the set. These voltages will be ampli-

---

* The variable mu tubes are especially designed to prevent modulation distortion and the service man has the option of rewiring the receiver to take these tubes, which is rather simple if the set originally used '24 tubes. If the receiver originally used the C bias volume control, no change will be necessary except in some cases increasing the value of the variable resistor. All other methods of volume control should be replaced by this one. Tube change over should not be attempted with A.V.C. receivers. You may try new grid resistors or a 2,000 ohm and .1 condenser filter in the R.F. plate supply to each tube.

fied by the receiver and will appear as hum in the speaker output. For example: the wires carrying the filament current for three or four screen grid tubes and the wires carrying the filament currents for the output tubes, carry currents of the order of 5 to 10 amperes. This is a very large current and may produce, under favorable conditions, large magnetic fields. If these wires pass next to the grid circuit of the detector tube, a small alternating current from these may induce a voltage in the grid circuit of the tube, and the result will be that this voltage will be amplified by the detector and audio amplifier of the receiver and a loud hum will be heard.

Hum due to wiring may be introduced in the following ways:

1. Wires carrying raw alternating current and passing close to the detector grid or to parts of the audio amplifier such as the audio transformer grid leads. This can be detected by visual observation and the correction is simple. The leads should be moved as far as possible from such circuits.

2. Alternating current leads not twisted. Pairs of leads carrying alternating currents such as the two wires feeding the filaments should always be twisted. Twisting these leads reduces hum voltages which may be induced in other circuits. The same applies to the high voltage leads from the secondary of the power transformer.

3. Proximity of the power supply cord to the detector circuit or antenna circuit or to the radio frequency circuit. The power supply carries the 110 volt alternating current voltage. The field from this cord may be great enough to induce voltages in these various circuits and so produce hum. It should, therefore, be kept as far away as possible both in the chassis and outside of the chassis.

MISCELLANEOUS CAUSES OF HUM

A number of miscellaneous causes of hum may be enumerated, some of which are subject to correction and some of which are not.

1. Poor or insufficient grounding. The ground lead should be securely attached to the chassis, and all points intended to be grounded should be checked. On some receivers, grounding the cores of the power transformer and audio transformers helps to reduce hum, and on others it does not. Trial only will show the proper connection.

2. Grounding one side of the power line through a condenser frequently helps. The power line sometimes acts as an antenna and picks up line noises and hum from neighboring power circuits. These disturbances are transmitted through the set by way of the ground and power supply. The best way to eliminate this source of hum is to filter the 110 volt line, or to use two condensers connected as shown in Fig. 19 rated at 220 volts A.C. and grounded in the center. The audio frequency disturbances picked up by the line are short circuited to ground through the condensers.

3. Room reflections. In many cases the following phenomenon will be observed in a room. As you walk away from the speaker, you will find points where the hum is loud and other

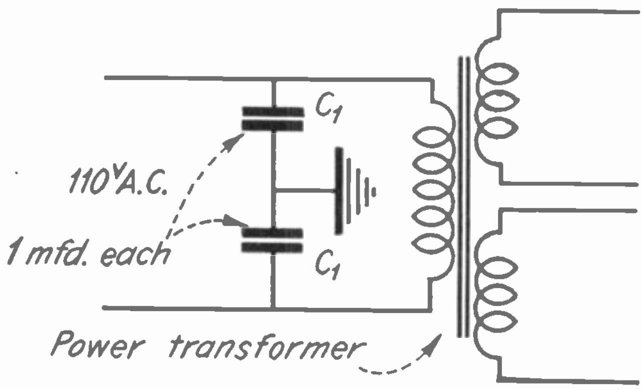


Fig. 19

points where there is no hum. This is due to reflections occurring from walls and ceiling in the room. At some points of the room these reflections reinforce the original hum and therefore at these points the hum will sound loud. At other points the reflected hum will oppose the original hum and at these points the hum will be low or disappear entirely. These alternations of loud and weak hum are called "standing waves." The only remedy here is to try changing the position of the set or speaker to eliminate these reflections.

4. Hum adjuster and center tapped resistors. The hum adjuster and center tapped resistors are used to balance the filament circuits by finding the electrical center. In the case of the hum adjuster, the arm is rotated until that position is

found which gives least hum. A defective hum adjuster will produce hum. The possible defects are:

1. Poorly soldered connections.

2. Arm not making contact. The blade should be adjusted until it makes contact.

3. Oxidized contact. The arm should be sandpapered to clean it of oxides.

In the case of the center tapped resistor, the tap is brought out at the center of the resistance. The voltages from the center to each end should, therefore, be equal. If they are not, the center tap should be moved to the point which gives equal voltages on each side or to the point which gives least hum. Opens or shorts on either side will also throw the balance off and produce hum.

TEST QUESTIONS

Be sure to number your Answer Sheet with *the number* appearing on the front cover underneath the title of this text.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another set ready to send in. Send each lesson in by itself before you start on the next lesson.

In that way, we shall be able to work together much more closely, you'll get more out of your Course, and the best possible lesson service.

1. Why would a poor contact at a plate prong of an '80 type rectifier tube cause hum?
2. If hum appeared in a receiver using a Meissner filter, and was traced to the filter, what defect would you look for first?
3. Explain why hum may appear only when the receiver is tuned to a station.
4. How would you attempt to eliminate hum that was traced to a first audio '26 type tube?
5. Explain the fact that hum originating in a detector stage may be due to its position with respect to the rectifier tube.
6. How can you prove conclusively whether hum originates in the rectifier and filter system of the power pack or not?
7. Show by a diagram how hum in a loudspeaker voice coil can be balanced out.
8. If shorting the grid of the second audio tube causes a hum to disappear, but the hum is present when the grid of the preceding tube is shorted, in what stage is the hum originating?
9. How can hum be introduced into a receiver by unmatched '81 type tubes arranged for full-wave rectification?
10. Why should A.C. filament leads be twisted?

Receiver Hum. No. 45 RH

1. The rectifier would act as a half-wave rectifier and the filter system is not effecient enough to eliminate the lowered frequency ripple.

2. You would look for a leaky input condenser.

3. A.F. ripple voltages in the R.F. circuit would not be amplified. But when a signal is being picked up they modulate on the carrier, are detected, amplified by the audio system and appear in the loudspeaker output.

4. You would readjust the variable center tap potentiometer, install one if none was provided, or insert a hum bucking arrangement as shown in Fig. 12.

5. The intense alternating electrostatic field about the plates of the rectifier tube may link with the detector tube elements, inducing a voltage which results in hum.

6. By substituting B batteries for the high potential portion of the power pack.

7. See Fig. 15.

8. In the first audio stage.

9. The current outputs might be unequal and the wave form of the current fed to the filter would be irregular.

10. To prevent heavy A.C. magnetic fields from being picked up by signal-carrying circuits or voltage supply circuits.

HOW TO ELIMINATE MAN-MADE INTERFERENCE

46RH-1

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

INITIATIVE

The man who does only the routine tasks, the ordinary jobs in his profession, always waiting for the other fellow to take the lead, can expect only moderate returns for his labors. He who is continually on the alert for new ideas and new uses for his talents—who is alert to grasp each new opportunity—gets the greatest profits. The immediate financial returns from work in a new and specialized branch of your profession may not be great, but the reputation which you gain for progressiveness will soon result in more profitable routine jobs. It all boils down to these simple facts—you must do out-of-the-ordinary things, stand above the crowd in some way, to attract favorable attention. People remember you first for the unusual, then for your ability to do ordinary work well.

Radio interference-elimination, the subject of this book, can prove a very profitable radio side-line and reputation-builder for the man who has initiative backed by knowledge and "horse sense"; it is for you to decide just how much attention you want to devote to this particular phase of radio.

J. E. SMITH.

NATIONAL RADIO INSTITUTE

WASHINGTON, D.C.

1942 Edition

A LESSON TEXT OF THE N. R. I. COURSE
WHICH TRAINS YOU TO BECOME A
RADIOTRICIAN & TELETRICIAN
(REGISTERED U. S. PATENT OFFICE) (REGISTERED U. S. PATENT OFFICE)

NCP2M642 Printed in U. S. A.

How To Eliminate Man-Made Interference

A GROWING PROBLEM

THE radio public is today being supplied with receivers of greater sensitivity than ever before; short-wave reception of foreign as well as local programs is an accepted feature of the modern home receiver, and listeners are gradually becoming conscious of the superior performance of high fidelity receivers. These three important factors make the problem of man-made interference more and more important as new receivers reach the hands of the public.

Radio receiver manufacturers are now capable of building receivers which create only a negligible amount of interference within themselves; older receivers which develop internal noise can readily be repaired by the Radio-Trician, but still program-spoiling interference increases.

Oil burners, electric power-generating systems, refrigerators, motor-driven appliances, medical equipment, electric signs and scores of other new electrical appliances are man's contributions to radio receiver interference. Thus man creates more interference at the same time that he builds radio receivers which are more sensitive to interference; profitable work for the serviceman trained in interference elimination is the result. Remember that no radio installation is complete and satisfactory until it is as free from interference as is humanly possible. The man who can render this interference elimination service efficiently and intelligently will "cash in" on an opportunity for profit and prestige which grows bigger every day.

NOISE NOT DUE TO RECEIVER DEFECTS

We know that when noise is heard in a receiver, the first step is to eliminate receiver defects as possible causes of the trouble. A line filter is inserted in the power line of the receiver, the antenna and ground leads are disconnected from the receiver, and antenna and ground binding posts are shorted together; if, when this is done, the noise disappears or is reduced an appreciable amount, the trouble is definitely not a receiver defect. It is, therefore, an external disturbance which can or cannot be eliminated, depending upon its nature.

External noise disturbances which cannot be eliminated may be divided into two groups: (1), those due to *local* electrical storms or lightning; (2), those due to the accumulated effects of distant electrical storms, sun disturbances and disturbances created by distant industrial or electro-medical equipment.

The new frequency modulation system of broadcasting almost completely eliminates atmospheric interference, but both broadcasting systems (f.m. and a.m.) have serious man-made interference problems.

The accumulated noise disturbance is often referred to as background noise; * this has a definite level (microvolts per meter) which will vary with the antenna location. Industrial towns and cities will usually have a high noise level, this being exceptionally high near factories and shopping centers. The only remedy in such cases is to cut down the sensitivity of the receiver or confine tuning to broadcasts whose intensities are much greater than the noise level. In localities of high noise level the customer should be taught to listen only to local or high-powered stations.

When receivers having automatic volume control are tuned off a broadcast signal, the AVC acts to boost the gain, and background noise becomes disturbingly prominent. This has led to the development and use of inter-carrier noise suppressors, found on a number of receivers.

Man-made static, usually of local origin and having an intensity comparable with that of the normal received signal, is often so annoying that the usefulness of a receiver is destroyed. It is the purpose of this text to show the origin of such disturbances and suggest ways and means of eliminating or at least greatly reducing such interference. The "cure" is generally applied in two steps: first, by seeking to keep the noise signal out of the receiver; and second, by "killing" the interference at its source.

ORIGIN AND NATURE OF NOISE SIGNALS

Wherever there is an electric spark or arc, there you will find a source of possible noise interference. The spark need not be large or even visible to create a disturbing effect. Contrary to general belief, the spark itself does not radiate interference, nor is it generally true that the spark creates a broadcast band radiation.

* This background noise should not be confused with noise originating within the receiver due to thermal agitation of the electrons in the conductors and to the impact or shot effect of electrons as they hit the plates of vacuum tubes. It is this noise which is heard when antenna and ground terminals of a high quality receiver are shorted and the gain turned up.

A spark is accompanied by a sudden current change in the circuit where it originates, the change being transmitted to all parts of the circuit. This sharp current change gives rise to a fundamental audio frequency noise signal whose frequency depends upon the duration of a single disturbance, and a large number of audio and super-audio frequency harmonics of this fundamental. These noise signals may reach the receiver by conductive, magnetic or capacitive coupling, and may either affect the audio stages directly or, more likely, enter a resonant R.F. circuit. The latter is more troublesome, for through shock-excitation it results in the formation of an R.F. current which is modulated with the original noise signal. Because the original noise signal wave form is not destroyed or altered, the expert is usually able to judge, after listening to the noise emitted from the loudspeaker, what the probable source of interference may be.

When a spark occurs in an electric circuit, the current surge is transmitted through the connecting wires, away from the origin of the spark, in both directions * and out of phase. In a power transmission circuit this means that a large area—several blocks—will be affected. This disturbance will continue to travel until it is dissipated by the system. If the circuit contains transformers or other circuit-changing components, part of the disturbance will be reflected back to the origin at the first of these points, be reflected again at the disturbance source, and continue to travel back and forth until the losses in the circuit wipe out the disturbance. The remainder of the surge passes through the first obstacle and out over the line to the next, where it in turn is partially reflected, partially transmitted.

Whenever the surge of current meets an electrical obstacle in the line, be it a transformer, a change in wiring construction, or even a noise-eliminating filter introduced into the line improperly by an untrained radio man, the surge moves back and forth between its origin and this point, creating a standing wave or ultra high frequency oscillation whose frequency is determined by the line length. This wave is radiated through space in much the same way that R.F. currents are radiated by a transmitter antenna.

Sparks in auto ignition systems are typical examples; because the ignition wires are short, the natural wavelength of the radiation is somewhere between 1 and 10 meters. This explains why 5 to 10 meter ultra short-wave reception is so greatly affected by auto ignition disturbance.

* If you were to drop a stone in a long trough filled with water, the disturbance would likewise travel away from the source to both ends of the trough, and then would be reflected back to the origin of the disturbance.

Bear in mind that a spark or arc produces a current surge or impulse which is fundamentally of an A.F. or super-audio frequency. Because the circuit in which this impulse is created has reflecting points, ultra high frequency radiations are produced. The original A.F. impulse currents, flowing along the transmission lines, also produce strong magnetic and electrostatic lines of force which may travel an appreciable distance through space. Magnetic and electrostatic interference fields of this nature get into the radio receiver through the aerial and ground, over the power supply lines or directly through the chassis. As these impulse fields induce strong impulse voltages in the R.F. or I.F. oscillatory circuits, forced oscillations modulated by the original noise currents are produced.

A study of Fig. *1*, which shows a typical "man-made static" problem, will bring out many of the facts just discussed. An electric motor, located in a house, is sparking at *S*, one of the brushes. Impulse current, therefore, passes out of the feeder line to points marked *1*, where a part divides to flow to points *2* and *4*, and the remainder is reflected back to the motor to produce a radiation whose wavelength is determined by the distance between *S* and *1*. At point *2* the impulse current will again divide, a part going to house *B* before being reflected back. The radio antenna on house *B* picks up noise radiation from all electric wires in the house and from the power line system, and the radio receiver itself receives the impulse current directly through the power line. A radio in house *B*, therefore, picks up more interference than a radio in house *C*, which is unwired and therefore receives noise signals only through space.

It would appear that because of the parallel power leads in this system, out-of-phase impulse currents in the two wires would produce canceling fields. This is not true, because spark *S* is rarely produced in the electrical center of the disturbing device. In this example, where sparking is occurring at one brush, one impulse passes directly into the line while the other passes through the armature and the other brush first. The inductance of the armature thus reduces the strength of one of the impulse current signals and prevents cancelation of the currents. It is safe to say that any line which is connected electrically to a spark source will send out an interfering induction field.

Reflection of the current impulses at points *1*, *2*, *3* and *4* produces standing waves on the line; radio waves modulated with noise signals are, therefore, radiated by the line to create troublesome interference in all-wave receivers.

REDUCING MAN-MADE INTERFERENCE

In tackling any interference-elimination job, the practical aspects of the problem must be carefully considered, and even human nature itself must not be overlooked. Broadly speaking, however, the interference-eliminating procedure may be divided as follows: *1*, eliminate or reduce the sparking, if possible; *2*, prevent the interfering current impulses from leaving the disturbing device; *3*, prevent the various interfering signals from reaching and affecting the radio receiver. It is generally conceded that elimination of interference at its source is the best procedure, but in cases where this is impractical, filters and other devices which will keep the signal out of the radio receiver must be used.

Reducing the interference at its source is not always the simplest

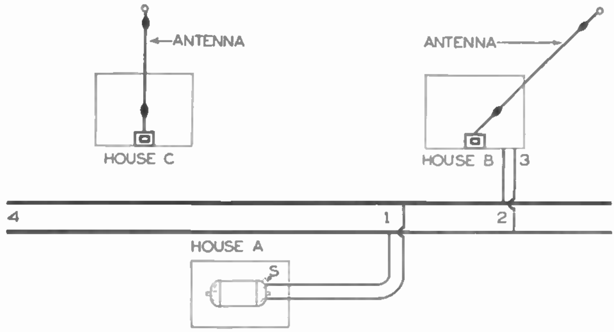


FIG. 1. Diagram illustrating how interference created by sparking brush *S* on motor in house *A* can reach radio sets in vicinity.

procedure, nor is it always permitted by the owner of the disturbing device. If a customer calls you on an interference job and you can directly trace the trouble to some device in the customer's home, the logical procedure is to kill the interference at its source. On the other hand, where your tests show that the interference is being created outside of the customer's home, you must decide whether to search for the location of the interfering device or prevent the interference from affecting your customer's receiver; remember that once a disturbing device is located you must convince its owner that there is a need for interference-eliminating work, and that this work will make his own receiver more free from interference.

After proving to yourself that the chassis of the receiver in question is not picking up noise directly (which of course includes trying a line filter to prove that the interference is not coming in over the power line), your next important move is to install a noise-reducing antenna. You cannot, of course, guarantee that this will entirely eliminate noise interference troubles in the receiver, but you can be sure that it will improve radio reception as well as give a worth-while reduction in interference pick-up. Always make this perfectly clear to a customer who is ordering a noise-reducing antenna. Then, if the antenna fails in its primary purpose, you will not be blamed by the customer for something which is beyond your control, and you will be allowed to tackle the more difficult procedure of locating and eliminating the source of interference.

NOISE-REDUCING ANTENNAS

You are already sufficiently familiar with noise-reducing antennas, so they will not be discussed in detail in this lesson. The type of antenna which you select for a job depends upon the type of receiver encountered, the antenna location, and to some extent upon your personal preferences gained through experience with the products of different manufacturers. An all-wave receiver calls for an all-wave antenna, while a broadcast band antenna should be put up where only American broadcast band stations are to be received. The length of the antenna and lead-in wires will vary according to the space available.

The effectiveness of any noise-reducing antenna depends upon your ability to locate this antenna in a position where it will pick up a minimum of noise interference. You can determine the ideal position with a battery receiver, using a loop or pole antenna and moving the set about until you locate a zone where the least noise is heard, but these three general rules for locating noise-reducing antennas will often allow you to "spot" a good location at a glance: *1*, Place the antenna as high as is reasonably possible, keeping all unshielded vertical wires short; *2*, keep the horizontal or straightaway portion of the antenna at a maximum distance from known sources of interference; *3*, place the horizontal portion at right angles to nearby trolley lines, main power lines or transmission lines. The antenna on house *C* in Fig. *1*, for example, is at right angles to the main power line running from points 2 to 4; the antenna on house *B* is not at right angles to this line, and is, according to the general rule, incorrectly placed. This antenna may actually give better results than an antenna which is perpendicular to the power line, for oftentimes interference radiated from various points will cancel itself in certain regions. If an antenna erected according to general rules fails to reduce the noise sufficiently, try it in various directions. An antenna located in a noise-free zone, with the shielded or twisted leads correctly balanced and grounded, may be expected to prevent pick-up of noise signals.

In a few instances it may be necessary to locate the exposed portion of the antenna at distances as great as 1,000 feet from the receiver, in order to get the antenna into a noise-free zone. Very little signal strength is lost by a long lead-in such as this, provided that both the antenna and the receiver are correctly impedance-matched to the lead-in, using shielded R.F. transformers for this purpose. Quite often, as in locations near railroad tracks along which run high tension power lines, or in locations near high power cross-country transmission lines, the placing of the antenna at a remote point is the only practical solution to the problem of interference elimination.

SUPPRESSING NOISE AT THE SOURCE

Assuming for the moment that the disturbing device has been located, you will invariably find it to be a spark, an arc or a rubbing condition. (All conductors such as pipes in homes acquire electrical charges; rubbing together of two of these pipes results in current impulses which cause interference.) If the spark or arc is not essential to the operation of the device, it should be eliminated or reduced in intensity. Rubbing parts should either be completely insulated from each other or bonded together with flexible metallic braid or stranded wire.

When the sparking can neither be eliminated nor reduced, the logical procedure is to prevent the current impulses from flowing any distance away from the device. For this purpose filters consisting of condensers alone, or combinations of condensers with choke coils, are available and in general use. The correct sizes for these condensers and choke coils are usually quite difficult to determine in advance; it is necessary to try different values and use the smallest electrical sizes which satisfactorily stop the interference.

The most commonly used coil-and-condenser combinations for filtering or blocking impulse currents are shown in Fig. *2*. That shown at *A*, consisting simply of a condenser connected across the power line as close as possible to the noise source, is often quite effective as a filter. The shunt capacity provides a low impedance path back to the noise source for the high frequency component of the impulse current, lessening the tendency for this current to flow out over the power line. When this condenser is installed on a vacuum cleaner, for example, it should preferably be connected to the terminals of the motor and not across the outlet plug terminals on the wall. If possible, try grounding the metal frame of the offending device; a *short* ground lead oftentimes reduces interference appreciably. All condensers used for filtering purposes on 110- or 220-volt A.C. power lines should have peak voltage ratings of between 600 and 1,000 volts, for these units must withstand high voltage surges caused by impulse currents.

When trying various filter combinations, it is important that some one listen to the receiver to note the effectiveness of each combination when the disturbing device is not within "ear shot" of the receiver. Oftentimes the customer will be only too glad to listen to the receiver for you, but better results can generally be obtained with a trained assistant. If you are working alone, it is wise to set up a portable battery receiver near the location of the disturbing device, using headphones rather than a loudspeaker if the interference noise proves too annoying to those nearby.

With the filter shown at *A* in Fig. *2*, there is no assurance that the impulse currents will pass to ground; the balanced condenser filter, having its center points grounded as shown at *B*, is therefore more effective.

When condensers of a reasonably high capacity, such as 1-mfd. units, fail to give satisfactory noise reduction when used alone, a combination condenser-and-choke filter like that shown at *C* should be tried. This is essentially a brute filter which allows only very low frequency currents to pass through to the power line. The higher the electrical values of the coil and condenser, the better is the filtering action. Always use the smallest commercially available size which gives satisfactory results, for purposes of economy. The condenser may be connected either to the load side of the choke coil (*C*) or to the line side of the choke coil (*D*). As a rule, however, the closer the choke is to the source of interference (*D*), the better is the impulse filtering action. Try the choke coil in one power lead first, then the other, to ascertain which position gives the better reduction in noise.

Two choke coils and one condenser connected either as at *E* or *F* will often give improved results, while the grounded combinations shown at *G*, *H* and *I* are even better filter combinations. Where several different parts of a device are sparking, such as in commutator type switches for signs or groups of contacts on a relay, then each line which carries impulse currents should be filtered in the manner shown at *J*. A choke coil is inserted in each line, and a suitable condenser connected from the load side of each line to ground.

Improved suppression of interference is often obtained by using a balanced filter having a ground connection which can be electrically varied in the manner shown at *K;* this circuit is otherwise essentially the same as those shown at *G* and *H*. The same balancing scheme can be used with the simple two-condenser filter shown at *B;* a 100-ohm potentiometer, with its variable tap grounded, is connected between the two condensers.

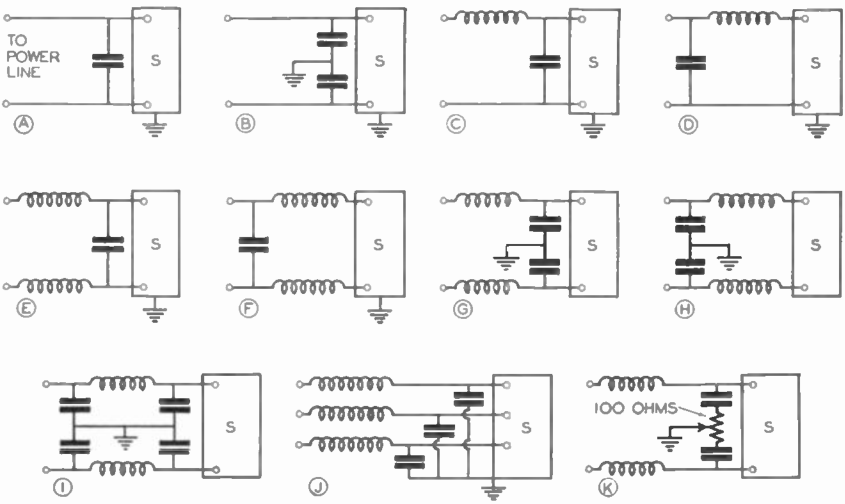


FIG. 2. Condenser filters and condenser-coil filters are here arranged approximately in the order of their effectiveness, the circuit at *I* being the most effective for interference eliminating purposes. Circuit *J* is used with devices which have three make-and-break contacts or with a three-phase load, while circuit *K* is a variation of circuit *G*, which permits adjustment of the ground point. Grounding of *S*, the disturbing device, is optional in circuits *A* through *F*.

A TEST DEVICE FOR DETERMINING THE MOST EFFECTIVE FILTER

Any serviceman, having located an interference-producing device, can almost always secure an effective cure by installing an expensive filter like that shown at *I* in Fig. *2*. But cost to the customer must also be considered in a successful noise elimination job. If noise-free reception costs too much, many people will forego the use of their receivers or endure the noise, rather than pay the price; this is clearly not an encouraging condition for the radio sales and service business. Experience has proven that a satisfactory job done at the lowest possible cost to the customer—a charge which gives a fair profit—is one of the most important requirements for success in radio servicing. This means that the simplest and lowest cost filtering devices should always be tried first, working up gradually to the more complicated and more expensive combinations until the lowest cost unit is found which gives satisfactory filtering.

A variable filter combination system which gives a choice of circuit combination *A*, *B*, *C*, *D*, *G* or *H* in Fig. *2* simply by changing the setting of a rotary switch and changing connections to the unit is shown schematically in Fig. *3*. All condensers used here should preferably have working voltage ratings of between 600 and 1,000 volts, while the choke coils should be capable of handling at least 5 amperes. Use non-inductive paper type condensers mounted in metal cases which can be grounded. Notice that two outlet receptacles, each having a plug-in cap with insulated alligator clips attached to flexible leads, are used for the input and output connections. A ground connection is made by means of a flexible lead having at one end a prong

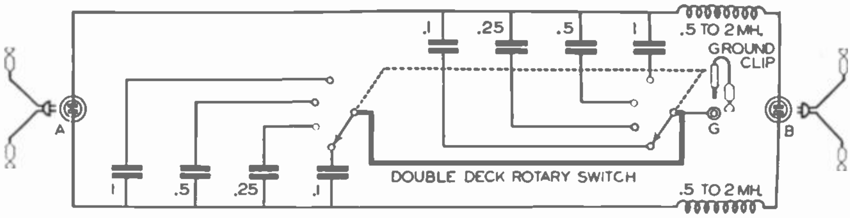


FIG. 3. Circuit diagram of a variable filter combination system which you can easily make for use in determining the most effective filter combination for an interference-creating device. Connections are made by plugging into standard electrical receptacles at *A* and *B*, and by plugging test prong into pup jack *G*. Mount parts in box of convenient size. Be sure power is off before making connections. The filter circuits provided here are those most generally used.

which plugs into a "pup" jack on the unit; at the other end of this lead is an alligator clip which is to be attached to the frame of the interfering device or to a grounded object.

When side *A* of this variable filter circuit is connected to the offending device, the condensers are next to the source of noise; when side *B* is connected to the device, the choke coils are closest to the source of noise. Single condenser connections and single choke and condenser filters are obtained by using one lead at *A*, one at *B* and the ground connection. When using condensers alone, always start with the lowest capacity, increasing the capacity up to 1 mfd. before resorting to choke coils. In making this test filter, be sure to use only those parts which can be readily obtained from radio supply houses at any time, for once the best filter setting is found, you must duplicate the parts used at that setting.

The method just described for using a variable filter combination system to determine the correct filter for a given job was first introduced by the Sprague Products Company; the interference analyzer which they developed for this purpose is shown in Fig. *4A*, while the circuit diagram of their analyzer appears in Fig. *4B*. This device is used in much the same way as that which was just described. The condensers and choke coils used in the Sprague Analyzer are exactly the same as the units supplied by the Sprague Products Company for use in interference filters; several of these are shown in Fig. *5*. The choke coil is capable of handling currents up to 10 amperes; where larger currents must be filtered, larger capacity chokes can be obtained.

When the condensers and choke coils required for a noise elimina-

COURTESY SPRAGUE PRODUCTS CO.

FIG. 4A. This Sprague Interference Analyzer is one of the serviceman's most effective weapons in the war against man-made radio interference. The knob on top controls the circuit-selecting rotary switch.

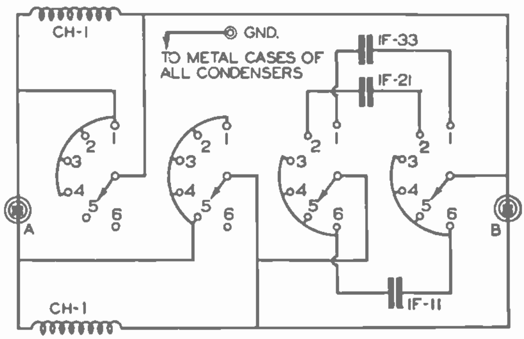
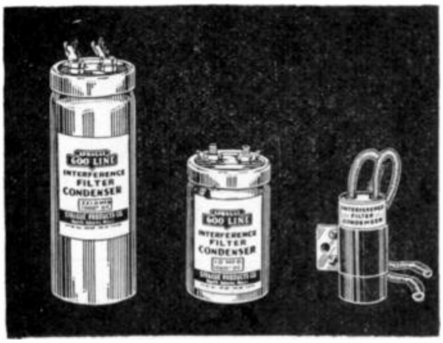


FIG. 4B. Circuit diagram of Sprague Interference Analyzer; numbers alongside condensers and choke coils refer to special interference elimination condensers and chokes sold by the Sprague Products Company, and shown in Fig. 5. A four-deck switch with six contacts per deck gives six different combinations of filtering units. Connections are made by inserting standard connecting plugs into the receptacles at A and B, and by plugging a test prong into the pup jack marked GND. Condenser IF-11 is of the dual-unit type, with the metal case serving as the common grounded connection. Positions 3 to 6 give balanced condenser filters.

tion job cannot be readily installed inside or on the disturbing device, it is wise from the standpoint of eliminating fire hazards, securing a shock-proof installation and improving the general appearance of the installation, to mount the condensers and chokes in a standard electrical cut-out box such as is shown in Fig. *6*. This procedure is compulsory for heavy-duty electrical devices which must pass fire underwriters' specifications and the regulations of local electrical inspectors.

As you already know, a filter unit must be placed as close as possible to the source of sparking if it is to be effective in reducing noise. When a cut-out box is used, the leads connecting it to the source of disturbance should be run through BX conduit or iron pipes, this conduit being permanently clamped at one end to the cut-out box and at the other end to the disturbing device; if necessary, a separate ground wire should be clamped or soldered to the conduit. This shielding procedure will prevent the standing waves, formed on the connecting wires, from radiating modulated disturbance waves of low wavelengths, which might cause interference in ultra high frequency receivers.

As a rule, interference filters have little effect upon the sparking or arcing itself, and serve only to prevent the current impulses from getting into the power line. Quite often the sparking at relay contacts, switch contacts and other make-and-break contacts can be greatly reduced by using a resistor in series with a single filter condenser connected across the spark source. This connection is especially



Courtesy Sprague Products Co.

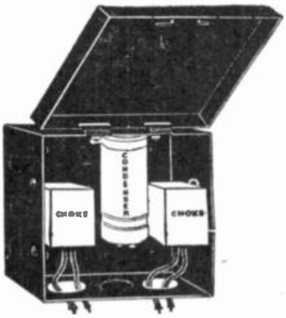
FIG. 5. Typical interference elimination units. Left to right: Sprague Type IF-11 dual 1 mfd., 600 volt condenser with metal can serving as common terminal; Sprague Type IF-50 single 1 mfd., 1,000 volt condenser unit with two terminals; Sprague Type IF-33, 1,000 volt rating condenser with two flexible leads, available in two capacities; Sprague Type CH-1 special interference eliminating choke coil (above), rated to carry 10 amperes and mounted in a metal case which should always be grounded.

worthwhile if you wish to prevent sparking contacts from pitting badly and producing even more serious disturbances at a later date.

THE NOISE DETECTIVE

You now know what to do once an interference-producing device is located; locating the offending device itself is another problem, however, and one which often calls for systematic thinking and even detective work. A well-trained interference-elimination technician can listen to the noise coming in over a radio receiver, ask a few questions of the customer and from these observations get clues which will permit rapid isolation of the offending device. Just as a detective asks questions when searching for a criminal, so should the Radio-Trician ask questions when on an interference job. When was the noise last heard? At what time of the day or night is it usually heard? Is the noise always the same in character? When was the noise first heard? These are questions whose answers may give you clues to the solution of the problem. The opinion of the customer as to the source of the trouble is also of value. Ask if the noise began about the time that some one in the neighborhood bought an electric refrigerator, a vacuum cleaner, fruit juice extractor, or other electrical appliance; try to associate the beginning of the interference noise with the arrival of a new neighbor, the installation of traffic lights at the corner, or the installation of a new neon sign in a nearby store. Neighborhood gossip can provide useful tips for the noise detective.

The value of knowing the time when interference noises are heard can easily be demonstrated. For example, interference heard for a



Courtesy Sprague Products Co.

FIG. 6A. The required combination of interference eliminating chokes and condensers should be mounted in a steel cut-out box like this, with all wires to the sparking device being run through BX conduit or pipe to meet fire underwriters' regulations and give a more efficient installation.

FIG. 6B. Another arrangement of filter units in a steel cut-out box. It is a good practice to place a fuse in series with each condenser, as is done here, for breakdown and short-circuiting of a condenser would otherwise place a direct short across the power line.

little while around breakfast time and perhaps occasionally late in the evening at a time when you know that the neighbors are having a party, may be produced by a fruit juice extractor; noise heard at intervals fifteen to thirty minutes apart may be due to an oil burner, a refrigerator, an air compressor in a nearby beer parlor or any other device which is operated only for short periods of time and is automatically controlled. Interference which is heard only when a street car or train is passing near the house gives an obvious clue; interference heard in apartments when the elevator is in operation proves that the trouble is in the elevator motor. Clicking noises heard when lights are turned on in the house tell their story at once. Your questioning of the customer, once you suspect a possible cause of the trouble by listening to the noise yourself, should result in a quick isolation.

If the interference can be picked up by the radio receiver at the time when you call, give special attention to any peculiarities of the sound; note whether the interference is heard with the same intensity at all frequencies. With a little experience you will be able to make very good guesses as to the causes of different types of interference noises. Until you have gained this experience, use the following suggestions which have been prepared by the Tobe Deutschmann Corporation of Canton, Massachusetts, as your guide in recognizing the sources of interference noise which you hear.

Whirring, crackling, buzzing, humming, droning and *whining* sounds are characteristic of motors and generators. When motors start, the pitch of the whine increases until it reaches a steady value. This is especially true of commutator type motors. Repulsion starting single-phase induction motors may have a sputtering, whirring, crackling, buzzing or humming sound. When such sounds are heard, look for such electrically operated equipment as:

Adding Machines	Farm Lighting Plants
Air Conditioning Units	Floor Polishers
Automatic Towel Rollers	Generators
Barber Clippers	Hair Dryers
Beauty Parlor Devices	Humidifiers
Billing Machines	Massage Machines
Cash Registers	Motor-Generators
Dental Engines	Portable Electric Drills
Dishwashers	Printing Presses
Dough Mixers	Sewing Machines
Drink Mixers	Shoe Dryers
Electric Addressing Machines	Small Blowers
Electric Computators	Telephone Magnetos
Electric Elevators	Toy Electric Trains
Electric Refrigerators	Vacuum Cleaners
Electric Vibrators	Valve Grinders
Fans	Washing Machines

Rattles, buzzes and *machine-gun fire* sounds indicate interference from buzzers, telephone dials or doorbells. These noises are usually intermittent, starting and stopping at irregular intervals. Short machine-gun firing sounds indicate telephone dialing interference. Look for such interfering devices as:

Annunciators	Doorbells
Automobile Ignition Systems	Elevator Controls
Buzzers	Sewing Machines
Dental Laboratory Motors	Switchboards
Dial Telephones	Vibrating Rectifiers

Violent heavy buzzing or *rushing* sounds are often heard over a large area or even a whole town, the sounds being at times so loud that they drown out the radio program. They may be louder at one end of the tuning scale of the receiver, indicating high frequency noise-modulated radiation; they may be heard only on certain bands of all-wave receivers. These sounds may be traced to:

- Air Purifiers
- Battery Chargers
- Diathermy Machines
- Doctors' Apparatus
- Flour Bleaching Machinery
- High Frequency Apparatus
- Insulation Testers
- Neon Signs
- Ozone Devices
- Spark Transmitters
- Spark Ignition in Oil Burners
- Violet Ray Apparatus
- X-Ray Machines

Crackling, sputtering, snapping, short buzzes or *scraping* sounds indicate loose connections; if in the house, they will be especially noticeable when walking about; if outside, heavy traffic or street cars may increase the intensity of the sounds. Look for:

- Defective Light Sockets
- Flimsy Elevator Controls
- High Tension Lines
- Power Lines Grounded to Trees
- Street Cars
- Wet Line Insulators
- Loose connections in floor lamps and appliance cords; broken heater elements in household appliances. Unbonded rubbing metal contacts in houses, such as adjacent water pipes.

Clicking sounds are a definite indication of some sort of make-and-break connection essential to electrically operated industrial equipment, such as:

- Elevator Controls
- Flashing Signs
- Heaters, Automatic
- Heating Pads
- Incubators
- Irons
- Mercury Arc Rectifiers
- Electric Typewriters
- Ovens
- Percolators
- Shaving Mug Heaters
- Soldering Irons
- Telegraph Relays
- Thermostats
- Traffic Signals
- Safe Time Clocks

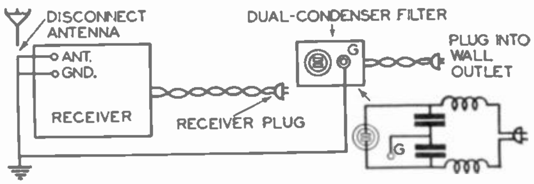
Heavy violent buzzing sounds, usually of short duration, are characteristic of heavy sparking or arcing across a gap. Such sounds are traceable to:

- Arc Lights
- Automobile Ignition
- Breaks in Third Rails
- Electric Car Switches
- Electric Elevators
- Motion Picture Projectors
- Pole Changer (Telephone Interrupter)
- Street Car Switches
- Street Lights
- Toy Electric Trains

TRACING THE ORIGIN OF INTERFERENCE

After making a survey of an interference problem, the Radio-Trician is generally able to tell whether the interference noise heard is produced in the customer's house or outside the house; in an apartment building he can readily tell whether devices in the customer's apartment are at fault. When the source of noise can be quickly located, a simple filter will remedy the trouble at minimum expense to the customer.

When, however, locating the offending device involves a search through many apartments in a building or many houses in a neighborhood, by all means give the noise-reducing antenna first considera-



Make this simple test with a condenser-choke filter of the plug-in type to determine whether interference is reaching the receiver directly over the power line. If interfering noises are still heard when the set is connected as shown, with the dual condenser line filter inserted in the power line, you have proved that the receiver itself is creating the noise; if no noise is heard but noises return with full intensity when the filter is removed, the interference is coming in over the power line. The remedy in this case is obvious: Install a line filter. The circuit diagram for the line filter recommended for this test is shown at the lower right.

tion, after you first try a line filter across the power leads of the receiver. Occasionally noise signals get in by this route.

Before actually installing a noise-reducing antenna, make sure that direct chassis pick-up of the noise signal is not involved, either by making the usual test with antenna disconnected and the receiver input terminals shorted, or by operating another receiver in the same location. Direct chassis pick-up is ordinarily encountered only in older types of receivers which have a number of unshielded parts.

Interference Originating in the Customer's Location. A quick test which will rule out the customer's location as the source of interference can be made with a portable battery receiver of the type which uses a loop or fish-pole antenna and no ground connection. The interfering noise should be heard on the battery receiver when it is placed in operation near the customer's receiver; if the noise is not heard, check the customer's antenna and ground system for poor joints and exposed wires which are rubbing against a tree or building. Assuming that the interference noises are heard on the battery receiver, have some one open the main power switch which controls the entire electrical system in the house or apartment. If the noise disappears or is greatly reduced when this is done, at least one of the offending devices is in the place.

Locating the Noise-Producing Device in the Home. In small homes or in apartments this is easiest done by switching each of the electrical appliances off and on while the customer's receiver is in operation. In large homes this is done more quickly by having an assistant remove the fuses for each electrical circuit in the house in turn, while you note the effects on the customer's receiver. When the noise stops, you have isolated the defective device to one particular circuit; there remains only the checking of each part, device and connection in this circuit. The following procedure has proven very effective for isolating noise-producing sources:

1. Check the antenna, lead-in and ground for loose or poor connections.
2. Be sure that none of the service wires which enter the house are rubbing against the branches of trees or against the building.
3. Make certain that the service conduit containing the supply wires leading into the house is grounded.
4. The wiring in the house should be grounded as provided by the accepted local electrical code. Have a licensed electrician check this if there is any doubt in your mind.
5. Be sure that all switches in the distribution system make firm contact. All line fuses should be firmly in place, with clean contacts. No temporary fuses or fuse shorts should be allowed. Fuses should be checked, as a loose connection between the fusing material and the contact cap will create arcs.
6. Inspect all connections in switch boxes, distribution boxes and fuse boxes for looseness, tightening terminal screws where necessary.
7. Examine all lamp bulbs used in the house and make sure that they are firmly screwed into their sockets. Turn on each lamp and tap it on the side for loose elements and poor base connections. Question the socket.
8. Check all lamp extensions and attachment plugs to every appliance, looking for loose contact. Shake extension cords, listening to the radio for signs of poor internal connections while the device connected to the cord is turned on. Extension cords with knots and kinks, as well as worn cords, are prolific sources of interference.
9. Repair or replace snap switches which do not open quickly.
10. Water and gas pipes or electric conduit pipes rubbing against each other may discharge their electrostatic charges. Bond the pipes together at the rubbing joint or insulate the contact surfaces. Quite often the turning on of a water faucet, walking through the house, use of household appliances or the operation of oil burners or refrigerators will start such electrostatic interference. With experience you will be able to distinguish electrostatic noises from those produced by electrical apparatus.

In checking these items the receiver should be turned on, with your assistant or even the set owner listening to the receiver, while you check various things in the house. A broom handle may be used for probing or knocking against pipes; when the region surrounding the noise source is probed, noise will be clearly heard in the receiver.

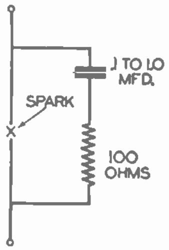
Interference Outside the Customer's Home. When your tests show that the noise source is not in the customer's home, and the installation of a noiseless antenna proves inadequate, then the defective device must be isolated by means of an "interference locator." A portable receiver with self-contained batteries may be employed. The receiver should be sensitive, employing three to four R.F. pentode stages if a T.R.F. set; a portable superheterodyne may also be used. If the receiver is not already well shielded, it should be built into a heavy aluminum box. Inexpensive and sensitive portable battery receivers may be purchased from large radio mail order houses. In addition to the headphones used as an output indicator, a copper oxide rectifier type 0-5 volt voltmeter having a 1,000 ohm per volt sensitivity should be permanently connected to the output. Thus both aural and visual output indications are available. Whatever receiver is used, it must *not* have A.V.C., for this would tend to conceal changes in interference intensity.

The pick-up system may be a 7-foot collapsible aluminum pole or a loop antenna. In the latter case the antenna coupler in the receiver must be disconnected and the input condenser arranged to tune the loop. For an .00035 mfd. input variable condenser a box type loop containing 24 turns spaced 1/8 inch apart on a 20-inch square form will be needed to cover the broadcast band. Use No. 18 or 20 gauge D.C.C. wire. Both pole and loop antennas may be used by installing a D.P.D.T. change-over switch. The pole antenna is preferred where there are many overhead wires in the vicinity of the home; the loop antenna performs best in open spaces.

In locating a noise source, first listen to the noise signal on the portable receiver, with the tuning dial set to a frequency where broadcasts are not heard. Using the loop antenna, rotate the loop until a maximum output meter reading is obtained. The noise origin will be in the plane of the loop (along a horizontal line parallel to and passing through the top of the loop), but may be either ahead or behind the loop. Walk in the direction which gives increased output readings. Where overhead supply wires exist (we assume that the investigation is started outdoors, as everything in the house has been checked), the greatest noise signal will be evident when the loop is *parallel to* the overhead wires. This does not identify the source, however. Where overhead wires do not exist, then the direction of interference may be identified from two positions about 200 feet apart and, by following the two directions to their apparent intersections, the approximate location is obtained.

With the pole antenna use the "hot-and-cold" method, walking in the direction which gives increased noise in the phones or an increased output meter reading. Where an overhead power line is involved, follow the line for maximum output. The loop antenna may also be used in the above "hot-and-cold" method. Always point the loop in the direction of greatest output and follow the direction of maximum output indication. Follow overhead lines with the loop parallel to the line.

If some indication of the direction of the interference is secured from the customer, increased output should be obtained when moving



A condenser and resistor in series, connected as shown, will reduce the intensity of a spark at make-and-break contacts.

the interference locator toward the suspected point. For instance, if you are told that noise started when the neighbor installed a new refrigerator, walking to the neighbor's home when the noise commences should show increased noise output.

The independent interference man must realize that in locating a fault he may have to trespass on private property. Where the trouble originates in a home or building, it should not be difficult to obtain permission, once he identifies himself. In case the trouble is traceable to power lines and line equipment, the power service superintendent should be informed; he will without doubt have his engineers cooperate in the matter and make the necessary corrections. Most power companies and public utilities have engineers who specialize in interference work. This text does not consider interference troubles peculiar to public utilities; where the trouble is traced to telephone equipment, street railway lines or other public service equipment, explain the situation to the customer and suggest that he notify the company in question.

Once the noise has been localized to some house or business establishment, first secure permission from the tenant or owner, then proceed to isolate the defective device in the same manner which you would use in the customer's home. If the noise is traced to a point some distance away from the customer's home, it is probably due to a device which draws considerable power; thermostat contacts, electric light switches, and electrostatic sources of interference can generally be ruled out in a case like this.

COMMON INTERFERENCE CONDITIONS

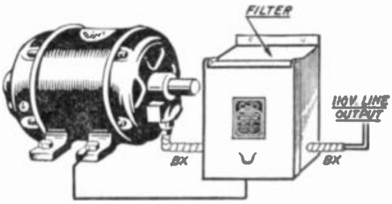
A study of a few common interference-producing conditions which may arise in various types of electrical equipment will help to clarify this important problem of interference elimination.

Electric Motors and Generators. Any electric motor, especially the D.C. and universal A.C. motors which employ commutators, should be suspected as a source of noise interference. Probable causes of trouble here include sparking at the commutators due to poor contact with the brushes, and dirty or uneven commutator segments. Sparking causes pitting and burning of the commutator segments, and the interference situation rapidly grows worse; before attempting to clean up the motor, connect the interference analyzer and determine whether a simple filter combination will completely eliminate the present interference. If the combination of filters required proves excessive in cost, repeat the analyzer test after you have remedied the sparking; a less-expensive filter should now prove sufficient. For motors try the filter combination shown at *B* in Fig. *2* first; if this is insufficient, add two choke coils as shown at *G* in Fig. *2*, making sure that the coils used will carry continuously the full load current of the motor. For 110 volt motors figure 10 amperes per horsepower; estimate 5 amperes per horsepower for 220 volt motors.

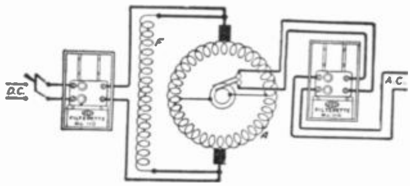
No interference-remedying job on a motor can be considered complete unless the cause of the trouble is removed or at least rectified. The commutator should first be cleaned and made smooth with fine sandpaper, and the brushes then reshaped if necessary to fit the commutator better. It is common practice to smooth the commutator, where it is not too badly worn, by wrapping or tacking sandpaper to a flat block of wood and applying this while the motor or generator is revolving. Brushes can be reshaped with the motor or generator at rest; slip a piece of sandpaper under a brush, with the cutting surface facing the brush and the sandpaper pressed against the commutator. Rock the commutator back and forth slowly until the brush takes its proper curvature. When you have finished, wipe off the brushes and the commutator carefully and apply a very small amount of vaseline over the surface of the commutator.

Oftentimes sparking at brushes can be reduced by shifting the positions of the brushes to get improved commutation. Rock the brushes slowly back and forth a very short distance until minimum sparking is observed; this should be done while the machine is operating at normal load if best results are to be obtained. With generators, moving brushes *in the direction of rotation* ordinarily reduces sparking; with motors the opposite holds true.

Make-and-Break Contacts. With simple make-and-break contacts such as are found in switches, temperature control thermostats, automatic electric irons, electric water heaters and similar devices, a filter consisting of a single condenser or a condenser in series with a



Combination choke-condenser filters mounted in metal cut-out boxes are often necessary to stop interference created by medium and large sized motors. Connections between motor and filter box must be run through flexible BX conduit, as shown here.



Both input and output leads of a rotary converter must be filtered, using choke-condenser units mounted in cut-out boxes and mounted as close as possible to the machine. F represents field coil, A the armature of the converter, which here changes D.C. to A.C.

resistor will usually prove sufficient to eliminate the interference. It is always a good plan to clean and adjust the contacts, in order to prevent a prolonged arc which would prove destructive to the contact points and cause even more severe interference than before.

Oil Burners. Interference produced by oil burners can usually be traced to the high tension ignition circuit, to automatic switching devices, or to the motor. Some burners use a gas pilot light, eliminating ignition systems as a possible source of interference; this you can easily confirm by inspection. If the interference noise is continuous for the period during which the burner is operating, the motor is clearly at fault; if the noise is heard only for a short period when the burner starts, the ignition system, one of the relay devices or the starting mechanism in the motor is at fault. Trouble at the motor can usually be eliminated by installing a filter as close as possible to the brushes.

Ignition system troubles are remedied by shielding all high tension wiring either with metal conduit, with flexible metal loom, or with metal braid, the shield being well grounded at each end in all cases. Some servicemen recommend that the frame of the oil burner be bonded to the boiler and to ground with heavy wire or metal braid, to prevent radiation. Try a coil and condenser type filter across the input leads of the ignition transformer; try simple condenser filters across thermostat contacts and relay contacts. Oftentimes it is necessary to place a wire shield around the ignition electrode in gun-feed type oil burners and ground this shield to prevent ultra high frequency radiation.

Here are a few practical suggestions concerning oil burners. If the noise elimination job on a burner appears at first inspection to be a rather involved affair, it is well worth while to contact the local distributor of that burner. Similar interference conditions will have been encountered in other installations, and often the distributor can make suggestions or supply special equipment which will remedy the trouble in short order. Once you prove that you can eliminate interference on that type of burner, the distributor may even refer similar jobs to you. Remember that all filters should be placed in metal housings to conform with underwriters' regulations.

Electric Refrigerators. The motor is the usual source of trouble in electric refrigerators; its treatment has already been taken up. Static charges accumulating on the compressor-motor belt sometimes cause trouble; the remedy here is bonding the motor frame and the compressor frame either to the refrigerator frame, to some large metal mass in the unit or to ground. Refrigerator mechanisms are usually mounted on spring supports; occasionally you will find that a spring has weakened, allowing a make-and-break contact between the refrigerator frame and the part in question; in this case install a new spring. If the interference is traced to a sparking thermostat, it is wise to call in a refrigerator serviceman; adjustments on refrigeration control devices such as this require specialized knowledge.

Electro-medical Apparatus. X-ray machines, violet ray apparatus and diathermy machines can cause a great deal of annoying interference; these may prove the most stubborn cases which you will encounter. Most of the equipment now being marketed is designed to create a minimum of interference,but older models are trouble-makers. Modern vacuum tube type diathermy machines create interference at only one frequency in the short-wave region; this interference can be eliminated only by placing the machine in a screened room.

With medical apparatus in general, the first step involves placing a choke-condenser filter in the supply line to the device. If this is insufficient, the only recourse is to place the apparatus in a screened room. The frame of the room can be either of metal or wood; this is then covered with either iron or copper screening, preferably both inside and outside of the framing, and the screening is well bonded together at all joints. The door must be so constructed that it makes firm electrical contact with the remainder of the screen when closed. Filters should be placed on all power lines which enter or leave this screened room, for otherwise interference would be conducted outside and there radiated; the filters should be placed as close as possible to the exact points where the lines pass through the screen.

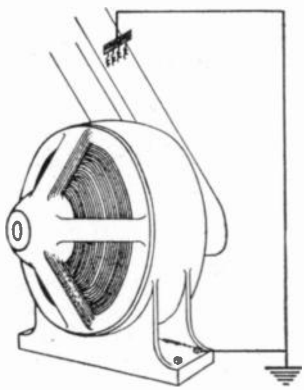
Courtesy Tobe Deutschmann Corp.

When electromedical apparatus is creating noise interference a grounding screen cage like this must often be used. All joints must either be soldered or continuously bonded in some way. Filter units must be attached to all power lines at the points where they enter the cage. All devices and filter units inside the cage should be grounded to the screen; connect the screen to a nearby ground if this gives an additional reduction in interference.

Flashing Signs, Traffic Lights and Neon Lights. In general, interference from these three sources can be spotted by visual inspection and by studying the nature of the sound heard in the receiver. For example; if a steady choppy noise is heard in synchronism with the flashes of a yellow blinker light up the street, the defect is immediately isolated. If a steady rolling or clicking sound is heard, and you note in the vicinity a sign having a continuous change of light, perhaps around the border, that sign is very likely the offender. Whenever there is some question as to the source of trouble, use the portable receiver to localize the trouble. The next step is a study of the device in question to determine the simplest filtering procedure.

Simple flashing signs which have a single make-and-break flasher require only a filter condenser connected directly across the contacts; the closer the condenser is to the contacts, the more effective it will be. Motor-driven contactors are generally used in signs which create the effect of motion; the first step with these is to filter the motor supply leads, then the main supply leads to the electric lights. If this fails, it is then necessary to connect a filter to each contact on the contactor. The condenser should be connected from the contact to the common terminal for all circuits, which is ordinarily easily located. In severe cases of interference it is necessary to place a choke coil in each lead to the lights, the condenser being connected from the contact side of the coil to the common power lead. Short connections are essential here to prevent high frequency radiation.

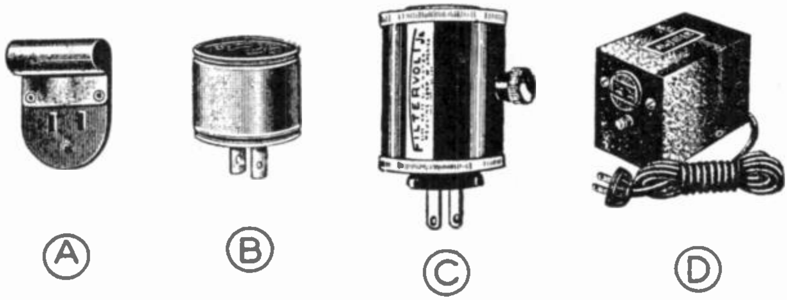
Flashing traffic lights are treated in much the same manner, using condenser filters across the contacts and line filters where necessary. This work must naturally be done under the supervision of the proper authorities.



Moving belts and belt conveyers are sources of static discharges, not only creating noise interference but actually endangering the lives of nearby persons and the insulation in the machinery. A grounded metal comb with flat or coil springs rubbing on the belt will discharge this static electricity harmlessly to ground and at the same time stop the radio interference. Use a good ground which is carefully erected. In any industry where static electricity is produced, all fixed and movable parts of machinery should be grounded.

Neon signs of the non-flashing type do not as a rule cause interference troubles; where interference is positively traced to these signs, about the only remedy is the installation in the primary leads of the high tension transformer of a condenser-coil filter of the type shown at *G* and *H* in Fig. 2. When a rotating contactor is used in the primary circuit of a number of neon transformers to switch from one group of tubes to another, filters must be connected to each contact and to the motor of the contactor. Where the rotating contactor is in the secondary circuit, switching high tension currents from one to another of a number of small sections of neon tubing, condenser filters are out of the question because of the high voltages involved. Try inserting 10,000 to 25,000 ohm spark suppressor resistors in each high tension lead; choke coils inserted in these leads may also reduce the interference. In certain severe cases the only remedy may be a complete change-over of the sign-operating mechanism, which will place the rotating contactor in the primary circuit and provide a separate transformer for each section of tubing; such an arrangement is more readily treated for noise suppression, but the cost of making the change-over is generally so high that the job of filtering is given up.

Quite often neon tubing will accumulate an electrostatic charge which leaks off to the nearest metal objects or at points of support; try placing mica sheets at these points. The two chains which sometimes support neon signs in show windows often acquire a difference in potential; insulating each chain from the neon tubing or using a non-metallic type of support will effect a remedy. Neon signs should be kept as far away from glass windows as possible, to prevent ac-



Examples of typical commercial filter units for interference-creating electrical appliances. At *A* is a single condenser unit which may be slipped over the prongs of the appliance plug; *B* is a similar unit, but of larger capacity, for insertion between appliance plug and wall outlet; *C* is a dual condenser filter with a midpoint terminal which can be grounded; *D* contains a condenser and coil combination designed for use with larger appliances. These devices are generally carried by those servicemen who do not make a specialty of interference elimination; by trying each device in turn, they can generally find one which will give satisfactory noise reduction where there is only mild interference. Never connect condensers larger than 1 mfd. directly across an A.C. line for filtering purposes; the power losses in larger condenser units are often high enough to cause excessive heating on continuous duty, resulting in failure of the condenser.

cumulations of static charges on the glass. Quite often a general overhauling of the neon sign, done by a sign expert, will greatly reduce the interference and make ordinary filtering procedures effective. This involves cleaning of all insulators and all tubing, to prevent high tension currents from leaking over dust-covered glass surfaces.

Thus you can see that the elimination of interference, once the source has been located, calls for "horse sense" and a certain amount of "trial and error" work, as well as a knowledge of the causes of interference and the technique of filtering.

Radio Noise Survey. Although the results of any survey made of causes of radio interference noises will vary with the locality, the following data taken from one such survey gives a general indication of the frequency with which various noise complaints occur. Out of

9,000 complaints, about 30 per cent were traced to power companies and public utilities, about 30 per cent to apparatus owned by the general public, about 15 per cent to defective radio sets and the remainder to transient or unlocateable conditions. Of the 30 per cent traced to devices owned by the public, motors and motor-operated devices accounted for 10 per cent, defects in wiring of building—6 per cent, switches and interrupter apparatus—5 per cent, electro-medical apparatus and neon signs—3 per cent, and miscellaneous—6 per cent.

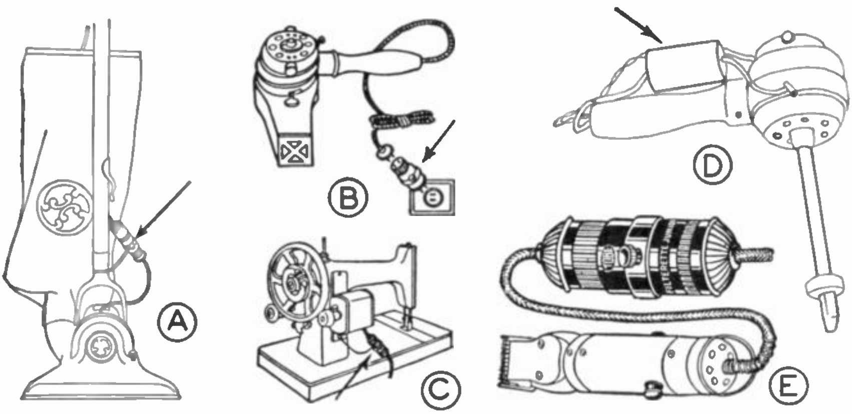
SECURING INTERFERENCE ELIMINATION BUSINESS

Noise is as old as civilized man, but radio has made the public more noise-conscious today than ever before. Noise ruins the entertainment value of radio programs, changing the radio receiver from a luxury to a nuisance in the customer's mind. Interference elimination is so much a community affair that many towns and cities have passed ordinances which compel those people owning interference-creating devices either to eliminate the noise or to cease using the offending device; as the public demands better and better radio programs, laws become more widespread. With laws such as this in your favor, the securing of interference elimination business is comparatively simple, but even if you must first sell the idea of noise elimination to a customer, there are enticing profits awaiting you in this field. In addition, this side-line of servicing will bring more regular service jobs to your shop.

Always make inquiries about possible interference on each radio receiver service call which you make; bringing noise interference to the attention of the public and stressing the fact that practically all noise can be eliminated, will eventually produce many interference elimination jobs for you. If you plan to become a specialist in noise elimination, it is a wise plan to select a certain section of your town, preferably in the immediate neighborhood of your shop, for complete noise elimination. It may take weeks or months to locate and remedy all noise sources in this section, but once all noise has been eliminated, your reputation will spread throughout the town, and your work in other sections will prove more easy. Then, too, the experience gained will be of great value in solving similar problems elsewhere.

Be sure to contact the trouble-shooting department of your local power company, and the same department in any other nearby public utility. These firms constantly receive complaints of interference; once you have shown that you can handle this work, they will welcome you with "open arms" and even send jobs your way. Whenever you encounter an interesting or particularly successful job, always call your local newspaper; anything with a little human interest makes a good story for the newspaper and gives profitable publicity to you.

Having selected a six or eight-block square section of your town as a starting point, the best approach is to announce that you are making a "radio interference survey." Visit the homes and business establishments in this section, preferably during your spare time,



Courtesy Tobe Deutschmann Corp.

Examples of filter installations on small electric appliances which are creating interference because of sparking or arcing. *A*—vacuum cleaner motor interference can generally be cured by inserting a dual condenser filter in the connecting cord, not more than six inches away from the motor, and grounding the midpoint terminal to the frame of the appliance; arrow points to filter. *B*—interference created by the blower motor of a small hair dryer can often be satisfactorily reduced by placing a condenser filter of the plug-in type between the wall outlet and the hair dryer plug. *C*—plug-in type dual condenser filter inserted in sewing machine motor cord, as close as possible to motor, gives a neat interference-reducing installation where it is not feasible to make connections directly to motor terminals. *D*—condenser filter connected directly to terminals of a small mixer; this is not an ideal installation, for the filter interferes with the use of the appliance. *E*—plug-in type condenser filter inserted in cord of barber clippers, close to motor, gives satisfactory elimination of interference in most cases. Always try plug-in filters at wall outlet first, to avoid unnecessary cutting of appliance cord. Ground midpoint of filter to frame of appliance or nearby ground wherever possible.

explain what you are doing and ask if they have noticed any radio interference noises. Secure their permission, if possible, to turn on their radio receiver so you can listen for the noise yourself. By starting in a section where you are known, opposition to such a survey will be at a minimum. Keep your eyes open for regular service jobs while making the survey, and put in your bid for the job either at the time of the call or at a later date.

After each call, when making the survey, write your observations on a small card, perhaps of the three by five-inch size. With these cards arranged in geographical order, a study of them should show you where interference is a maximum; your first efforts should be concentrated in this region. Secure permission to check on all suspected devices, and apply the interference-isolating technique which has already been explained.

If you hesitate to make a sales talk in each home in order to explain your purpose, send printed post-cards or letters explaining what you intend to do; this will tend to offset possible objections or the need for lengthy explanations when you make your call. A cartoon or drawing on the card or letter will attract attention to the purpose of your message and thereby give better results for you. Literature like this can also be used to explain why certain devices cause interference and why this interference should be eliminated at its source; this literature, by calling to the attention of customers man-made interference situations which they may not have recognized as such, will make it easier for you to sell filters and interference-elimination services at a later date.

LINE FILTER CONSTRUCTION DATA

Line Filters for Radio Sets. Get two .5 mfd. tubular paper condensers rated at 600 volts D.C. working voltage, one bakelite coil form about 6 inches long and 3 inches in diameter, and a half pound of ordinary No. 18 bell wire. Unwind the wire and cut into two pieces of equal length.

Drill two holes (each about 1/8 inch in diameter) at one end of the coil form, locating them about a half inch in from the edge of the form and about one inch apart. Anchor each wire by looping it once or twice through its hole, leaving about 6 inches projecting for connections. Proceed to wind the two wires side by side on the coil form in a single layer, with turns as close together as possible. When all but about 6 inches of the wire has been wound in this manner, drill two more holes about one inch apart and loop the ends through these holes for anchorage. This will give you two coils of approximately 35 turns each, wound on a single coil form.

Insert this filter choke in the radio set power cord, either at the wall plug or at the radio set. In other words, cut the two wires of the radio set cord at the desired location, connect one pair of cut wires to the leads at one end of the choke, and connect the other pair of cut wires to the two leads at the other end of the choke. Now connect one terminal of each .5 mfd. condenser to one of the leads at the *receiver* end of the choke coil; connect the remaining two condenser leads together and provide a means for grounding this common condenser connection (to a convenient water pipe or to the radio set ground if you know that to be good). Cover all exposed connections with friction tape. This completes the filter itself, but you will probably want to mount it in a wood or metal box so no dangerous 110 volt A.C. terminals will be exposed. The circuit of this filter is like that shown on page *16* (with the receiver connected and plugged into the outlet on the filter), or like that in Fig. *2G* if *S* represents the receiver.

General Filter Construction Hints. The same general filter construction described above will serve for practically any line filter application *if the wire used in winding the choke is the same size as the power cord wire used for the appliance being filtered.* In other words, if you are filtering an electric motor having No. 14 wire in its line cord, wind the choke with about 35 turns per coil (70 in all) of No. 14 insulated wire; No. 14 tinned solid copper push-back wire will do nicely, or you can use the same size of double cotton-covered wire and apply a coating of insulating varnish to the completed choke. To get this number of turns, you will have to order about 60 feet of wire in whatever size is required. Naturally you will need a longer coil form for heavier wire, since the choke must be in a single layer. The condenser size specified is all right for all cases; in general, the condensers should be connected to that end of the choke which will make the interfering signals go through the *choke* before they reach the condensers.

TEST QUESTIONS

Be sure to number your Answer Sheet with the *number* appearing on the front cover underneath the title of this text.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your Course, and you will receive the best possible lesson service.

1. What effect does a tone control, which cuts off the high audio frequencies, have on static noises?
2. In locating the best position for the straightaway portion of a noise-reducing antenna, what three rules would you follow?
3. What type of filter would you try if simple condenser filters using 1-mfd. units failed to give satisfactory noise reduction?
4. What should be the peak voltage rating of condensers used on ordinary 110 or 220 volt A.C. power lines for filtering purposes?
5. What are the probable causes of noise interference in D.C. motors?
6. What type of filter would you use on a make-and-break contact?
7. When interference-producing apparatus is located in a completely screened room or cage, where should the line filters (which are placed on all power lines entering the room) be placed?
8. When using a pole antenna with an interference-locating receiver, how can you tell when you are approaching the source of noise?
9. If interference noise traced to an oil burner is continuous for the period of operation of the burner, what is the cause?
10. What should be the current-carrying capacity of a choke coil which is to be used in filtering the power leads to a 220 volt, one horsepower motor?

How to Eliminate Man-Made Interference. No. 46 RH-1

1. It dulls the static noises.

2. (1), Place the antenna as high as is reasonably possible; (2), keep the antenna at a distance from known sources of interference; (3), place the antenna at right angles to trolley line or power lines.

3. A combination condenser-and-choke filter.

4. Somewhere between 600 and 1,000 volts.

5. Sparking at the commutator due to poor contact with brushes, dirty or uneven commutator segments.

6. A simple condenser, or a condenser in series with a resistor.

7. As close as possible to the exact points where the lines pass through the screen.

8. Increased noise will be heard in the phones, and the output meter will give a higher reading.

9. The motor.

10. 5 amperes.

FIELD AND BENCH TESTING OF RADIO PARTS

47RH-1

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

WHAT THEY SAID ABOUT LEARNING

Who knows useful things, not many things, is wise.

Æschylus.
(Early Greek poet.)

Some people will never learn anything, for this reason—because they understand everything too soon.

Alexander Pope.
(Famous English writer.)

Learning teacheth more in one year than experience in twenty.

Roger Ascham.
(Tutor to Queen Elizabeth of England.)

NATIONAL RADIO INSTITUTE

WASHINGTON, D. C.

1941 Edition

A LESSON TEXT OF THE N. R. I. COURSE
WHICH TRAINS YOU TO BECOME A
RADIOTRICIAN & TELETRICIAN
(REGISTERED U. S. PATENT OFFICE) (REGISTERED U. S. PATENT OFFICE)

NCP2M1041

Printed in U. S. A.

Field and Bench Testing of Radio Parts

WHEN TESTS ON PARTS ARE REQUIRED

The average serviceman, whether servicing a receiver or amplifier in the field (on the job) or at the shop bench, is vitally interested in the condition of the part that he suspects to be defective. Then, too, the time it takes to service a job is important. If the part is obviously defective and is not an expensive component, it should be replaced at once. Should the part be expensive and its defective condition doubtful, then more rigid inspection and tests are required. If an expensive component or a part difficult to get is found defective, a repair may be wise.

Small and large service shops invariably collect a large number of parts, taken from receivers or amplifiers that have been serviced. Quite often, obsolete (out-of-date) receivers are dismantled, so the good parts may be used for exact replacements in receivers of similar make. In all such cases a routine check of the salvaged parts is deemed advisable before they are placed in stock for future use. You are the only one to decide how extensive these tests should be. Experience and good judgment must be fully exercised. Not all the tests given here may be required.

If you plan to manufacture an appreciable number of amplifiers or tuners, or if you are connected with some radio equipment manufacturer, remember that a lot of final inspection and trouble shooting can be eliminated if you test each of the components that go into the manufacture of the device. Of course, large manufacturers employ automatic testing machines, but the electrical systems of these testers basically follow many of the tests to be described here.

To be sure, there are many ways of making a given test. Engineers differ in their opinion as to the value of a given method. We shall, however, limit ourselves to the more direct and the simplest of tests. Wherever possible, we shall suggest a method of repair. The exact procedure will vary with the construction of the part. In general, the best plan is to scrap a part that fails to meet the lowest acceptable tests.

We shall not consider vacuum tubes, speakers and mechanical parts, as they are considered elsewhere. We shall consider such basic parts as resistors, condensers, transformers and coils without much regard to their use. Fundamentally, a resistor is a resistor whether used in an A.V.C. system or as a load across a transformer. There is no doubt that the use that a part is put to will determine the rigidness of the tests. Thus many factors must be taken into consideration, such as frequency, voltage, current, power, etc. A part may be 100 per cent with regard to one factor and not acceptable for one or more other factors. Deficiency in any one factor may destroy its use for a given purpose, although for other uses more than one factor may have to be low. Here is where experience and judgment play an important part in your work.

FIXED RESISTORS

Fixed resistors are extensively used in radio circuits. You will find them in the signal circuits, the power system, in the decoupling and filter circuits. They are made in three ways: (*a*) carbon or some other high resistive material deposited on a tube or rod of glass or some ceramic material like isolantite or porcelain; (*b*) carbon mixed with a ceramic or moulding resin in various proportions and extruded into short lengths; (*c*) resistance wire wound over bakelite or fiber strips or on porcelain tubes. Types (*a*) and (*b*) are of the high resistance variety which vary from 20,000 to 20,000,000 ohms in electrical value. The ends are metal capped, with or without pigtails, and the resistor colored according to the R.M.A. code. The wire wound resistors run from a fraction of an ohm to 50,000 ohms. Those used for voltage dividers have three or more terminals. Those wound on porcelain are dipped in vitreous enamel or bakelite varnish and baked.

All resistors must be carefully made to withstand temperature rise, humidity and overload without appreciable change in resistance value. Also, their design and construction must be such that the resistor is noiseless; that is, there should not be any minute variations in the element or at the terminals which will ordinarily cause crackling noise in sound amplifiers.

Tests on the Job.—The usual test made while a resistor is still connected into the chassis is to measure the resistor for its ohmic value, using an ohmmeter. If it carries D.C. current, the voltage drop is a sufficient test. If the resistor gets unusually hot and the above tests are normal, then a resistor with a higher watt dissipation rating should be used. When you suspect that the resistor is noisy, the most reasonable thing to do, after the connections have been checked and considered normal, is—try a new one.

Load Resistance Values.—At the bench more convincing tests are required. Wire wound resistors may be checked with an ohmmeter or a Wheatstone bridge, using, of course, whichever device you happen to have. Resistors of the coated or compounded type may or may not be tested in this manner. Where a variation of 5 or even 10 per cent is not important, this sort of a test may be used.

Where exact values are important and there is some belief that the resistance of the resistor depends on the current or voltage, as is the case with carbon resistors, a load test should be made. The resistor under test is placed in series with a milliammeter and the correct voltage applied to it. This simple circuit is shown in Fig. 1. The voltage divided by the current (expressed in amperes) minus the resistance of the milliammeter (which should have a low resistance) gives the true load resistance value. Here is an example:

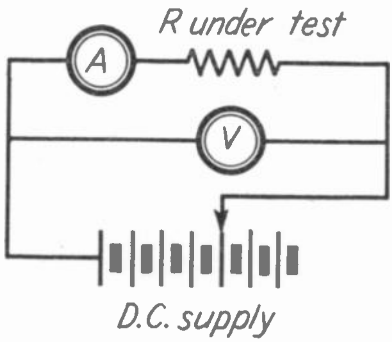


FIG. 1

Suppose you were selecting a bias resistor for a pentode vacuum tube (6C6) to be used as a detector. A tube table tells us that a 10,000 ohm resistor is used and when no R.F. is applied to the grid this resistor has a drop of 4.3 volts and .43 milliampere flows. Thus, in testing a suitable resistor in the circuit of Fig. 1, the voltage is adjusted to 4.3 and a resistor that passes .43 milliampere is considered to have a load rating of 10,000 ohms.

Grid resistors which normally carry only a few microamperes should be checked under a load of about 10 microamperes. Adjust the voltage for this value and compute the resistance for this load.

Resistors that do not have any markings to show their electrical value may be checked with an ohmmeter and placed in stock for use where a tolerance of 10 per cent is satisfactory.

Of course, you can test any resistor for temperature and humidity effects by duplicating the desired condition. This test is only considered advisable as a factory procedure, where a machine is designed for severe weather conditions; as, for example, for the tropics, for far northern territories, for coastal or sea use. In most cases a tolerance of 10 per cent is good.

Power Loss Rating.—Resistors should be rated according to power dissipation. Either the power rating or the current it is designed to carry should be given. The power rating is computed from: current × current × resistance. What should you consider the rating when no information is given? High resistance units may be roughly rated according to their diameter, as follows: 7/32″—⅓ watt; 9/32″—½ watt; 11/32″—1 watt; 7/16″—2 watts; 15/32″—3 watts. Of course, the length of the resistor will in practice vary with the diameter, being shorter for small diameters. For wire wound power resistors, figure 1 watt for every ⅓ square inch of exposed surface.* In general the greater the exposed surface the greater the power rating of the resistor.

Noise Tests.—There is only one satisfactory way of checking a resistor for its noise producing properties. Operate it under normal D.C. load conditions and feed its voltage drop to a high gain noiseless amplifier. A simplified circuit is shown in Fig. 2. A D.C. current near rated value is passed through resistor *R*, the one under test, by depressing the key. Resistor *r* is varied to get rated value. A true continuous current will produce no output sound or hiss. But any periodic or intermittent variation of *R* will produce an A.C. voltage which will be amplified and made audible.

The amount of noise to be tolerated can be fixed by adjusting the gain of the test amplifier. In general, use a gain about equal to the amplification of the audio system in which the resistor is to be used. Resistor *r* in Fig. 2 should be of the wire wound type and the battery of the storage or secondary type. The battery should not be freshly charged, otherwise it will in itself produce a hiss. The two 8 mfd. condensers are of the paper type.

VARIABLE RESISTORS

Variable resistors are generally the controls in radio equipment. Because their action is best understood by the owner of

* For round resistors, the area of the exposed surface is obtained from the formula: 3.14 × diameter × length. All measurements are in inches. For every square inch figure 3 watts.

the receiver and because they are continuously used, a defective variable resistor is very often the reason for a service call. Set owners quickly recognize that a control must have: positive action, that is, do what it was intended for; have smooth, continuous action; and no noise should accompany the variation of the control.

Do not condemn the variable resistor if its volume or tone control action is not as it should be. Check its resistance variation by connecting an ohmmeter to it and, if found normal, test the associated parts and circuits. Perhaps the control is a replacement and the previous serviceman did not bother to connect it into the circuit with the proper tapering *off* or *on* of resistance. If the action is too critical, reverse the terminal connections.

If the action is jumpy or discontinuous, either the resistance element (in the case of carbon resistors) has broken down, or

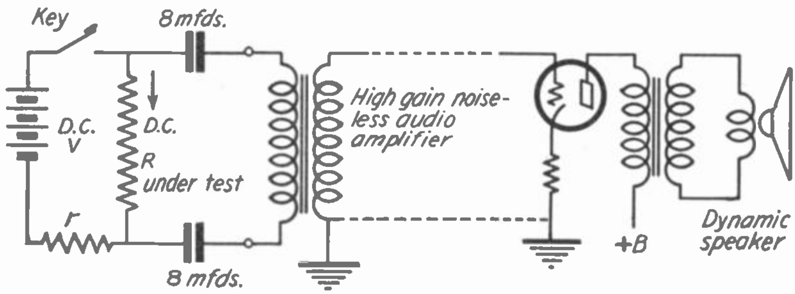


FIG. 2.

the variable contact (in the case of wire wound resistors) no longer makes uniform smooth contact. You should only try to adjust the contact; do not try to build up the carbon element. Replacement volume and tone controls are easily obtained and are inexpensive. Therefore, replace defective variable resistors wherever possible.

When you make a replacement be sure you get one with the right tapering action. Variable resistor manufacturers usually compile a list of important radio receivers and the correct model number resistor of their make to use. Be sure to consult such a list in ordering *tapered* variable resistors.

PAPER CONDENSERS

Filter and by-pass condensers are extensively used in radio equipment; in fact, in a well-designed receiver or amplifier the number used may even exceed the number of resistors. In the opinion of many servicemen, condenser failures account for most service calls, with the exception of vacuum tubes. As you know, condensers are of the paper, mica and electrolytic (wet and dry) types. Paper condensers are now extensively used as by-passes and in low frequency circuits. Although in the past paper condensers were used in the filter circuits of power packs, they are now almost universally replaced by electrolytics. Even when peak voltages of more than 600 volts are encountered, two or more electrolytics may be used in series. Mica condensers are generally used in R.F. circuits and are tested in the same manner as air condensers. We are now considering paper condensers whose electrical size may be any value from .006 to 10 mfd.

Field Tests.—A service technician cannot take elaborate testing equipment into the home or to the job. Yet he very often questions the condition of a paper condenser. There are many simple checks that a Radio-Trician may make. He assumes that the questionable condenser, if it is original equipment, is of the correct size. The only remaining problems are: shorts, leakage and opens.

Shorted condensers are quickly checked with an ohmmeter. Always use a high range ohmmeter, especially one which uses a 22½ or 45 volt B block. If the condenser is not shunted with a device that has measurable resistance, the check may be made directly while the condenser is connected into the circuit. Otherwise, one lead of the condenser should be unsoldered and the condenser then checked. If the condenser is not shorted, the behavior of the needle on the meter gives definite information regarding leakage. At the first application of the probes, the ohmmeter needle will "kick" up scale. This "kick up" indicated that a charging current flowed. If a condenser has negligible leakage (very high insulation resistance) the needle will return to zero or its original position. When checking low capacity condensers, the needle will return to zero more quickly than with high capacity condensers. This is due to their time constant (Capacity in microfarads $\times$ Leakage in megohms). Where the needle does not return to zero, a more rigid shop test should be made. If the condenser is inexpensive, make an immediate replacement; otherwise take the chassis to the shop.

Many servicemen test a large condenser (.5 to 10 mfd.) by temporarily connecting it across a high D.C. voltage supply (the output of the receiver power pack). After a minute or two the condenser is shorted. If a hot spark is observed, the serviceman assumes that it has little leakage; for it holds its charge.

When a condenser is suspected of having an open, it should be tested with a high range (high voltage) ohmmeter. An open condenser will take no charge, and the meter needle will not "kick" over. While you are testing any condenser, wiggle the leads of the condenser; the connectors may open.

While it is connected to a set that is turned on, wiggling or snapping a condenser may very often show up intermittent opens. Noise will be heard. Many servicemen test condensers while connected into the chassis and the receiver operating by connecting a good condenser in shunt with the one suspected open. If normal reception returns (for example: less hum, clearer tone, reduced or no oscillation, more volume), then a replacement is indicated. Where the size of the condenser is not indicated on the original part, a variable condenser box is connected to the circuit and a suitable condenser size estimated by trial. When installing new condensers, always connect the outside foil (if so marked) to the chassis or to the R.F. ground.

Now let us consider bench tests on paper condensers.

Leakage and Insulation Tests.—In testing for leakage we merely measure the resistance of the condenser. This is the resistance through the dielectric or the resistance of foreign material on the surface between the two terminals. In the case of old dirty condensers, it is a good idea to clean the surface with a cloth that has been saturated with alcohol. Wipe the condenser dry with a clean piece of cheese cloth.

Normal paper condensers have a leakage resistance of more than 80 megohms per microfarad. A paper condenser to be satisfactory must not have a leakage resistance of *less than* 50 megohms per microfarad. Thus a .1 mfd. condenser should have a resistance equal or more than 500 megohms; a .5 mfd. more than 100 megohms; a 1 mfd. condenser more than 50 megohms; a 2 mfd. condenser more than 25 megohms; a 5 mfd. condenser more than 10 megohms. Strictly speaking this condition should exist at normal working voltage (condenser rating) and at working temperature (room temperature will suffice). Working D.C. voltage (V) is applied to the condenser if it is not shorted and the current (I) measured with a D.C. microammeter. $V \div I$ is the leakage resistance in megohms, and it must not be less than 50 megohms per microfarad.

Unfortunately, most servicemen do not have a microammeter. A high resistance voltmeter, the higher the better, may be used. A 0 to 1,000 volt 2000 ohm per volt voltmeter is easily obtained. This meter, which will have a resistance of 2,000,000 ohms or 2 megohms, may be incorporated in a high voltage megohm tester. A very useful bench "megger" is shown in Fig. 3a. All part values are clearly shown and these parts are easily obtained from a radio supply house. This megger may be used to test insulation resistance in coils and transformers as well as condenser leakage. High grade parts with very little leakage must be used. The potentiometer, condenser switches and terminals must be mounted on high grade bakelite or hard rubber. The device you are testing should be set on a small bakelite panel. The pee-wee alligator clips should have insulated handles.

To test a condenser for leakage, connect the pee-wee jaw clips to the condenser. Set switch *S* to point *1* and adjust the 50,000 ohm potentiometer so the voltmeter reads the working voltage of the condenser. If this information is not known, 500 volts is a good value to select. Call this voltage E_1. Now set switch *S* to point *2* and record the voltmeter reading after the needle has come to rest. Call this voltage E_2. The leakage re-

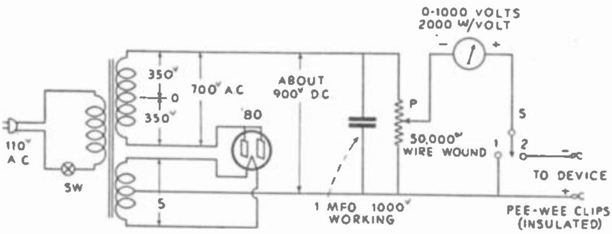


FIG. 3a. *P* should be a 25 to 50 watt wire wound potentiometer. You may use a 50,000 ohm ceramic coated voltage divider with at least 5 taps. Use a switch to vary the voltage.

sistance of the condenser or any other device is given by the formula:

$$R = R_{vm} \times \left(\frac{E_1}{E_2} - 1 \right)$$

Where R = leakage resistance

R_{vm} = voltmeter resistance

Let us take an example. Suppose a 1 microfarad 500 volt working condenser is tested with a 2 megohm voltmeter and the meter readings obtained are: $E_1 = 500$ and $E_2 = 10$ volts. Then:

$$R = 2{,}000{,}000 \times \left(\frac{500}{10} - 1 \right)$$
$$= 2{,}000{,}000\ (50 - 1)$$
$$= 2{,}000{,}000 \times 49$$
$$= 98{,}000{,}000 \text{ ohms or } 98 \text{ megohms}$$

and the 1 mfd. condenser is good.

If you build this tester exactly as shown, the leakage resistance is always 2 megohms less than 2 times the ratio of the two voltages. A calibration chart is shown in Fig. 3b, for E_1, equal to 500 volts. Incidentally you need not worry about a shorted condenser in this test. If a condenser is shorted, E_2 will equal E_1. When testing for leakage, always wiggle the condenser; intermittent connections are indicated if the meter needle reading fluctuates. When testing small condensers (less than .25 mfd.), a barely perceptible indication on the megger should O.K. the condenser.

You will find that practically every commercial condenser will have some leakage. A condenser when originally tested should, if good, cause a needle "kick" over due to the charging of the condenser. Condensers used across a large voltage should

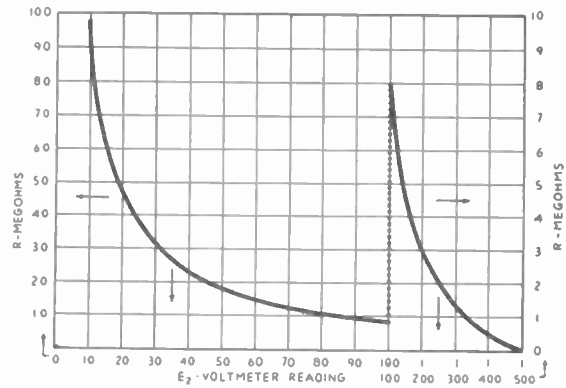


Fig. 3b.

be critically examined. If the condenser leaks current will flow, heat will be generated within the condenser; and when the insulation gets hot its resistance drops considerably and finally the condenser will break down.

Measuring Capacity.—There are many ways of measuring the capacity of a condenser. Laboratories usually employ an A.C. Wheatstone bridge. As this is not a practical service bench procedure we will not consider it here.* All practical testers require an A.C. voltage and an A.C. milliammeter or voltmeter or both. A practical capacity tester suggested by Aerovox, a condenser manufacturer, is shown in Fig. 4a. Its calibration is

* If interested, refer to any advanced textbook on Radio Frequency Measurements. "High Frequency Measurements" by Hund, published by McGraw-Hill Book Company, New York City, is good.

given in Fig. 4b. Construction details are given in the caption of Fig. 4a.

This capacity meter must be pre-adjusted before it is used. We assume that you purchase a reliable 0–1 milliampere copper oxide rectifier meter; and a 0–100 A.C. voltmeter, a copper oxide rectifier type with a sensitivity of 1,000 ohms per volt. Assume that the capacity tester is assembled. Plug the cord cap into a 110 volt 60 c.p.s. outlet. Set P at *0;* the voltmeter will read zero. Close switch *SW–2*; open switch *SW–3;* set *SW–4* at *Range 3;* connect the pee-wee test clips to a 10,000 ohm resistor. Place the voltmeter across points A and B. Slowly (be sure it is slowly) increase the voltage reading by moving P towards *110,* until the milliammeter reads 1 milliampere. Note the voltmeter reading. Jot the reading down on a piece of paper, so you will not forget it. Now switch *SW–4* to *Range 2.* Adjust resistor R_2 until I_{AC} reads 0.1 milliampere. Readjust P until V_{AC} reads

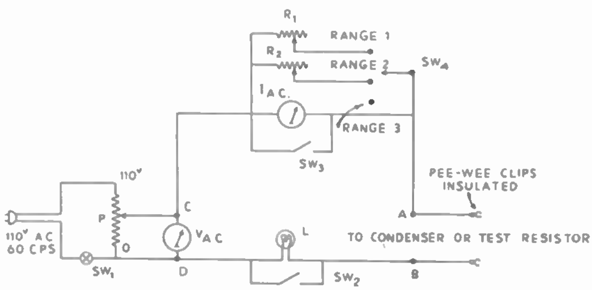


Fig. 4a. P, a 200 ohm potentiometer; R_1, 100 ohm adjustable resistor; R_2, 750 ohm adjustable resistor; *SW-1, SW-2, SW-3* are single pole single throw toggle switches; *SW-4*, a 3 point tap switch; $V_{A.C.}$, a 0–100 A.C. voltmeter, 1000 ohm per volt sensitivity; $I_{A.C.}$, a 0–1 milliampere copper oxide rectifier meter; L, a 25 watt lamp.

the value you jotted down. Again adjust R_2 so I_{AC} reads 0.1 milliampere. Finally switch *SW–4* to *Range 1.* If the voltmeter reads about 9 volts—and it should—increase the voltage *exactly* 10 times by varying P. Figure it out to be sure. Adjust resistor R_1 so I_{AC} reads 0.1 milliampere. If you switch back to *Range 2,* the meter should read full scale, if the voltmeter reading has not changed.

Connect the voltmeter to points C and D, as shown in Fig. 4a, disconnect the 10,000 ohm resistor and open switch *SW–2.* You are now ready to use this capacity tester. You have just adjusted the milliammeter for 1, 10 and 100 milliampere maximum readings. You need not adjust R_1 or R_2 again except for checks on calibration.

The capacity meter is used in the following manner. Set *SW–4* to *Range 1.* Close *SW–3.* Set P so V_{AC} reads 100 volts. Connect the condenser to the meter by means of the pee-wee clips. If the lamp does not light, the condenser is not shorted.

Therefore close *SW–2* and moving *SW–4* select a range which gives the maximum I_{AC} reading. Refer to chart in Fig. 4b for the capacity. Read the correct range scale. This capacity meter will satisfactorily measure condensers from .0005 to 2.6 microfarads.

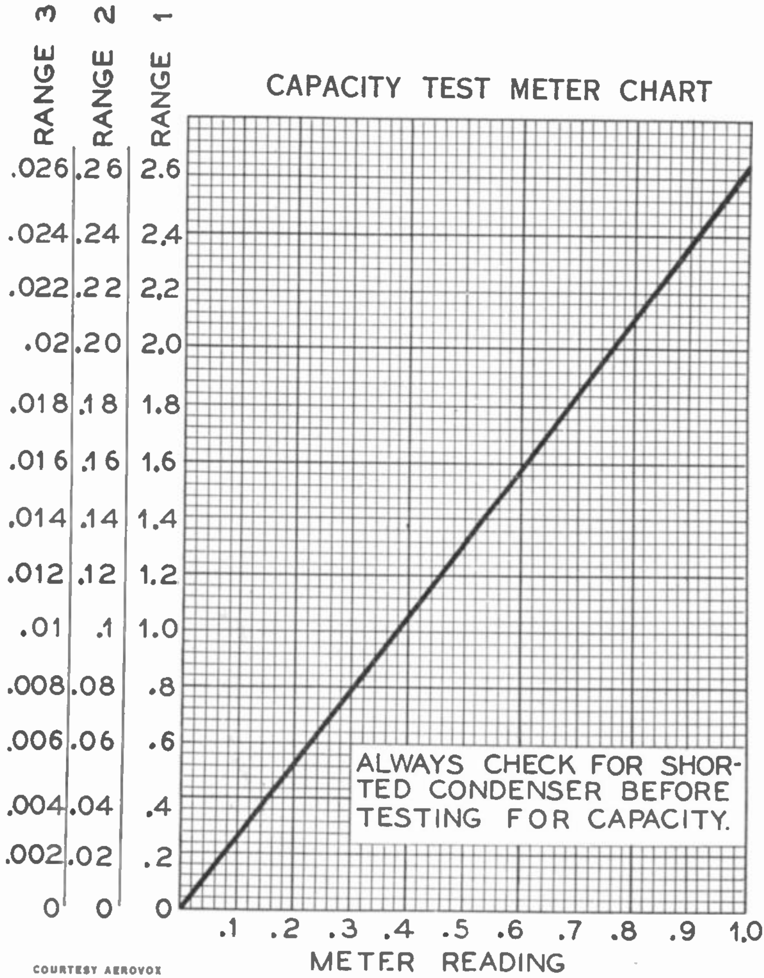


Fig. 4b.

ELECTROLYTIC CONDENSERS

Perhaps the electrolytic filter condenser is the most unstable part in a modern receiver. The electrolyte, whether of the liquid or paste type, is a caustic material. It may corrode the elements and leads so the condenser shorts or opens. When electrolytic condensers have not been used for some time the formed dielectric film may break down and the condenser become extremely leaky. Furthermore, electrolytics should not be used above their rated peak voltage. Even when originally satisfactory, long idleness may reduce their peak working voltage, and thus create receiver hum, motorboating, and rectifier tube destruction.

In replacing an electrolytic condenser, its peak voltage and working voltage must exceed those in the circuit in which it is to be used. Modern filter condensers have high ratings, and if you use a reliable make little attention need be given to these facts. Electrolytics used as by-pass condensers have high capacity and low working voltage. Here more thought is necessary before a replacement is selected. The replacement condenser should have a D.C. working voltage equal to or greater than the voltage of the terminals across which it is to be placed and a peak or surge voltage rating 20 to 40 per cent greater.

Field Tests.—Should you, in an actual service job, trace the defect to electrolytic filter condensers (often indicated by ionized rectifier tubes, excessive hum, motorboating), simple tests may be conducted. First listen to the condensers. If they *sizzle*, you can make up your mind that they are breaking down on peak voltages. Perhaps this noise disappears in a short while, due, of course, to the reformation of the film. (A condenser that sizzles should be reformed in a circuit designed for this purpose.) If the receiver is used a good deal and the forming is not retained, a new condenser is required. Remember that any defect in the receiver which would remove the load on the power pack may cause the condenser to sizzle. Hence check the output voltage of the filter circuit.

Always check the leakage resistance of an electrolytic condenser. Many servicemen merely disconnect the + (plus) lead and check the resistance with a high range ohmmeter; one having a 22½ or 45 volt battery. Connect the ohmmeter so the needle reads progressively greater resistance. A normal 8 mfd. condenser should have a leakage resistance of .25 to 1 megohm. If less, either reform the film or replace the condenser.

Most servicemen carry replacement electrolytics in their service kit. They reason: if an electrolytic is defective replacing the suspected condenser with a good one is sufficient proof, if the effect is obvious, that a replacement is needed. A temporary connection, the original temporarily disconnected but not dismounted, is made. Dry electrolytic condensers of the rectangular type are considered the most convenient types of replacements. You can mount them in any position.

A Bench Leakage and Capacity Checker.—Figure 5 is a rather useful bench instrument, where a large number of electrolytic condensers are to be serviced and tested. The device will form the dielectric film, measure leakage current and condenser capacity. Condenser C_x is the capacitor that is being serviced and tested. D.C. voltage is applied from the circuit on the right, the voltage controlled by *P* and measured by V_{DC}, a 0–500 D.C. voltmeter. A.C. voltage is applied by the circuit on the left. Both right and left hand circuits are fed from a 110 volt 60 c.p.s. line. Condenser C_1 (4 mfd. or more rated at 600 volts) is a very large paper capacitor which prevents the D.C. from flowing into the secondary of T_1, and forces the D.C. current through C_X; choke L_1, a 30 to 50 henry choke, prevents A.C. current from passing into the rectifier circuit and forces the A.C. current through C_x.

Before an electrolytic is measured for capacity, its leakage

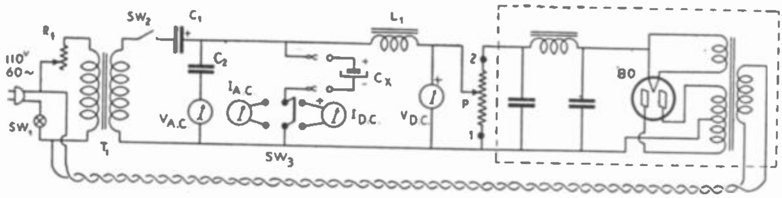


Fig. 5. T_1, a 2 to 1 step down transformer (220 to 110 volt transformer is just the thing); R_1, a variable 400 ohm 20 watt resistor; *SW-1* and *SW-2*, S.P.S.T. toggle switches; *SW-3*, D.P.D.T. toggle switch; C_1 a 4 mfd–600 volt paper condenser, or larger; C_2 a 4 mfd–400 volt paper condenser; L_1, a 30 to 50 henry choke; *P*, a 10,000 ohm potentiometer, 25 watt (a slider type is satisfactory); $V_{A.C.}$, a 0–150 A.C. voltmeter, a 1000 ohm per volt copper oxide rectifier type; $V_{D.C.}$, a 0–500 D.C. voltmeter; $I_{A.C.}$, a 0–250 A.C. milliammeter, magnetic vane type; $I_{D.C.}$, a 0–10 D.C. milliammeter; and the circuit within the dash–dash lines may be the high voltage supply of a discarded receiver. D.C. forming currents may be measured with this A.C. ammeter.

current should be normal. If the leakage current of a condenser in use for some time is more than .5 milliampere per microfarad, the film should be restored. To form the dielectric film, set potentiometer *P* at point *1;* open switch *SW–2*, set *SW–3* to the I_{AC} side; close *SW-1* and increase V_{DC} until the current meter reads about 40 milliamperes. The forming current will gradually decrease. Continue to increase the forming voltage, until the latter is at rated value of the condenser. Never allow the forming current to get too large.

For a good electrolytic condenser you will find that when working D.C. voltage is applied, the initial current reading will average about 10 milliamperes per microfarad. In about 5 minutes the leakage current will drop to a value varying from .05 to .5 milliampere per microfarad. It should not exceed the larger value of .5 ma. per mfd. Thus after 5 minutes a 16 mfd. condenser should pass less than 8 ma.; an 8 mfd. condenser less than 4 ma., a 2 mfd. condenser less than 1 ma.; and a 1 mfd. condenser less than .5 ma. If no current flows the condenser is open; if the current is too large, an inadequate film formation, impurities in the condenser and deterioration is indicated. If the film cannot be restored or the condenser electrolyte has evaporated, discard the unit. Set *SW-3* to the I_{DC} position for accurate leakage current values, but only after the leakage current has reduced to less than 10 milliamperes.

Assuming that the leakage current is normal, we may measure the capacity of the condenser. The important factors are the frequency, the A.C. voltage (V_{AC}) and the A.C. current (I_{AC}). The capacity may be computed from a general formula,* but a simpler formula and procedure is possible. If you adjust R_1 so V_{AC} always reads 53 volts, then the capacity in microfarads is given by the simple formula:

$$\textit{Microfarads of } C_x = .05 \textit{ times } I_{AC}$$

or, I_{AC} in milliamperes divided by *20* gives the capacity of C_x in microfarads. The reading of V_{DC} should never be less than 75 volts, otherwise, the electrolytic condenser will start to act as a rectifier. If large capacity condensers are to be used, working at low working voltage, C_1 should be larger than C_x (an electrolytic condenser will suffice). The A.C. voltage may be reduced to 5.2 volts and the reading of I_{AC} divided by 2 gives C_x in microfarads. V_{DC} must not be less than 7.5 volts.

POWER TRANSFORMERS

A great many receiver and amplifier failures are traced to the power supply and particularly the power transformer. The transformer breaks down because: turns have shorted; insulation became charred; became overheated due to defective filter condensers in the output circuit or shorts in the tube circuits; or the receiver was operated on too low a frequency line or a D.C. current main. Incidentally a 40 c.p.s. receiver may be used on 60 c.p.s. line, but not on a 25 c.p.s. line.

From a practical point of view, a power transformer is best tested in its chassis. There is too much set-up required, if removed and tested by itself. In the chassis, normal operating conditions exist. To be sure, the chassis is brought to the service bench.

Tests made on power transformers are: *1*, continuity of windings; *2*, resistance of windings; *3*, leakage and ground

---

*$C_x = \dfrac{1000 \times I_{A.C.}}{6.28 \times f \times V_{A.C.}}$ microfarads; $I_{A.C.}$ is in milliamperes, f in c.p.s.

tests; *4*, excitation current; *5*, full load output voltages; and *6*, temperature rise. Let us consider these tests and their importance.

1. Continuity of Windings.—If no output voltage is obtained, the first test should be a check on the continuity of the windings. Use an ohmmeter and disconnect circuit wires when they may falsify the ohmmeter readings. The input or primary circuit should be tested first and from the prongs of the power plug. A fuse or a switch in the primary circuit may be open. When opens are found, inspect the extension leads and particularly those to the outer coil layer. An open at the surface may often be reconnected.

2. Resistance of Windings.—Where the resistance of the various windings are given in the service diagram, they should be checked for ohmic value. Only the resistance of the high voltage windings have any practical value. The two halves of the high voltage secondary windings are measured for their resistance. They should be nearly equal. Although they must supply equal voltage, their resistance may differ, the inner half less than the outer half. Only when they differ to a considerable extent should the transformer be considered defective. Shorted turns, which usually alter the resistance by a small value, are best checked by the no-load excitation current test which we will consider shortly.

3. Tests for Leakage and Grounds.—All windings should be insulated from each other and the core. It is not unusual for the insulation of a power transformer to break down. The tester shown in Fig. 3a is ideal for this test. Be sure that *P* is adjusted for maximum voltage. Check between each winding and all others and to the core. The leakage resistance should be greater than 20 megohms. On a service job, an ordinary ohmmeter may be used, the purpose being to check for shorts rather than for adequate high insulation resistance.

4. Test of Exciting Current.—This test involves the measurement of the current through the primary turns with no load on any of the secondary windings. (Removing all the tubes in the circuit, the rectifier in particular, duplicates this condition.) The current drawn depends on the reactance of the primary and the iron losses of the power transformer. More than normal current indicates whether the transformer was well or poorly designed and whether any of the windings are shorted.

An 0–3 ampere A.C. ammeter is placed in series with the primary and the supply. Since the exciting current is the true no-load primary current, it can readily be seen that if the primary or any of the secondary windings have shorted turns, excessive power will necessarily be drawn from the primary. This will, of course, show up in the measurement of the exciting current. In well-designed power transformers for use with radio receivers, the exciting current should measure between 100 and 400 milliamperes A.C., depending on its design and size.

This test will not only show up shorted turns, but, in addition, the presence of charred windings. A charred winding does not generally open the winding. It burns the paper insulation between layers, shorting the windings with the result that the exciting current becomes extremely large.

Great care must be exercised when making this test to prevent damage to the ammeter should a winding be shorted. In this event the exciting current might be several amperes. Don't hold the test prongs of the ammeter on the contacts across which you are testing, at first—just barely tap them and watch the meter. If the meter needle flies off-scale you know that there is a burnt-out winding or a direct short somewhere.

5. *Measurement of No-Load and Full-Load Voltage.*—The tests outlined above will indicate whether the transformer is defective or not. But, after we know that a transformer is not defective, we may want to know how well it functions as a voltage supply—whether the secondary voltages drop excessively when a load is placed on the secondary.

The method of making load and no-load secondary voltage tests is simple. Measure the voltage across the secondary with the tubes out of the sockets. Then measure the voltage of each secondary with all tubes in the receiver or amplifier; that is, the secondaries drawing full current.

6. *Tests for Heat or Temperature Rise.*—The question often arises: Does the transformer get too hot? Of course, if the receiver has been in operation for some time, exactly as you found it and no external conditions such as charred insulation or melted tar or obnoxious odors are observed, it is safe to assume that the transformer will not give any trouble. This opinion is further substantiated by the fact that an excitation test indicated no internal shorts. The condition often arises, where a new installation is made and you want to make sure that no interruptions in service will occur due to power transformer failure. A test for temperature rise will answer this question.

The resistance of a winding, particularly the high voltage secondary is measured with a Wheatstone bridge—see Fig. 6, using the following procedure:

(*a*) Measure the resistance of the winding under test when it is cold. Let this be known as R, at room temperature "t" (degrees Centigrade).

(*b*) Measure the resistance of the winding after current has been flowing through it for some time (at least equal to a normal operating period). Let this resistance be known as R'.

The temperature rise "Δt" of the winding of the transformer in degrees Centigrade can then be calculated from the formula: *

$$\Delta t = \left(\frac{R'}{R} - 1\right) \times 235$$

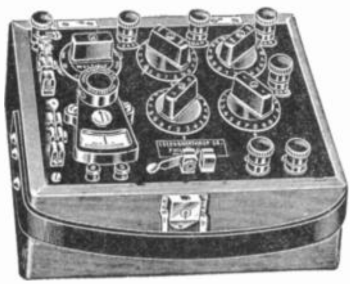
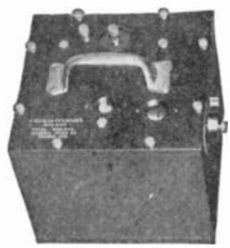


FIG. 6. Leeds and Northrup Type S Portable Wheatstone Resistance Bridge.



Precision Condenser made by the General Radio Co., Cambridge, Mass.

In practice the secondary and primary windings are generally checked for temperature rise. The Fire Underwriters require that the temperature rise of any power transformer be less than 50 degrees Centigrade.

It will be found, however, that most defects in power transformers are generally opened or shorted windings. These windings burn out because of defective rectifier tubes, excessive voltage between windings, a defective filter condenser, improper use of the power transformer, poor transformer insulation or a too low frequency of the source of supply.

AUDIO TRANSFORMERS

From the standpoint of worthiness of an audio transformer as a coupling device in an audio amplifier, the simplest of tests

* This procedure may be applied to any electrical device with a winding whose resistance is readily measured.

must often suffice. Where a receiver defect is traced to an audio transformer in a receiver or P.A. amplifier, the usual tests of continuity, resistance of winding, leakage and shorts are made. The procedure taken is no different than for a power transformer, so we need not repeat them. Resistance values of the primary and secondaries are often given in the service diagrams and these values afford a reasonable check on shorts, as the resistance of the windings will be of such values that they can be readily measured with a reliable ohmmeter. To be sure, only an inductance check can give reliable information on internal winding shorts.

When transformers are salvaged from dismantled radio equipment, they should be measured for turn ratio and primary and secondary impedance before placed in stock for future use. A better replacement may be made if these factors are known.

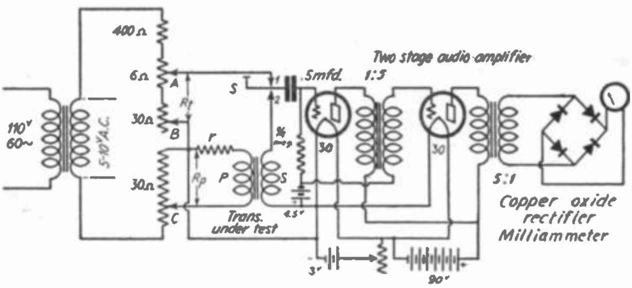


Fig. 7.

If you plan to build amplifiers this information is indispensable. Quite often it is desirable to know the amplification that a given tube and an available transformer will give. When you want to use a transformer for matching purposes, the basic fact that the impedance of a winding should be at least 3 to 5 times the impedance or resistance of the device it couples, indicates that impedance measurements of a transformer are quite important.

Turn Ratio of Windings.—This test may be made on a 60 c.p.s. source, an ordinary wall socket outlet. A suitable test circuit is shown in Fig. 7 and all important circuit values are given. The input connection is made through a toy transformer or a tube filament transformer. The audio amplifier need not be calibrated for gain. Resistor *r* is used only when the behavior of the transformer with a desired tube is the information sought; in which case *r* is the same value as the A.C. plate resistance of the tube you plan to use. For ordinary turn ratio measurements r is omitted. Measurements are made as follows:

(*a*) Set equipment in operation by lighting amplifier tubes and inserting the connecting plug to the 110 volt A.C. source.

(*b*) Throw switch *S* to position *1* and adjust resistance arms *A* and *B* until needle on meter moves to the half-way position on its dial. Record the resistance value between *A* and *B*, the value R_t.

(*c*) Insert transformer to be tested as shown.

(*d*) Throw switch *S* to position *2*, and adjust contact arm *C* until the same reading is obtained on the meter *M* as in step *b*. Record resistance value between *B* and *C*, the value R_p.

(*e*) The ratio of resistance values in steps *b* and *d* ($R_t \div R_p$) is the same as the voltage ratio and consequently the same as the winding ratio of the transformer under test.

Let us take a practical example. Suppose the resistance value of step *b* was found to be 28 ohms and step *d* was 7 ohms. The voltage ratio of the transformer would then be 4 and the winding ratio 4 to 1; that is, the secondary has four times as many turns as the primary.

This method is sufficiently accurate for ordinary measurements on auto-transformers and transformer windings. Of course, as shorted turns in any of the windings will affect the voltage ratio, this test should not be made until continuity, resistance, leakage and ground tests have been made.

Response Tests.—Set-up shown in Fig. 7 may be used as previously explained to measure the gain of a stage by inserting resistor r. The actual gain of the stage is μ times the value measured, where μ is the amplification of the tube to be used. Gain of complete amplifiers may be measured in the same way by replacing the audio transformer with the amplifier. The A.C. mains are replaced by an audio oscillator. The maximum resistance of *A* and *B* should be many times greater than indicated. Instead of turn ratio you measure gain. When gain is plotted against frequency, a response characteristic is obtained.

Impedance and Inductance Tests.—In most cases only the approximate impedance or inductance value of an iron core reactor is needed. If we are willing to ignore the effect of the D.C. polarizing current (assuming that it is used in the circuit the device is designed for) and neglect the A.C. voltage swing, the test circuit shown in Fig. 8 may be used. Only materials readily obtained are used. Here is how this device is employed:

Connect the reactor or transformer to the circuit and in the latter case the unconnected coil or coils remain open. Plug cord into a 60 c.p.s., 110 volt outlet. Close *SW-1* and *SW-2*. Set *SW-3* to tap *1* and adjust *P* until the voltmeter reads exactly 50 volts. Set *SW-3* to tap *2* and adjust *R* until the voltmeter reads exactly 35 volts. Open switch *SW-2* and connect an ohmmeter to points *x* and *y*. The value obtained equals the impedance of L_x at 60 c.p.s. To find the inductance of L_x in henries, divide the measured resistance by 380. Remember all values are approximate. Incidentally you may measure the reactance of a condenser by replacing L_x with the condenser.

Where large as well as small inductance values are to be measured, under conditions of exact polarizing current and applied A.C. voltage, the measuring circuit shown in Fig. 9 is recommended. A condenser decade box will be required. In fact, no service bench is complete without one. It may be made with: 28 single pole single throw toggle switches, 9—.01 mfd. condensers, 9—.1 mfd. condensers and 9—1.0 mfd. condensers. You

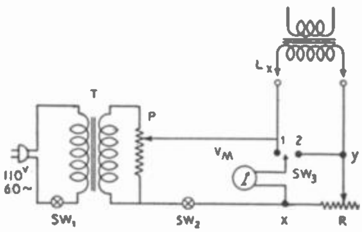


Fig. 8. *T*, is 220–110 volt step down transformer *SW-1* and *SW-2*, S.P.S.T toggle switches; *P*, a 500 ohm potentiometer; *SW-3*, a S.P.D.T. toggle switch; *R*, a 100,000 high grade wire wound variable resistor; V_m, a 0–100 copper oxide rectifier 1000 ohm per volt A.C. voltmeter; *x* and *y* readily accessible binding posts and L_x, the reacter to be measured.

should order these condensers directly from a reliable condenser manufacturer specifying 2 per cent tolerance. The condenser box is assembled as shown schematically in Fig. 10.

Now let is see how the circuit shown in Fig. 9 is used. The iron core inductance is connected to circuit as shown. P_2 is set at point *1*; the power cord is plugged into the supply and switch *SW-1* closed; P_1 is varied until you get the desired A.C. voltage variation. *SW-2* is thrown to position *2* for no polorization current, to position *1* for a D.C. polarizing current. In the latter case, R_2 and *B* are varied until I_{DC} reads the desired polarizing current. Now adjust P_2 so the meter I_{AC} reads mid-scale. Adjust the decade box until I_{AC} reads at a minimum value. Compute *L* from the formula:

Henries = 7.04 divided by Capacity in microfarads.

The decade box is easily read. The number of switches *on* in the lower row is the figure before the decimal point; the number of switches *on* in the center row is the figure after the decimal point; and the number of switches *on* in the upper row is the figure two places to the right of the decimal point. Thus you may obtain any capacity from 0.01 to 9.99 microfarads. The discharge switch is used whenever the decade box is connected to a D.C. supply and removed. The condensers should be discharged by placing this switch temporarily to its *on* position.

IRON CORE CHOKES

Iron core reactors are chiefly found in the rectifier filter systems, in impedance coupled audio amplifiers and in some cases in the output coupling systems of receivers and amplifiers. They are made to have an inductance from 1 to 1000 henries, and they usually pass a D.C. current of 10 to 250 milliamperes. As a rule their D.C. resistance rarely exceeds 1000 ohms.

Field Tests.—Defects in iron core chokes are rather few in

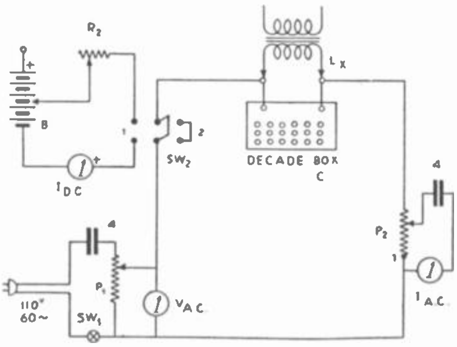


Fig. 9. *SW-1*, a S.P.S.T. toggle switch; P_1 and P_2, 500 ohm potentiometers, P_1, a 25 watt type; R_2, a 500 ohm-25 watt variable resistor; *B*, a 135 volt B block, variable tap; all condensers 400 volt working; $V_{A.C.}$, a 0–100 A.C. voltmeter, inexpensive type; $I_{D.C.}$, a 0–100 D.C. milliammeter; *C*, a .01 to 9.99 microfarad variable condenser box; $I_{A.C.}$, a 0–250 A.C. micro-empere meter; $I_{A.C.}$ may be replaced by the two stage amplifier and meter shown in Fig. 7.

number. Chokes usually open up, become shorted, or ground to the core. These defects are quickly checked with an ohmmeter. In most cases a low range ohmmeter is required. Opens in a filter choke show up as no reception and no main voltage supply. Shorted filter chokes may result in excessive hum and high voltage supply. On the other hand, open chokes in an audio amplifier will show up as no reception and lack of plate-cathode voltage in the defective stage. Audio chokes with shorted turns invariably result in distortion. Ohmmeter and D.C. current meters are the proper test instruments.

At the service bench, where chokes are tested by themselves, you are limited to ohmmeter tests, unless you are willing to resort to more technical procedures. These special tests are: leakage resistance, excitation or inductance measurements, and air gap adjustments.

Bench Tests.—As most chokes have a single winding, a leakage test is merely made by connecting the megger shown in Fig. 3 to the core and to one coil terminal. Again the resistance should be more than 20 megohms.

Total shorts are quickly checked with a low range ohmmeter. Partial shorts are not readily detected in this way. Either an excitation current measurement or an inductance check is required. Unfortunately unless an exact replacement is available, all such tests must be tempered by experience. In a factory, where chokes are tested before use, the inductance tests shown in Figs. 8 and 9 may be used. For the average serviceman, the choke may be placed in series with a variable range A.C. ammeter and this arrangement connected to an A.C. 110 volt 60 c.p.s. line. The excitation current drawn will be

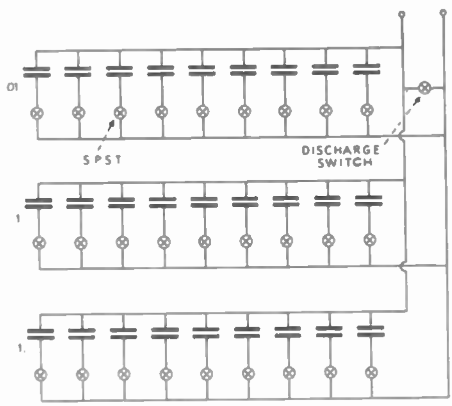


Fig. 10.

approximately given by the formula: *Milliamperes = 300 divided by Henries.* You are therefore required to know what the approximate inductance should be. A much larger current than the computed value indicates shorted turns.

Should a close examination of a choke, usually filter chokes, show that the air gap has been forced out of line, and you have reason to believe that the inductance is low, an air gap adjustment should be considered. The air gap usually runs from .005 to .020 inch. The opening can only be measured with pieces of paper of various thicknesses. Here is how the correct air gap may be selected. Connect the choke to the circuit shown in Fig 9. Adjust for normal operating conditions and resonance. Throw out one or more extra .01 condensers so the meter needle is at mid-scale and adjust the air gap for minimum meter deflection.

GANGED VARIABLE CONDENSERS

A surprising amount of trouble is traced to defective variable condensers. A shorted section will destroy a receiver's ability to receive, a leaky or misaligned condenser will reduce its sensitivity and selectivity or even make the reproduction noisy. Practically all these defects may be remedied while on the job.

Field Tests.—A defective R.F. stage is quickly isolated by the stage by stage elimination trouble shooting procedure, or a circuit disturbance test. A check on plate emission, emission control, and finally input resistance tells us if the input is shorted. Should the input resistance be zero (use a low range ohmmeter), disconnect the coil from the stator of the variable condenser and check that section for a short. Usually a short will be apparent even before a test is made by the rubbing of the plates.

Of course, the previous test will not show up leaky or dirty contacts. When a receiver has poor volume or no selectivity, you should form the habit of cleaning the plates of the ganged condensers with a pipe cleaner, and the rest of the condensers with cheese cloth and a hand bellows, if you have one. Be especially careful to wipe dirt and grease off terminal strips. Then by disconnecting the stator connection, you may test for leakage by connecting a higher range ohmmeter between the stator terminal and the frame of the condenser. At the bench, the megger shown in Fig. 3a should be used.

Finally the condenser and its associated coils may be aligned in the usual manner. The method of doing this has been considered elsewhere and will not be repeated here.

Bench Tests.—At the shop, tests on variable condensers include, of course,, the usual field tests. Naturally more careful attention to details can be given. Be sure to inspect the contact between the rotor and the frame. If a lubricant is necessary, graphite grease may be applied. If a spring contact is used, increase its pressure. Where the shaft is loose, it would be a good plan to install a pigtail connector. Contact resistance may be checked by connecting a low range ohmmeter to the shaft and the condenser frame. Each condenser on the gang must have its own wiping connection to the rotor shaft or a pigtail should be added. It does not pay to go to the trouble of adding pigtails to the condensers of an inexpensive receiver especially when the customer expects a low price job.

When a gang of condensers is taken out of the chassis for mechanical repair and alignment, or a replacement condenser is installed, it is a good plan to align the condenser alone at the bench. Most servicement do not bother to synchronize (align) a new replacement condenser, assuming that the manufacturer did this job before shipment. You, of course, must be the judge, of whether a check is necessary. Nevertheless here is the procedure:

A good tester to use for synchronizing gang condensers is shown in Fig. 11. There is an oscillatory circuit *A* which is coupled to tuned detector circuit *B* through capacities C_3 and C_4. In the tuned detector circuit *B*, one section of the gang condenser forms the capacity C_x. For a given setting of C_1, C_x is brought to resonance (resonance is indicated by a maximum

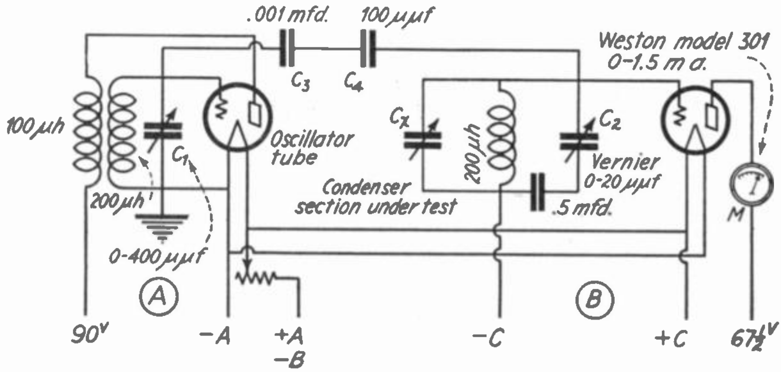


Fig. 11. Use type 30 tubes; *A* battery, use 2 #6 dry cells in series; rheostat, 30 ohms; *C* battery, 7.5 volts. Oscillation circuit in section *A* may be any broadcast coil and a .00035 mfd. condenser. Add plate coil turns to get strong oscillations.

deflection of meter *M*) ; and as the various sections of the gang condenser are substituted for C_x, the difference in capacity between sections is noted on vernier condenser C_2. The vernier condenser C_2 is equipped with an 0-100 dial for purposes of quick and accurate reading. The oscillator *A* should be calibrated. This is a simple enough matter—all you have to do is to beat it with signals received over a radio receiver from stations whose frequencies are known.

Synchronizing gang condensers is made easier by the use of serrated (slit) end rotor plates. It will be noted that there are three or four radial slits in the end plates, dividing these into four or five sections. Most modern ganged variable condensers have this feature, for better circuit alignment.

The various steps to be followed in synchronizing a gang condenser that is mechanically in good condition are outlined below:

(*a*) Set dial of oscillator, C_1, to about 1400 kc. Disconnect the trimmers on the ganged condensers or open each one as wide as possible and to an equal amount. Be sure that all sections line up mechanically at full capacity.

(*b*) Place one section of the gang condenser in position C_x.

(*c*) Set vernier dial of C_2 in a mid-position; if it is divided into 100 divisions, set it at 50.

(*d*) Rotate shaft of gang until C_x resonates its associated circuit, shown by maximum deflection of meter *M*.

(*e*) Without moving any part or touching any of the adjustments, place the second section of the gang condenser in position C_x.

(*f*) Adjust vernier dial C_2 until resonance is indicated on meter *M*. The difference between vernier settings shows how much this section of the gang condenser is out of line with the previous section. For example, if C_2 has to be set at 60 for resonance, we know that the capacity of the second section is 10 divisions less than the capacity of the first. To correct this condition, you would set C_2 to 50 on the dial and adjust the proper segment of the slit rotor for maximum deflection of the meter.

(*g*) Set the third and other sections of the gang condenser in the same way.

After all the sections of the gang have been checked on a high frequency setting, adjust the oscillator to a lower frequency and repeat the procedure as outlined above. A condenser may be perfectly synchronized at a low capacity, but may be badly off at a higher capacity.

It is a general procedure to check gang condensers at five positions over the entire capacity range of the gang, and these positions are usually just at those settings where a segment of the slit rotors just mesh with the stator plates.

After synchronization the condenser gang should be allowed to stand for several hours before being connected into its circuit, as it sometimes happens that the adjusting segments spring out of adjustment. If they change too much, the gang condenser has to be re-synchronized.

As for the trimmers themselves, they should be adjusted only when the radio frequency system is trimmed up as a whole with the tubes in place.

The capacity of any condenser may be measured with the circuit in Fig. 11, provided a precision calibrated condenser is available. The condenser to be measured is connected to the circuit, set to the position at which the capacity value is desired. Vernier C_2 is disconnected. C_1 is varied for maximum deflection of M. Now C_x is replaced with the precision calibrated condenser, and the latter is adjusted, using its vernier control (all precision condensers have a vernier) until the deflection of M is a maximum. The reading of the precision condenser is the value of C_x.

RADIO FREQUENCY COILS

R.F. coils and chokes are widely used in radio receivers. It is important that their windings are continuous, there are no grounds or leakage and that coils be matched when similar T.R.F. stages are in cascade. Quite often it is desirable to know the inductance of a coil. In the field, tests are limited to continuity, possible resistance measurements and leakage tests. At the bench, you may match coils or measure their inductance.

Continuity, Leakage, Ground and Resistance Tests.—By connecting a low range ohmmeter to a coil its continuity may be quickly checked. It is always wise to refer to the circuit diagram to be sure that the coil tested is not shunted by some other device, which may give apparent continuity.

Using a high range ohmmeter, leaks and grounds between windings are quickly checked. Again you must be guided by the circuit diagrams. Of course, at the bench, the megger shown in Fig. 3a is the most reliable leakage tester. Values of 20 megohms or more indicate good insulation. Be sure you check to chassis or to the coil shield.

Fortunately modern service diagrams give the resistance of the various coils. To check a coil's resistance a very low range ohmmeter is required, one in which one ohm gives a reasonably large deflection. A suitable ohmmeter is shown in Fig. 12a and its calibration is given in Fig. 12b. This ohmmeter will cause a large current to flow through the coil, hence you must be careful to connect it only for a moment to the coil that is being checked—just long enough to get a reading.

Matching R.F. Coils.—You will save yourself a lot of trouble, if a replacement coil is matched to the others in the T.R.F. circuit. If a complete set of coils is to be replaced, all of the coils should be matched. This procedure is quite simple if you have a test circuit like the one shown in Fig. 11. All tests should be made at a reasonably high frequency, 1200 kc. if they are broadcast coils. By doing this you obtain a closer match.

In this test your standard coil (a good one out of the re ceiver) is connected in shunt with C_x. The oscillator is tuned to 1200 kc., C_2 is set at mid-scale, and C_x is next varied for resonance. Now the replacement coil is put into the circuit in place of the standard and C_2 adjusted for maximum deflection of the meter needle. If you have several replacement coils pick one that brings C_2 back to mid-scale. If you have only one coil, you may have to make a turn adjustment. Can you spread wires on the coil to decrease L or push them together to increase the coil inductance? If you can, adjust the coil turns so C_2 reads mid-scale for maximum *M* deflection.

Suppose the turns cannot be adjusted in the previous manner. If C_2 reads appreciably below mid-scale (that is, less than half of its capacity), one turn may be taken off at a time until the condenser C_2 returns to mid-scale for resonance. Of course,

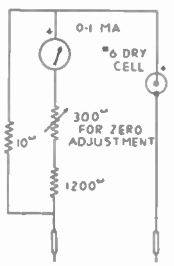


Fig. 12a

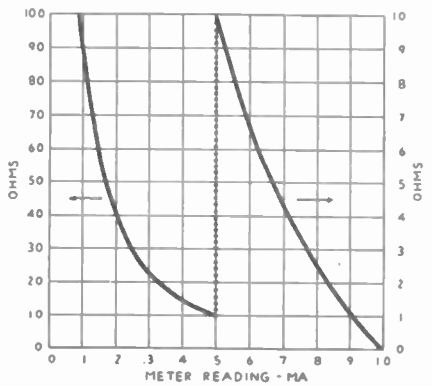


Fig. 12b

if C_2 is originally 5 to 10 divisions (out of a total of 100) off mid-scale a fair match exists. Any difference in coil inductance that does exist may be compensated for by the trimmers on the gang condenser when the coil is in the receiver and the stages of the latter are being aligned at a high frequency.

On the other hand, suppose you have only one replacement coil and its inductance is lower than those in the receiver. If you are skillful enough, you may add 2 or more turns and then take off as many as are necessary. Or you may match all the coils in the receiver to this coil. In the latter case you will disturb the frequency calibration of the receiver station selector dial which can be slightly corrected by using more of the trimmers on the ganged variable condensers.

We have so far considered the coils in a T.R.F. set, or the preselector coils in a superheterodyne receiver. Consider the oscillator coil of a superheterodyne receiver. The only case where the oscillator coil is identical to the coils in the preselector is where the oscillator condenser (the one on the gang of variables) has shaped plates. Naturally the oscillator coil in this case is matched to the others. Where the coil is different, that is, when the variable condenser sections are all alike, it is best to check a replacement coil after it is connected into the repaired receiver. The receiver is set into operation and a calibrated signal generator set to 1400 kc. connected to it; the one in Fig. 11 may be used if you use a plate milliammeter in the second detector as an output indicator. Set the receiver dial at 1400. If you can adjust the trimmer on the oscillator section of the variable condenser to peak receiver output you are reasonably sure that your coil is a fair replacement. In the case of receivers with low I.F. (262 or less) you may be able to get two trimmer positions for maximum output. As you know, choose the setting which makes the trimmer capacity the least. This assumes that the set oscillator works above the station signal frequency.

In the case of receivers with a high I.F. you must get maximum output with the oscillator condenser trimmer set at relatively the same position as the trimmers on the preselector circuits. If you do not, you must check the exact frequency of the set oscillator. This is how it may be done: Use a second receiver with an output indicator in the second detector. Set your signal generator to 1400 kc.; couple it to the second receiver and tune the latter to maximum output. Now set the receiver being repaired to a frequency of 1400 minus the set's I.F. frequency. Run a wire from the ANT of the second receiver to the receiver under repair, winding a loop of it around the first detector tube. If the replacement coil is of a correct value, the indicator on the second receiver will give maximum output. In any event, if you have to increase the second or test receiver to a higher frequency to get maximum output, the replacement coil has too little inductance; if you have to lower the frequency setting on the test receiver, the inductance of the replacement coil is too large. This assumes that the trimmers on the repaired receiver are at normal positions.

Measure Coil Inductance.—Circuit shown in Fig. 11 may also be used to measure coil inductance. C_x should be a calibrated precision variable condenser. The vernier C_2 should be disconnected. Shunt the precision condenser with the coil you wish to measure for inductance. Set oscillator *A* to 1000 kilocycles and tune the precision condenser so *M* reads a maximum. Assume the condenser readings are given in or are changed to micro-microfarads. The inductance is computed from the formula:

L in microhenries = 25400 divided by C_x in micro-microfarads

Measuring the inductance of R.F. coils has a very important service use. In measuring similar coils (same turns, diameter, etc.) and one coil has unusually low inductance, you can be quite sure that it has shorted turns.

TEST QUESTIONS

Be sure to number your Answer Sheet with the number appearing on the front cover underneath the title of this text.

Place your Student Number on every Answer Sheet.

1. While on a job, what is the simplest test on a resistor suspected of being noisy?

2. Would a resistor with a large diameter or a small diameter have the greater power dissipation?

3. What three vital facts concerning variable controls are quickly recognized by a set owner?

4. When an ohmmeter is connected to a paper condenser, what indicates that a charging current existed?

5. Would a 1 mfd. condenser having a leakage resistance of 98 megohms be considered good?

6. In checking wet electrolytic condensers, what effect would you observe if they were worked over their rated peak voltage?

7. How much leakage current should a good 8 mfd. electrolytic condenser pass five minutes after being normally excited?

8. How large should the leakage resistance be between coils of a power or audio transformer?

9. Of what particular value is the excitation current test, used in connection with power transformer tests?

10. Will shorted turns on an R.F. coil *increase, decrease, or leave intact* the coil's inductance?

Field and Bench Testing of Radio Parts. No. 47 RH-1

1. Try a new one.

2. The resistor with the larger diameter would have the greater power dissipation.

3. 1, positive action; 2, smooth continuous action; and 3, no noise.

4. The needle "kick up."

5. Yes.

6. A sizzling sound.

7. Less than 4 milliamperes.

8. Greater than 20 megohms.

9. Check for shorted turns and charred windings.

10. Decreases the coil inductance.

SERVICING, CHECKING AND EQUALIZING AUDIO AMPLIFIERS

48RH-1

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

SUCCESS—2,500 YEARS AGO AND NOW!

551-478 B.C.

In all things, success depends upon previous preparation, and without such preparation there is sure to be failure.

Confucius (Chinese philosopher)

495-406 B.C.

Success, remember, is the reward of toil.

Sophocles (Greek poet)

1807-1882

The talent of success is nothing more than doing what you can do *well,* and doing whatever you do without a thought of fame.

Longfellow (American poet)

1819-1881

Every man who can be a first-rate something—as every man can be who is a man at all—has no right to be a fifth-rate something; for a fifth-rate something is no better than a first-rate nothing.

J. G. Holland (American novelist)

1881-

Preparation and hard work will bear a certain measure of success in any field, but you can multiply the rewards of that success by applying your energies in new and fast-growing fields like Radio, Television and Electronic Control.

J. E. Smith

NATIONAL RADIO INSTITUTE

WASHINGTON, D.C.

1942 Edition

A LESSON TEXT OF THE N. R. I. COURSE
WHICH TRAINS YOU TO BECOME A
RADIOTRICIAN & TELETRICIAN
(REGISTERED U. S. PATENT OFFICE) (REGISTERED U. S. PATENT OFFICE)

NCP2M642

Printed in U. S. A.

Servicing, Checking and Equalizing Audio Amplifiers

INTRODUCTION

AUDIO frequency signal amplifiers are to be found in radio receivers (after the demodulator stage), in public address and intercommunication systems, in electric phonographs, sound movie equipment, hearing aids, sound-recording systems, photoelectric apparatus, electronic control devices and a host of other vacuum tube systems.

When trouble occurs in an audio amplifier, the expert radio service technician is the logical man to restore the amplifier to its original working condition, for knowledge and experience acquired through work on these amplifiers in radio receivers can be applied directly to audio amplifiers in any other service. To get your share of this special service work, you must:

1. **Be able to service, check and equalize the audio amplifiers encountered in radio receivers.**
2. **Recognize that all audio amplifiers, regardless of where or how they are used, have essentially the same operating principles.**
3. **Know how various kinds of audio amplifiers should perform when working properly.**

This third requirement is quite important; it would be folly to spend hours in an effort to make an audio amplifier for an intercommunicator handle musical programs with high fidelity, as this amplifier was originally designed to handle only voice frequencies. Likewise, a high-fidelity phonograph amplifier could not be considered repaired if it were tested only with a recording of speech.

Although circuit diagrams and service instructions will generally be available for the audio amplifier on which you will work, there may sometimes be jobs which must be completed without such assistance. The general knowledge which you already have on audio amplifiers, together with your own ingenuity, should prove sufficient in these cases.

Amplifiers which require servicing may be dead (inoperative), may howl, distort, have low outputs, have excessive noise and hum, or may operate in some other improper manner.

TOOLS AND TESTING EQUIPMENT

You will be expected to carry all necessary tools and testing equipment with you when servicing audio amplifiers in the field. The tool kit usually carried by radio servicemen, containing a soldering iron, side cutters, several screw-drivers and pliers, an assortment of wrenches, rosin-core solder, rubber and friction tape, hook-up wire, etc., may be used. Your testing equipment should include at least three instruments: *1*, a conventional multimeter containing a D.C. voltmeter, a D.C. ammeter, A.C. voltmeter and ohmmeter; *2*, a reliable tube tester; *3*, some kind of audio frequency oscillator. A plug-in type set analyzer will also be helpful.

The audio frequency oscillator carried in the field may be a simple fixed frequency unit capable of producing a pure sine wave of either 400 cycles or 1,000 cycles, although many technicians prefer a portable 0-15,000 cycle beat frequency audio oscillator which can also be used at the service bench. The circuit diagram of a simple but entirely satisfactory fixed frequency oscillator which can be built at little expense is shown in Fig. *1*.

Of course, you will encounter jobs in the field which require additional testing equipment. Here you will either have to move your bench equipment to the job or take out the audio amplifier chassis and bring it

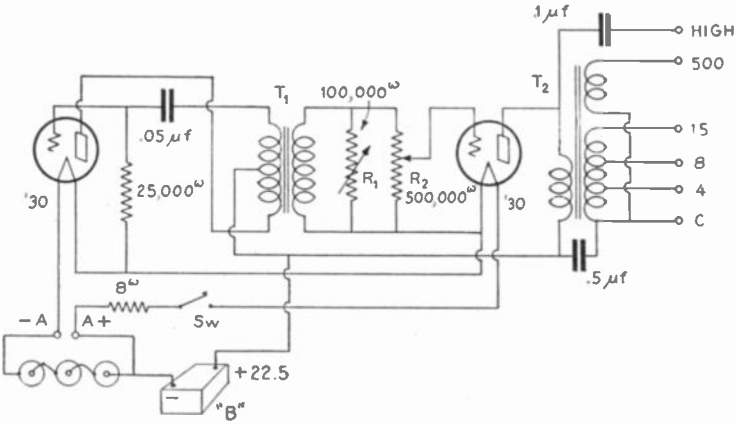


FIG. 1. For ordinary defect-isolation tests in audio amplifiers this simple audio oscillator, producing a sine wave A.F. output which is essentially fixed in frequency, will be quite valuable. Transformer T_1 is an ordinary input push-pull unit, while T_2 is a standard low power, multiple-output, impedance-matching unit. Rheostat R_1 gives a certain amount of control over the output frequency, while R_2 controls the output voltage.

to your service bench. The various pieces of additional equipment required at the service bench for checking the amplification, power output and fidelity characteristics of audio amplifiers will be discussed in detail later in this lesson.

GENERAL AUDIO AMPLIFIER SERVICE INFORMATION

Practically all audio amplifiers except those in radio receivers are in commercial service, where failure of the apparatus may involve a loss of business and money. Public address technicians, who are very frequently called upon to repair commercial amplifier systems, therefore try to do service work in the field if at all possible. You will do well to adopt this policy for your own work, as it means customer goodwill and often results in greater profits. Whenever it is necessary to hold up final repairs until a replacement part has been received, or whenever you take some part of the amplifier system to the service bench, it is always wise to make temporary connections where possible in order to permit use of the apparatus.

The knowledge of radio receiver servicing which you have already acquired will be of great help to you in servicing audio amplifiers, for the same general procedures are followed in both cases. A brief review of this general procedure will therefore be of value to you at this time.

1. *Confirmation of customer's complaint.* Always verify the customer's complaint by trying out the amplifier system yourself at its operating location before attempting to locate the trouble or make repairs. If you find other things wrong at this time, point them out to the customer and get his authority to make complete repairs.
2. *Inspection for surface defects.* Never make an easy job hard by omitting this simple step.
3. *Circuit disturbance test* (for dead amplifiers handling less than 5 watts of A.F. power). Make sure that the power supply for the amplifier is all right, then remove tubes or touch control grids one by one, starting at the output end, until you fail to get a click.
4. *Stage-by-stage elimination test* (for dead amplifiers of all sizes). Check the power supply, then feed an A.F. signal into the grid of each tube in turn, starting at the output end, until you find a stage which will not pass the signal. This procedure is recommended for high-power stages which cannot stand a circuit disturbance test.
5. *Effect-to-cause analysis* (for improperly operating amplifiers). A good understanding of audio amplifier principles, a certain amount of practical experience and a little intelligent thinking here can save hours of valuable time, especially if a schematic circuit diagram and a parts layout diagram are at hand for reference purposes.
6. *Analysis of defective stage.* Test the tube first, then use a point-to-point voltage test, a point-to-point resistance test or an electrode current and voltage test with a plug-in analyzer, to isolate the defective part.
7. *Repair or replacement of defective parts.*
8. *Check of performance, followed by circuit equalization if warranted.*

HINTS ON SERVICING DEAD AMPLIFIERS

A dead amplifier is one which fails to give any output when a normal A.F. signal is applied to its input. After checking for surface defects, the next step is naturally the isolation of the defective stage or section. Trouble in audio amplifiers is so often traced to tubes, however, that some technicians prefer to test all of the tubes even before they make a circuit disturbance test or defective stage isolation test. Tubes which have already given more than one thousand hours of service are very likely sources of trouble.

Replacing a bad tube will not always clear up trouble in an A.F. amplifier, for certain defects in A.F. circuits will cause a tube to "go bad" and will ruin a new tube inserted in its place. For example, a burned-out rectifier tube may indicate a defective condenser in the power pack of the amplifier. Output power amplifier tubes which have low emission are often an indication of a defect in the grid circuit of the output stage or of failure of the C bias supply. A defective tube in the voltage amplifier section may be a sign that operating voltages are incorrect.

If all tubes are found to be in good condition, follow the general service procedure for isolating the defective stage. This will tell you whether the trouble is in a power supply circuit or in a signal circuit. If all supply voltages are correct, look for poor or open connections, a shorted resistor, an open resistor, a defective transformer, or a defective condenser in one of the signal circuits.

HINTS ON SERVICING INCORRECTLY OPERATING AMPLIFIERS

With improperly operating amplifiers you must first confirm the complaint, then apply effect-to-cause reasoning to the observed symptoms of trouble and continue with the regular service procedure. There are, however, a few common conditions which, if recognized, will enable you to repair the defect without going through the entire service procedure.

Improper operation of an audio amplifier may be the result of poor impedance matches between various parts of the system. For example, a poor match between the impedance of the sound pick-up device and the amplifier input impedance may result in an input signal too weak to operate the amplifier. Likewise, a mismatch between amplifier output impedance and the impedance of the sound-reproducing system may reduce the power output of the system to a value below that required to operate the reproducers. Many people think that they can interchange microphones or loudspeakers as much as they like, but such is not the case with audio amplifiers. A velocity microphone having an output impedance of 200 ohms cannot be expected to work into a high impedance input circuit of an amplifier and give rated output, and likewise, the voice coil of a loudspeaker will not match a long line carrying signal current from the output of the amplifier. Be on the lookout for improper input and output devices, as well as for poor or incorrect connections to these units.

We will now consider in detail the most common probable causes of trouble in audio amplifiers when the complaints are excessive hum, noise, distortion, squeals and motorboating.

Hum Due to Magnetic Induction. Excessive hum in an audio amplifier may be due to magnetic induction effects between a power transformer in the amplifier and the transformer which is built into the case of the velocity or dynamic microphone. Magnetic induction effects between the microphone transformer at the input of the amplifier and the power transformer can likewise cause this same trouble. This condition will seldom be encountered in commercial A.F. amplifier systems, but is quite common in custom-built amplifiers.

Hum due to magnetic induction can be reduced considerably by rotating one of the trouble-making transformers enough to place the windings of the two transformers at right angles to each other, so that their magnetic fields will not interact.

Hum Due to Capacitive Coupling. Capacitive coupling between the input circuit of an amplifier and the ground may cause excessive hum when input signal intensities are extremely low. Proper grounding is the solution to this problem. The shield over the leads carrying the input signal must be grounded, and in large audio amplifier systems each individual chassis and each shield should be connected to a common ground.

Audio amplifiers which use an A.C. power supply and which are designed to operate satisfactorily with the low input signal intensities produced by condenser, velocity, crystal or dynamic type microphones, may have excessive hum if there is capacitive coupling between the primary winding of the power transformer and the chassis. In many cases grounding the chassis of the amplifier will correct the trouble. If hum still is heard when this is done, however, connect a .5 mfd., 600 volt paper condenser between the hot side of the power line and the amplifier chassis, after grounding the chassis. (To locate the hot side of the line, ground one terminal of this condenser and connect the other terminal to each side of the line in turn; that line which gives repeated sparks as contact is made and broken will be hot.)

Hum Due to Defective Filter Condensers. Defective power pack filter condensers are perhaps the most common cause of excessive hum in audio amplifier systems. It is therefore wise to check these first when hum is the complaint, before proceeding with other tests. Shunt each of the filter condensers in the power pack temporarily with a condenser known to be in good condition; an 8 mfd., 600 volt condenser can be used for this test. Be sure to observe its polarity if of the electrolytic type. If the connection of this test condenser across a condenser in the amplifier reduces the hum sufficiently, then that particular amplifier condenser is either open or of too low a capacity; if there is no reduction in hum, however, the condenser may be leaky or more than one filter condenser may be defective. Check the leakage resistance of each condenser with an ohmmeter or condenser tester when power is off.

Hum Due to A.C. Filament Power. With high gain amplifiers, and especially with pre-amplifiers designed for operation with microphones which have relatively low signal outputs, hum may result from the fact that the cathodes of the tubes are heated with alternating current. The first tube in the amplifier is most critical here; the heating and cooling of the cathode with each cycle of alternating current changes the plate current of this tube a slight amount and this 60-cycle variation in plate current can, after amplification by the remaining tubes, be sufficiently strong to produce an annoying hum. Removal of the first tube in the amplifier will eliminate the hum if the use of A.C. filament power is the trouble-maker. It is always wise to check the microphone also, for any drop in its output would tend to make such a hum more prominent. If the microphone is in good condition, the only solution is the use of direct current for the heater of the first tube or the first two tubes in the audio amplifier. Either batteries or a copper-oxide rectifier of the full-wave type with a filter may be used as the D.C. source.

Noise. A certain amount of noise is generally heard at the output of a high-gain A.F. amplifier because of noises inherent in the circuits and tubes used in the first stages of the amplifier. This noise may be reduced by using a sound pick-up device which has greater output than that originally used, thus permitting a reduction in the gain of the first stages. With experience you will learn to recognize this type of noise and be able to tell when it is abnormally high.

Any defective connection in an amplifier will, of course, be a likely source of noise. A condenser or resistor which intermittently breaks down while voltage is applied will result in noise heard in the loudspeaker. A stage-by-stage elimination procedure is the best way to locate the source of this type of noise. You can make this test safely in A.F. voltage amplifiers and low-power amplifier stages of a large A.F. system by removing tubes, but never remove high-power tubes while electrode voltages are applied. Tubes handling more than 5 watts of audio power may, when removed, cause excessive voltages to be applied to other parts in the amplifier. Parts in high-power stages can be checked one by one with an ohmmeter, while the amplifier is off, by tapping each unit or vibrating the entire chassis in an attempt to reproduce the intermittent condition.

Noise Due to Microphonic Tubes. Tubes in high gain amplifiers, and especially those designed for mobile service, may produce noises which build up into an annoying whine. This noise is due to vibration of the elements inside the tubes. This vibration changes the plate currents of the tubes, and these changes are amplified by succeeding tubes. Another condition which can occur is that where sound waves from a powerful reproducer strike the surfaces of tubes in a high gain amplifier, setting the tubes into vibration and giving the effect of continuous feed-back. The selection of tubes which are less microphonic in place of those employed is a simple cure in most cases; sometimes, however, it may be necessary to install a cushioned socket in the stage which has this trouble. The tube at fault is usually easy to locate, for touching a microphonic tube with your fingers will generally stop the vibrations and noise.

Noise Due to Defective Microphones. Defective carbon buttons in carbon microphones may produce an extremely objectionable hiss or noise. Repair of the microphone or installation of a new microphone is the remedy. It is usually better, especially if the microphone is inexpensive, to replace it with a new unit, for the repair of carbon microphones is a very delicate job. The frequency response characteristics of the microphone are dependent upon the pressure applied by the button to the diaphragm of the microphone, and the ordinary serviceman does not have the proper equipment to make this pressure adjustment properly. With expensive two-button microphones, it will often pay to send the microphone back to the manufacturer for reconditioning.

Distortion. Bad tubes, improper electrode voltages and overloading of a stage are likely causes of excessive distortion in A.F. amplifiers. If electrolytic condensers (either wet or dry) are found in an amplifier which has been in service for eighteen months or more, always check these condensers first as causes of distortion. The cathode by-pass condensers should also be checked for proper capacity value. Shorted or open transformer windings and open condensers in signal circuits can also cause serious distortion of the A.F. signal.

`It is of extreme importance that all circuits in an A.F. amplifier system be properly coupled together to prevent distortion due to overloading. For example, a 500-ohm circuit should be coupled to a 500-ohm load in a power output stage if overloading and distortion are to be kept at a minimum.

Squeals. Oscillations occurring at a *high audio frequency rate* in any part of an A.F. amplifier system are evidenced as squeals heard in the reproducer. These oscillations may be due to close coupling between the input and output leads of a high gain amplifier; in this case the condition can be cleared up by separating the input and output leads or by using shielded cable and grounding the shield to the chassis and then to ground.

Oscillation occurring at frequencies *above the audible range* will not be heard in the loudspeaker, but nevertheless these oscillations may cause distortion. This condition is most common in high-gain amplifiers where the input and output circuits are closely coupled together. It is very difficult to determine the source of distortion by simply listening to the reproduced signals. The condition is most likely to occur in stages where the grid return is made through a resistor of high ohmic value.

To identify the source of trouble, check the bias voltage developed across the cathode resistor in each of the first tubes in an amplifier. If this C bias voltage for any tube decreases as the volume control is advanced, there being no signal applied to the input of the amplifier, trouble due to oscillations above audibility is indicated. These oscillations cause additional rectified grid current to flow through the grid leak resistor when the volume control is advanced, making the net grid bias more negative. This lowers the plate current flowing through the cathode resistor and thus lowers the C bias voltage as the volume control is advanced. Making the operating C bias more negative in this manner moves the operating region off the linear portion of the characteristic curve, resulting in amplitude distortion.

This oscillating condition may usually be remedied by shielding the input and output leads near the amplifier and making sure that all tube shields are in position. Connecting a low-capacity condenser across the input circuit and another across the output circuit may reduce the high frequency oscillations enough to give satisfactory operation, but these condensers will reduce the high frequency response of the amplifier somewhat. Try condensers ranging in capacity from .0001 mfd. to .001 mfd. when making these tests, using the smallest condenser which satisfactorily eliminates amplitude distortion.

Motorboating. Oscillation occurring at very low audio frequencies in an audio amplifier, and caused by feed-back, is commonly known as "motorboating." This feed-back trouble is generally due to coupling between power supply circuits of an audio amplifier, it being more pronounced in high-fidelity amplifiers. Electrolytic filter condensers which have become low in capacity through drying out should be checked. Also check the values of all other filter condensers to determine whether they have the required capacity for proper isolation of amplifier power supply circuits. If motorboating continues when all filter condensers are of the correct capacity, then it may be necessary to use special filters (often called decoupling or anti-motorboating filters) in the first stages of the amplifier, in the manner shown in Fig. *2*. Here a resistance-capacitance filter consisting of a 4 to 8 mfd. condenser C and a 10,000 to 15,000 ohm resistor R have been inserted in the plate supply lead to the first tube in the amplifier, VT_1. This filter may be used when the voltage drop across the resistor R in the supply circuit will not materially lower the power output of the amplifier.

In cases where the plate voltage applied to a tube must be very nearly equal to the plate supply voltage in order to secure satisfactory output, an inductance-capacitance type of anti-motorboating filter can be used. One of these has been shown in the plate lead of tube VT_2 in Fig. *2* as an example; here choke coil CH has an inductance of at least 30 henrys, while condenser C_1 is approximately the same value as was used with a resistance-capacitance combination. The choke must be able to carry the plate current of the tube without heating excessively. The larger the value of the filter condenser and the greater the resistance of R or the inductance of CH, the more effective will be the filter in suppressing motorboating.

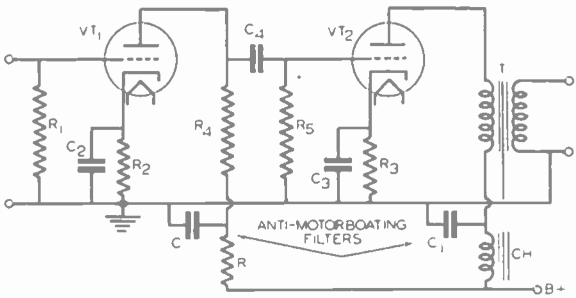


FIG. 2. First stages of an A.F. voltage amplifier, with two types of anti-motorboating filters inserted in plate circuits of tubes.

The installation of anti-motorboating filters is economical and practical only in voltage amplifier stages or low-power amplifier stages of amplifiers. With high-power, high-fidelity class B audio amplifier stages which are capable of amplifying extremely low frequencies, particularly below 30 cycles per second, very good power line voltage regulation is necessary in order to prevent motorboating. Usually motorboating will not start until a low frequency is applied to the input of the amplifier; a gust of wind across the diaphragm of the microphone may be enough to inaugurate motorboating. There are two possible remedies; improve the power line voltage regulation, or reduce the fidelity of the amplifier by equalizing in order to reduce the gain at the low frequencies. Details of this equalizing procedure will be given later in the lesson. Incidentally, when a microphone is used at a windy location, covering it with a porous cloth bag will often prevent motorboating.

EXPECTED AMPLIFIER PERFORMANCE

An inexpensive audio amplifier, and especially one which is designed only for voice frequencies, cannot be expected to give the quality of performance available with expensive amplifiers and those of the high-fidelity type. Any measurement of the performance of an amplifier must take into consideration the over-all frequency response (commonly represented by a curve like that shown in Fig. *3*), the noise and hum level, and the expected harmonic distortion at maximum power output. Regardless of the type of A.F. amplifier being serviced, you will need certain pieces of special testing and measuring equipment in order to determine accurately the operating characteristics. This testing equipment will now be discussed.

Although most servicemen will be primarily concerned with the installation, maintenance and servicing of audio amplifier equipment, some will also find it necessary to determine the actual operating characteristics of audio amplifiers. This check of amplifier performance is especially necessary when an amplifier has been assembled and placed into operation for the first time, or when an attempt is being made to improve the fidelity of an audio amplifier system.

CHECKING AMPLIFIER PERFORMANCE

A.F. Signal Generators. The audio frequency signal generator (A.F.S.G.) is an essential requirement for any service work on audio amplifiers. The fixed-frequency type of instrument, operating at from 400 to 1,000 cycles, is satisfactory for defect isolation work, but a continuously variable audio frequency signal generator is required for checking amplifier performance and for equalizing purposes. The variable beat frequency type, employing two radio frequency oscillators whose

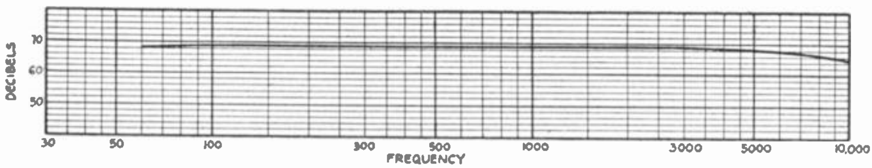


FIG. 3. Curves like this are used to show the frequency response characteristics of audio amplifiers. This curve tells that the amplifier which it represents will handle frequencies down to 60 cycles satisfactorily and will handle a 10,000 cycle signal with a drop of 5 db.

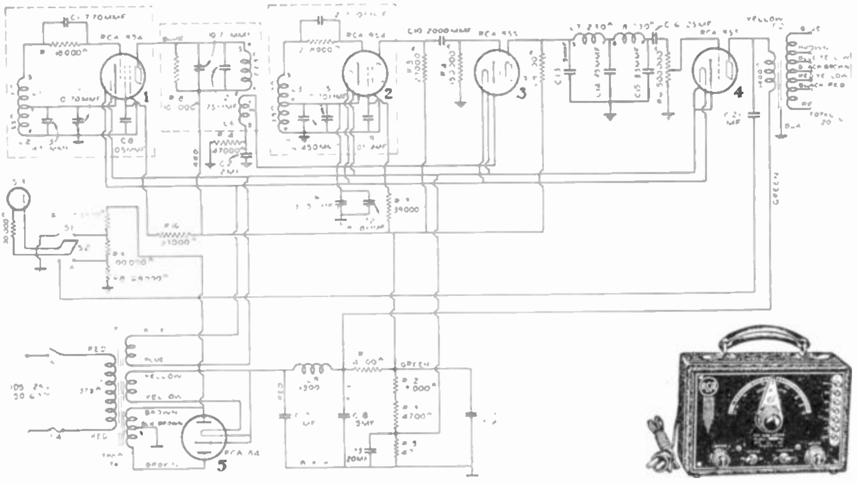
outputs are fed into a linear or square law detector which combines them and delivers the A.F. difference frequency, is the best type to use. A signal generator of this type should be purchased rather than constructed, for the assembly and calibration of such an instrument involves a great many problems.

Copper-Oxide Rectifier Type Voltmeters. In order to determine the gain of an audio amplifier, it is necessary to know its input and output voltages. These A.F. voltages can be measured with copper-oxide rectifier type voltmeters which have reasonably flat frequency response up to 15,000 cycles and which have at least two ranges, 0 to 3 volts and 0 to 250 volts. A single low-voltage meter may be used with suitable multipliers for measuring all of the A.F. voltages which will be encountered in audio amplifier work. Although copper-oxide rectifier type voltmeters are usually no more costly than vacuum tube voltmeters, they are more compact, more convenient, and above all, more reliable.

For equalizing purposes, it is desirable to have a copper-oxide rectifier type voltmeter which is calibrated in decibels above and below a 6 milliwatt zero level for the condition where a 500-ohm load is being used. The meter range should extend from at least minus 10 db to plus 6 db. The total output level of an audio amplifier in decibels may also be measured if the decibel instrument is provided with resistors for increasing its range.

Ordinary A.C. voltmeters such as are found in multimeters are generally not suitable for checking voltages at the higher audio frequencies encountered in audio amplifiers and in A.F. signal generators, for these voltmeters have sufficient capacity (because of the copper-oxide rectifiers used) to shunt out the higher audio frequencies and give incorrect voltage readings at these frequencies.

Vacuum Tube Voltmeters. Any vacuum tube voltmeter can be used for measuring A.F. voltages. The range of such an instrument can be



Circuit diagram of the RCA No. 9633 audio beat frequency oscillator, with a picture of the instrument at the lower right. As you can see from the diagram, the circuit uses two type 954 acorn tubes as R.F. oscillators, one being fixed in frequency at 350 kc. and the other being variable from 335 kc. to 350 kc. The output of each oscillator is combined and fed into a self-biased type 955 acorn tube which acts as detector and delivers audio frequencies ranging from 30 to 15,000 cycles into another type 955 tube acting as output amplifier. The power supply is built around a type 84 full-wave rectifier. An instrument such as this is necessary when checking the performance of an audio amplifier during an equalization procedure. The main dial indicates the oscillator output frequency directly in cycles.

increased for the measurement of high A.F. signal voltages by using a voltage divider type multiplier of the proper size.

The Cathode Ray Oscillograph. The more experienced you become in servicing A.F. amplifiers and improving their performance, the more valuable will you find the cathode ray oscillograph as a service instrument. When used in connection with an A.F.S.G. which is producing a pure sine wave output, a cathode ray oscillograph enables you to detect wave form distortion and even to trace it to the stage in which the distortion occurs. The cathode ray oscillograph which you select should have vertical and horizontal amplifiers, as well as a sweep circuit designed to operate at from 20 to 10,000 cycles per second. The larger C.R.O. tubes are preferable, for they give larger images and make it easier to detect wave form distortion.

MEASURING INPUT AND OUTPUT IMPEDANCES

Since the characteristics of the devices connected to the input and output terminals of an audio amplifier affect the frequency response and gain of the complete system, it is very important that correct impedance matches be obtained both at the amplifier input and at the output. Data is generally available concerning the input and output impedances of factory-built equipment, but there will be cases where such information must be secured by actual measurements.

How to Measure the Input Impedance of an A.F. Amplifier. Where the input circuit of an A.F. amplifier has no coupling device, the input terminals being connected directly to the output of the device which is producing the A.F. signal, we may consider that the input impedance of the amplifier is equal to 1 megohm; the exact value is not very important.

When the input circuit of an A.F. amplifier consists of some coupling device, such as a volume control, transformer or special pad, then the *substitution method* of measuring the input impedance may be used. Figure *4* gives the circuit for measuring input impedance by the substitu-

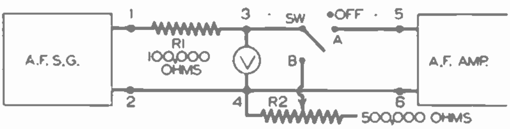


FIG. 4. Use this circuit for measuring the input impedance of an A.F. amplifier.

tion method. The A.F. amplifier is turned off, disconnected from its signal source, then connected into the circuit shown in Fig. *4*. The A.F.S.G. is set either to a 400 cycle or 1,000 cycle reference frequency, and its voltage output is then adjusted for the maximum obtainable value, which may be several volts. Resistor *R1*, having a resistance of 100,000 ohms, is necessary to prevent the impedance of the A.F.S.G. from affecting the accuracy of the measurements. With switch *SW* at position *A*, there will be a certain definite voltage between points *3* and *4*, and this voltage will be indicated by *V*, a vacuum tube voltmeter or a high-resistance copper-oxide rectifier type voltmeter. This reading is recorded, and switch *SW* is then changed to position *B*. Rheostat *R2* is now adjusted until *V* reads the same value as before; the ohmic value of *R2*, as measured now with an ohmmeter connected between points *4* and *B* when switch *SW* is in its OFF position, is exactly equal to the input impedance in ohms of the A.F. amplifier at the frequency for which this measurement was made (the input impedance of an audio amplifier varies somewhat with frequency, but for ordinary purposes one measurement at either 400 or 1,000 cycles is entirely satisfactory).

How to Measure the Output Impedance of an A.F. Amplifier. When an audio amplifier has a single output tube which feeds directly into a load, as is the case in Figs. *5A* and *5B*, we know that the correct value of load impedance is a value equal to the recommended load resistance for the tube being used. This recommended load resistance value can be determined from tube charts, and will generally be the value at which maximum undistorted power is delivered by the tube.

When the output stage of an A.F. amplifier feeds into an output transformer, as is the case in the circuits of Figs. *5C* and *5D*, the proper load impedance to connect between points *1* and *2* in each case must be determined by the substitution method, using a circuit arrangement similar to that shown in Fig. *4*. The audio amplifier is turned off, a resistance (2 watt rating) which is equal to the recommended plate load resistance for the tube is connected between points *3* and *4* without disturbing any output transformer connections, and terminals *5* and *6* of the measuring circuit in Fig. *4*, consisting of an A.F.S.G., *R1*, *R2*, *V* and *SW*, are connected to terminals *1* and *2* of the audio amplifier. That value of *R2* which makes meter *V* read the same for switch settings *A* and *B* then corresponds to the output impedance value required for the amplifier. (In the case of a push-pull amplifier, the ohmic value of the resistor connected between points *3* and *4* should be twice the recommended plate load resistance for one tube.) After the output impedance has been

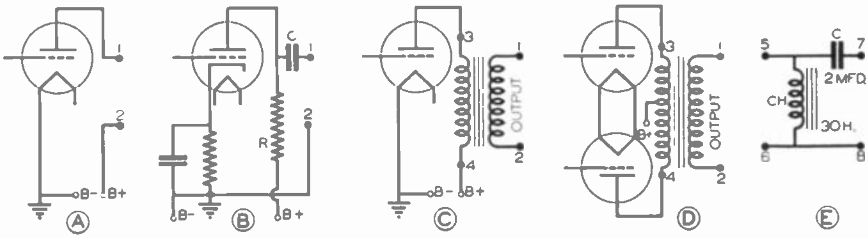


FIG. 5. Types of A.F. amplifier output circuits.

measured, be sure to remove the resistor which was connected to points *3* and *4*.

EQUALIZING A. F. AMPLIFIERS

The equalization of an audio frequency amplifier involves the introduction into the amplifier circuit of certain electrical components which change the frequency response of the amplifier. (The *frequency response* of an A.F. amplifier is a measure of its ability to amplify at various frequencies in its operating range; a typical frequency response curve for an amplifier was shown in Fig. *3*.)

There are two distinct reasons for equalizing an A.F. amplifier: *1*, to obtain a flat electrical frequency response; *2*, to obtain a flat acoustical frequency response. Flat *electrical* frequency response means that the gain of the amplifier is the same for all frequencies in the range being handled. Flat *acoustical* frequency response means that all frequencies in the reproduced sound have the same volume relation to each other as do the sound frequencies at the pick-up point; this flat acoustical response can be secured by making the amplifier itself compensate for deficiencies in the frequency responses of the sound pick-up device and reproducer; in some cases it is also necessary to make the amplifier compensate for the acoustical qualities of the location at which the reproducer is operating.

Amplifier Output Connections for Equalizing. When an audio amplifier is being equalized, a resistance load is always connected in place of the usual amplifier load. Never use a loudspeaker as a load when equalizing. Certain precautions must be observed when connecting this substitute load and when making measurements of output voltage during the equalizing process.

In amplifier output circuits of the type shown in Fig. *5A*, the resistance load which is connected in place of the usual amplifier load must not lower the plate voltage too much. It is therefore necessary to connect between the load resistor and the amplifier output terminals (terminals *1* and *2* in Fig. *5A*) a choke and condenser circuit like that shown in Fig. *5E*. Choke *CH* in this circuit must have an inductance of *at least 30 henrys* when normal D.C. plate current flows through, yet must have a very low D.C. resistance so it will not drop the plate voltage too much. This choke must also have negligible distributed capacity at the highest audio frequency under consideration. Condenser *C* is of the paper type, at least 2 mfd. in size and having a voltage rating equal to about twice the plate voltage of the stage. The load resistor, which will have an ohmic value equal to the recommended plate load impedance for the tube, is connected to terminals *7* and *8*.

With an audio amplifier circuit like that in Fig. *5B*, the necessary substitute load resistor can be connected directly to points *1* and *2* of the amplifier during the equalizing process.

With audio amplifier circuits like those in Figs. *5C* and *5D*, which have an output transformer, the necessary load resistor is connected directly to output terminals *1* and *2*. In each case the power handling rating of the load resistor must be at least equal to the power output value of the output stage. The vacuum tube voltmeter or copper-oxide rectifier type voltmeter which is used to measure the output voltage must, of course, be connected directly across the load resistor.

Connecting the A.F.S.G. to the Input of the A.F. Amplifier. In connecting an A.F.S.G. to an audio amplifier for equalizing purposes, there are three important requirements which must be met:

1. **The test source must be matched with the amplifier input impedance.**
2. **The minimum test source voltage must be one microvolt.**
3. **It must be possible to measure the test source voltage with a 0-1 volt voltmeter.**

The input circuit shown in Fig. *6* will satisfy these requirements. The output voltage of the A.F.S.G. is made high enough to give nearly a full-scale reading on voltmeter *V* (which can either be a vacuum tube or copper-oxide rectifier type voltmeter). By choosing the proper values for resistors *R1* and *R2*, the test source voltage between points *3* and *4* can be made *any desired fraction* of the A.F.S.G. output voltage, and can be measured simply by multiplying the meter reading by this fraction. A proper impedance match is secured by making the ohmic value of *R2* + *R3* equal to the amplifier input impedance.

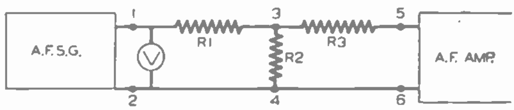
Assuming that the amplifier input impedance is known, the proper values for the three resistors are determined as follows: *R2* is made less than one-tenth the input impedance, with *R3* such that *R2* + *R3* together equal the input impedance. *R1* is then made equal to *R2* multiplied by a number which is one less than the desired voltage step-down ratio.

The amplifier input voltage (across *5* and *6*) will be approximately half the test source voltage, for *R3* is approximately equal to the input impedance. This input voltage is ordinarily varied by adjusting the A.F.S.G. output voltage, but large changes in input voltage must be secured by changing the ohmic values of the resistors.

Here is a practical example: An A.F. test source is desired which will supply .005 volt to an audio amplifier whose input impedance is 500,000 ohms. The voltage across *R2* must therefore be twice this value, or .01 volts. An A.F.S.G. which normally delivers 1 volt and a vacuum tube voltmeter having a 0-1 volt range are available. To get a suitable match, *R2* + *R3* must equal 500,000 ohms; if *R2* is made 25,000 ohms, then *R3* will be 475,000 ohms.* To get a 100 to 1 step-down voltage ratio (1 volt to .01 volt), *R1* must be 25,000 ohms multiplied by 100 — 1, which is 25,000 × 99 or about 2.5 megohms. Reading of meter *V* are then divided by 100 to get the test source voltage (across *3* and *4*).

Adjusting the Amplifier Input Voltage to Prevent Overloading. Before securing a frequency response curve which will tell how much equalization is necessary, you must first determine the input voltage level at

FIG. 6. Use this circuit for connecting an A.F. signal generator to the input of an A.F. amplifier.



which rated output will not be exceeded at any frequency. Rated output, as you know, is the output power in watts at which maximum permissible distortion occurs; this value is generally specified by the amplifier manufacturer, but can also be measured directly by a method to be described later. The output voltage corresponding to rated power output is obtained by multiplying this power in watts by the load resistor value in ohms, then taking the square root of the result.

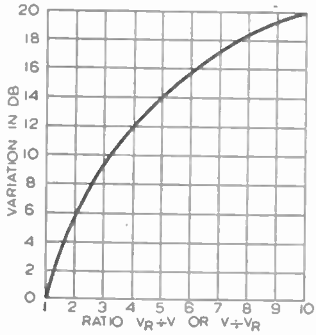
Now set the A.F.S.G. to give a normal output level, and swing the A.F.S.G. over the entire frequency range while watching the output meter. Note the frequency at which a maximum voltage reading occurs. With the A.F.S.G. at this frequency, adjust its output until the amplifier output voltage is at the value corresponding to rated output, and note the reading of the input voltmeter. If this reading is not exceeded during the remainder of the equalization process, distortion will remain below the maximum permissible amount and there will be no overloading.

Over-all Frequency Response Curve. The frequency response curve in Fig. *3* gives the gain of an entire audio amplifier at each frequency in its operating range, or in other words, gives the difference in decibels between the input power level and the output power level at each fre-

* This odd value of resistance can be secured by filing down the sides of a 400,000 or 450,000 ohm carbon resistor enough to increase its resistance to the desired value.

quency. The values for this curve are obtained by determining, for each frequency, the output and input powers in watts. These values are then converted into decibels by means of a power level table (given elsewhere in the Course), and the difference between the input and output decibel readings is taken as the gain of the amplifier (in decibels) at that frequency.

The actual procedure for measuring the over-all gain of an audio amplifier is as follows: Set the amplifier gain controls for maximum voltage amplification, then adjust the input voltage to a value which you know will not overload the amplifier at any frequency. Keep this input voltage constant throughout the test by adjusting the A.F.S.G. output. Of course, the output terminals of the amplifier are connected to a resistor which is equal in value to the recommended load resistance.



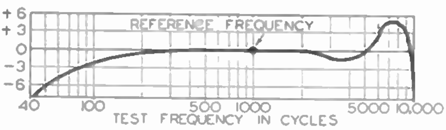


FIG. 8. (Above.) This type of frequency response curve gives, for any audio frequency, the db variation from the output level at a reference frequency (here 1,000 cycles).

FIG. 7. (Left.) This graph has been prepared especially to assist you in computing decibel variations in the outputs of audio amplifiers.

Measure the output voltage at several frequencies. To compute the output power at any frequency, multiply the load voltage by itself and then divide the resulting number by the ohmic value of the load resistance; this gives you the output power in watts. Convert this power into power level in decibels by referring to a suitable table.

Since the input power was held constant, we need compute it only once. Divide the reading of the input circuit voltmeter *V* by the step-down ratio of the resistance network to get the test source voltage (across *3* and *4* in Fig. *6*), then divide the result by 2 to get the amplifier input voltage. Multiply this input voltage by itself, then divide the resulting value by the input resistance of the amplifier to get the input power level in watts. Convert this power into decibels by referring to a table as before. Power levels below .006 watt will be minus when converted into db, or in other words, will be a certain number of db *down*. Subtract the input and output db levels if they are both plus or both minus (both above or both below .006 watt) and add them if one is plus and the other is minus. The resulting value is the gain of the amplifier in db.

If the gain in db is computed in this way for a number of frequencies, and the results plotted against frequency, a frequency response curve resembling that in Fig. *8* will be obtained.

Although it is customary for manufacturers of audio amplifiers to make gain response curves as outlined above, this cumbersome procedure is not required for equalizing purposes. Of course, a technician does want to know the true gain of an amplifier at times, so he can tell whether a certain desired output level will be secured with a pick-up device capable of delivering a certain amount of input power. For cases like this, the gain is measured at some one reference frequency; 400 cycles and 1,000 cycles are values quite commonly used.

For equalizing purposes, the technician wants to know how much the power output in decibels will increase or decrease when the input voltage is held constant and the frequency is varied above and below a certain reference frequency value. To secure this information, the A.F.S.G. is connected to the audio amplifier in the manner shown in Fig. *6* and the output of the amplifier is terminated with a resistor of the proper value, across which is placed a voltmeter. Set the A.F.S.G. to the desired reference frequency, usually 1,000 cycles, and adjust the input voltage to a value which you know will not cause overloading of the amplifier at

FIG. 9. Two methods of connecting a db meter to measure variations in db level directly regardless of what the output level is.

any frequency. Record the value of output voltage obtained at this reference frequency; we will call this output voltage V_R, the reference output voltage. Now set the A.F.S.G. to other audio frequencies in turn, separated 10 cycles for values up to 100 cycles, separated 100 cycles for values from 100 to 1,000 cycles, and separated 1,000 cycles for all higher frequency values, and at each frequency setting record the output voltage after making sure that the input voltage is the same value as for your first measurement. This output voltage for frequencies off the reference frequency we will call V.

If V_R is larger than V, divide V_R by V and place a minus sign in front of the result. This sign means that the output level is down at the frequency corresponding to voltage V. If V is larger than V_R, however, divide V by V_R and place a plus sign in front of the result; this means that the output voltage level has gone up at the frequency corresponding to voltage V. Use the graph in Fig. *7* to find the value of db variation corresponding to the voltage ratio for each frequency, being sure to retain the minus and plus signs. Now plot on graph paper the number of db the output is above (plus) or below (minus) the zero db reference level at each of the frequencies at which you took readings. When a smooth curve is drawn through these points, the result will be like that shown in Fig. *8*, which is really a frequency response curve indicating db variation from a reference level.

If you have a decibel output meter with a scale which reads above and below zero db, you can get db variations in gain directly without any figuring. With reference input voltage at the reference frequency, connect the db meter across the load either as shown in Fig. *9A* or Fig. *9B*, and adjust contact arm *P* until the meter reads zero db. At all other frequencies now, the meter will give the variations in db above or below the reference level selected.

EQUALIZING CIRCUITS

An analysis of the frequency response curve in Fig. *8* tells us that the amplifier has poor response below about 100 cycles and above about 6,000 cycles, for variations greater than 2 db from the reference level can be noticed by the critical listener. In making this statement, we are assuming that both the pick-up and the reproducer have a flat response characteristic from 40 cycles to 10,000 cycles. Flattening the response characteristic curve of an amplifier by means of additional equipment is called *equalizing;* this is a task which many technicians are required to do in connection with public address systems. With high fidelity radio receivers, the design engineer takes care of the equalizing work.

There are two fundamental methods of equalizing an audio amplifier. *Method 1 involves raising or lowering the gain of the amplifier in those ranges of frequencies where the db variation from the reference level is excessive. Method 2 involves noting the lowest db response in the entire frequency range and reducing the gain at all other frequencies to within 2 db of this lowest level.* In the second method it may be necessary to operate the amplifier at a higher gain setting or add additional stages to compensate for gain lost in flattening the response. Method *2* is most commonly used when equalizing entire amplifier systems. The equalizer circuits used with either method employ a combination of resistors, condensers and tuned circuits which act either as voltage dividers, dividing the circuit voltage in a different manner for each frequency, or act to shunt or block the input circuit of an amplifier stage by a different amount for each range of frequencies.

Location of Equalizer Circuits. Equalizer circuits may be introduced between any two stages of an A.F. amplifier, such as between points *1* and *2* in Figs. *10A* and *10B;* they may also be placed at the input of the first stage of the amplifier, as at points *1* and *2* in Fig. *10C.* Whenever possible, it is a good policy to locate the equalizer circuit in the first stages of the amplifier system, for this lessens the possibility of overloading any of the stages ahead of those being equalized. Now let us consider various equalizer circuits and their characteristics.

Cutting Down Gradually the Higher Frequency Response. The equalizer circuit shown in Fig. *11A*, consisting of a resistor *R* and condenser *C* in series, will cut down gradually the response of an A.F. amplifier at the higher frequencies in the audio range, with the amount of reduction increasing with frequency. Points *1* and *2* of this equalizer circuit are connected to points *1* and *2* of the amplifier circuits in Fig. *10.* Resistor *R* can be a 250,000 ohm variable resistor, permitting adjustment of its value to get the desired amount of equalization; condenser *C* should have a value somewhere between .0001 mfd. and .05 mfd. The larger the value of *C* and the smaller the value of *R*, the more will the higher frequencies be cut down.

Cutting Down Gradually the Lower Frequency Response. The intensities of the lower audio frequencies can be cut down gradually, with the lowest frequencies attenuated the most, by using the voltage divider circuit shown in Fig. *11B*. When this equalizer is used with amplifier circuits like those in Figs. *10A* and *10B*, points *1* in amplifier and equalizer are connected together, points *2* in amplifier and equalizer are connected together, and the grid connection for the second tube in the amplifier is changed over to point *3* of the equalizer circuit. When used with a circuit like that in Fig. *10C*, the connections to *1* and *2* are made as before.

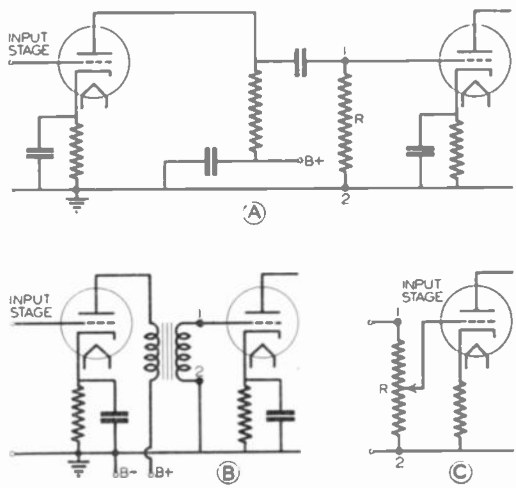


FIG. 10. Equalizer connections are made to points *1* and *2* in each of these three representative audio amplifier circuits. Whenever possible, equalizers are introduced in the first stage of the amplifier.

The grid connection to potentiometer *R* in the stage is left unchanged, and the upper end of this potentiometer is connected to point *3* in the equalizer circuit.

Since resistors *R1* and *R2* in Fig. *11B* are connected in series, with the grid of the second tube going to their common point *3*, there will be a division of the signal voltage which varies with frequency because the reactance of *C1* varies with frequency. At high audio frequencies condenser *C1* acts as a short circuit path across *R1*, and full signal voltage exists across *R2* for application to the next stage. At low frequencies the reactance of *C1* is quite high, with the result that there is a voltage drop across *R1* and *C1*, and less voltage is applied to the grid of the second tube. The greater the capacity of *C1*, the less will be the attenuation of the lower frequencies. The values of *R1* and *R2* depend upon the amount of equalization required; in any event, the total series resistance should not be more than 2 megohms. The best value for *C1* can be found by first using a .0005 mfd. variable air condenser, adjusting it until the desired effect is obtained.

Raising the Response in Certain Frequency Ranges. When the output of an audio amplifier is low in a certain range of frequencies, one way to secure flat response is by raising the gain (or the gain control) of the amplifier over the entire audio frequency range, and then lowering the gain at all *frequencies except those in the range which originally was low.* This latter step may be accomplished with one or more resonant equalizer circuits like that shown in Fig. *11C*, where resonant circuit *L1-C1* is in series with resistor *R1*. This combination is placed across the input of a stage (between points *1* and *2* in the circuits of Fig. *10*), the grid connection to the stage being left unchanged. There will be maximum impedance between points *1* and *2* of the equalizer circuit at the resonant frequency of *L1-C1*, and the shunting effect of the equalizer at this resonant frequency will therefore be less than at any other frequency. The amount of reduction in gain at other than the resonant frequency is controlled by resistor *R1*. Use a variable resistor for *R1* until you have secured the desired amount of reduction over the frequency range which originally was high, then substitute a fixed resistor of the required value.

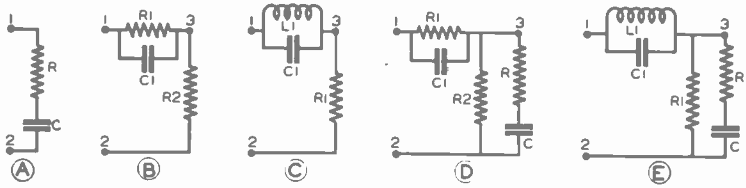


FIG. 11. Five typical equalizer circuits.

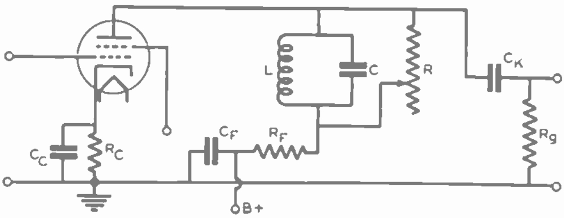
Experience has shown that for equalizers designed for audio frequencies, the required value for *L1* will be somewhere between 250 millihenrys and 100 henrys, and the required value for *C1* will range between 100 mmfd. and .15 mfd., with the lower values in each case being used for the higher resonant frequencies.

Lowering the Response in a Frequency Range. The equalizer circuit in Fig. *11C* may also be used to lower the gain of the amplifier over a narrow frequency range around the resonant frequency of the tuned circuit. With amplifier circuits like those in Figs. *10A* and *10B*, this can be done by connecting points *1* and *2* of the equalizer to corresponding points on the amplifier, and connecting the grid of the following tube to point *3*. With an amplifier like that in Fig. *10C*, connect the equalizer as above, but connect the *upper end* of potentiometer *R* to *3* instead of to *1*. Tuned circuit *L1-C1* will offer a high impedance to the range of resonant frequencies, lowering the voltage across *R1* and therefore lowering the voltage applied to the grid of the next tube at these frequencies. The amount of reduction in gain is dependent upon the value of *R1*; the lower its ohmic value, the greater will be the attenuation of resonant frequency signals. The action of an equalizer circuit is also controlled by the Q factor of the tuned circuit; in practical work, however, the highest possible Q factor should be used and *R1* varied to give the type of equalization desired.

Reducing Gain over a Wide Mid-Frequency Range. It is possible to combine the equalizer circuits of Figs. *11A* and *11B* in such a way that only the middle region of the audio frequency range will be attenuated (cut down). Equalizing action such as this is desirable when the response is down at the very low and very high frequencies; the circuit can be adjusted to bring the mid-frequency response down to the level of the high and low frequencies. The resulting combination equalizer network is shown in Fig. *11D;* it is connected in the usual manner between points *1* and *2* of the audio amplifier, with the grid of the A.F. amplifier tube (or the upper end of *R* in the case of an amplifier like that in Fig. *10C*) connected to point *3*. The same values of resistors and condensers should be used here as in the individual circuits. One equalizer circuit tends to compensate for the effects of the other, but under normal circumstances it is possible to lower the wide mid-frequency range at least 5 db. This is generally enough to give flat response over the entire range of frequencies.

Combining Equalizer Circuits. Suppose that the response of a particular amplifier had a decided rise from the low to the high frequencies and a high peak at one point over a narrow range of frequencies. An equalizer circuit like that in Fig. *11C* would reduce this peak, and the equalizer shown in Fig. *11A* would gradually reduce the response at high frequencies. Combining these two equalizer circuits to give a combination circuit like that shown in Fig. *11E* could therefore give a flat response to this amplifier. Connect points *1* and *2* of the equalizer in the usual manner to points *1* and *2* of the amplifier, and connect point *3* of the equalizer to the grid of the following tube or to the grid end of the volume control.

FIG. 12 Coil *L*, condenser *C* and rheostat *R* here comprise a special parallel resonant equalizer circuit which can be used to boost the gain of an amplifier over a limited range of frequencies.



Raising the Gain over a Limited Range of Frequencies. So far we have considered equalizing methods which involve the lowering of the gain over certain frequency ranges. It is also possible to *raise* the gain over any reasonable range of frequencies without affecting the gain at any other frequencies. This can be done by introducing into the load circuit of one of the voltage amplifiers a parallel resonant circuit like *L-C* in Fig. *12,* the impedance of which will be very high at and near its resonant frequency. This in effect increases the load impedance and thereby raises the gain of the amplifier.

This parallel resonant equalizer circuit may be used with screen grid and pentode tubes, where the load impedance is normally much lower than the A.C. plate resistance, but is not suitable for use with triode tubes (because triode tubes are normally operated at maximum possible gain, and increasing the load impedance would not appreciably increase the gain). Coil *L* and condenser *C* in the parallel resonant circuit should have high Q factors, in order to give a sharp increase in impedance at resonance. The broadness of resonance and the amount of resonant resistance introduced are controlled by varying the value of shunt resistor *R*, which may be a 0-500,000 ohm variable resistor. Grid resistor R_g in the following stage should be at least 1 megohm.

Two or more of these parallel resonant circuits can be connected in series in an amplifier load circuit in order to raise the gain at two or more points in the frequency range; each circuit is tuned to a frequency at which an increase in gain is desired. Do not expect a gain of more than 6 db from any parallel resonant equalizer circuit.

WHEN AND HOW MUCH TO EQUALIZE

In any complete P.A. amplifier system, the ultimate in fidelity is obtained when the frequency response from the pick-up unit to the listener's ears is perfectly flat. Suppose that a technician is installing a complete P.A. amplifier system; will he go ahead and assemble the various units in the system, then experiment on an audience to determine whether he is getting broad response? Not at all! He will first of all endeavor to select a pick-up, amplifier unit and reproducer which in themselves have the flattest possible responses. (Upon request, manufacturers of pick-up units and reproducers generally supply response curves for their products.)

The loudspeaker response will usually be the least flat; in fact, most of the peaks in the response of an average P.A. amplifier system can be attributed to the loudspeaker.

When an expert plans a complete P.A. amplifier system, he first plots the frequency response curves of each unit of the system in the manner shown in Fig. *13*, choosing a convenient reference frequency such as 1,000 cycles and plotting the response in db above or below this reference frequency level. This gives him curves *A*, *L* and *P* in Fig. *13*, representing the amplifier, loudspeaker and pick-up respectively. At a number of frequencies then, he adds together the responses of the various units (or subtracts them if the values so indicate), to secure points for the over-all frequency response curve of the system (curve *S*, shown by a heavy line in Fig. *13*). A study of curve *A* shows that the amplifier unit is reasonably flat (not more than 2 db down or up) from 30 to a little over 11,000 cycles. The loudspeaker is down more than 2 db at 50 cycles and is likewise down over 2 db at 10,000 cycles; furthermore, it has a decided peak at about 4,000 cycles. The pick-up unit is flat within 2 db from about 80 to 10,000 cycles.

Let me give you a few examples of how points on these frequency response curves are combined to get the over-all response curve. At 50 cycles, *A* is down .5 db, *L* is down 2.5 db, and *P* is down 4.5 db, making the over-all gain reduction at this point the sum of these values or 7.5 db down; this corresponds to point x. At 10,000 cycles, *A* is 0 db, *L* is down 2.5 db, and *P* is down 1.5 db, making a total of 4 db down for point

y on the over-all response curve. The entire over-all response curve is obtained by repeating this procedure for a number of other frequencies.

A study of the over-all response curve in Fig. *13* will show that it is down 7.5 db at point x, is down 4 db at point y, and is up about 5 db at 4,000 cycles. Equalization introduced into the amplifier must remove these variations if a flat over-all response is to be obtained.

Equalizing by Method 1. It is quite possible to use the equalizer scheme shown in Fig. *12* to raise the gain at the low and high frequencies (at points x and y); two of these parallel resonant circuits will be required, one tuned to 50 cycles and the other to 10,000 cycles. (If the increase in gain is insufficient, lower the value of R_F in Fig. *12* a small amount.) The gain could then be lowered at 4,000 cycles by means of the equalizer circuit shown in Fig. *11C*.

Equalizing by Method 2. Suppose we wanted the P.A. system to

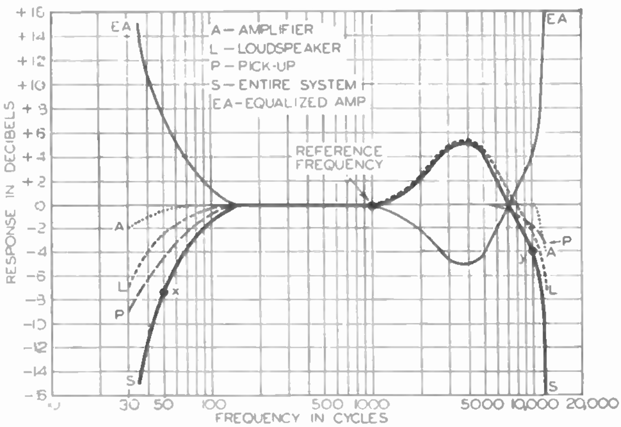


FIG. 13. Frequency response curves for the individual components of a typical audio amplifier system, together with the over-all response curve for the system, are shown on this one graph. The response is given in terms of decibels above or below the level at the reference frequency of 1,000 cycles.

have a flat response between 40 cycles and 11,000 cycles; the common procedure for accomplishing this involves introducing equalizers which will pull the gain of the amplifier at the reference frequency down to the lowest level on the over-all response curve. In Fig. *13* the lowest level in this frequency range is minus 11 db at 40 cycles. If it is possible to raise the gain of the amplifier 11 db without overloading it, to compensate for this loss, no additional amplifier will be required.

First we want an equalizer which will remove the rise in gain at 4,000 cycles. The circuit of Fig. *11C*, introduced in a voltage amplifier stage, will serve the purpose, reducing the gain to the reference level at frequencies around 4,000 cycles. Now we want another equalizer which will pull the gain down 11 db from 150 cycles to about 5,000 cycles but will put the gain down lesser amounts as we proceed toward frequencies lower and higher than this intermediate range. The equalizer circuit shown in Fig. *11D* will serve. Adjustment of the various components of the equalizer is necessary in order to get the desired change in gain at each frequency. When proper over-all equalization is obtained and the amplifier gain is raised 11 db, the response curve for the equalized amplifier will be curve *EA* in Fig. *13*.

When an audio system which has been properly equalized is installed at its location, faithful reproduction can be expected if the acoustic qualities of the location have no appreciable effect upon the loudspeaker output.

It is possible to measure the over-all frequency response from the pick-up to a listener's location in an auditorium or hall by using a sound level meter. This instrument contains an audio amplifier to which is connected a microphone (with the microphone-amplifier combination having a flat over-all response); an output meter, calibrated to indicate the level of sound reaching the microphone, is connected across the output of this amplifier. Sounds of various frequencies and known levels are fed into the input device of the amplifier system under test, and the sound output of the system at various listening points is measured with the sound level meter. Knowing the sound levels of input and output for each frequency, true and complete frequency response curves for the system can be secured for any listening location.

Obviously a procedure like this is far beyond the means of the average well-equipped sound technician. Instead, he equalizes as best he can before installing the system, then relies upon his own acoustical judgment and the opinions of expert listeners in the audience as to whether further adjustments are necessary. It is not at all uncommon for a technician to alter the response at either high or low frequencies to meet the approval of the audience, even though he knows that the response of the system is already flat. After all, pleasing the public is quite important in audio amplifier work.

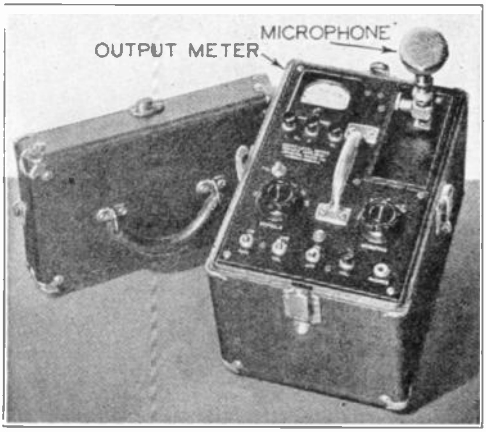
DISTORTION

Obtaining a flat over-all frequency response is only one phase of amplifier fidelity correction. A flat response means that there is no frequency distortion, but we still have to contend with amplitude distortion, which results in the introduction of undesirable harmonics.

Amplitude distortion may be present only at certain input levels, so it is important to check for it at various input levels. When amplitude distortion appears at high levels, it is important to determine which stage is causing it. More than likely the output stage will be at fault, but this should not be taken for granted. To check for amplitude distortion, you must introduce a sine wave input signal and observe the wave form at each stage in the amplifier.

In an amplifier which has serious amplitude distortion, a perfect sine wave input signal may take the form of a square wave at the output. The peak of the A.F. cycle becomes square rather than sinusoidal in form. This type of distortion causes the reproduced signal to have a higher tone than normal. The higher harmonics of the audio frequencies are amplified nearly as much as the fundamental signal frequency.

Checking Amplitude Distortion with a C.R.O. The cathode ray oscillograph (C.R.O.) is one of the most valuable instruments available to servicemen for checking amplitude distortion in A.F. amplifiers. The procedure is as follows: Connect an audio frequency signal generator to the input of the audio amplifier system in the manner shown in Fig. *6*. Adjust the A.F.S.G. to a reference frequency (assume that 400 cycles is selected). Connect the vertical amplifier terminals of the C.R.O. across the output of the A.F.S.G. and note the wave form of the pattern reproduced on the C.R.O. screen while using the internal sweep circuit and the synchronizing amplifiers for the horizontal sweep. Now adjust the horizontal sweep circuit of the oscillograph to 200 cycles per second, to give two complete cycles of the A.F. signal on the screen. Adjust the automatic synchronizing control on the C.R.O. if necessary, in order to hold the image stationary. (Detailed instructions for using a C.R.O. are given elsewhere in the Course.)



A typical sound level meter, employing a non-directional microphone, a high-gain battery-operated audio amplifier, and an output meter calibrated to indicate sound levels in decibels.

Courtesy General Radio Co.

Having made these preliminary adjustments, connect the vertical amplifier terminals of the C.R.O. to the output terminals of the A.F. amplifier under test. If this amplifier is functioning satisfactorily, the wave form which is now reproduced on the screen of the C.R.O. will be the same as that obtained for the input of the amplifier. This test should be made at a low input level. Now, by gradually increasing the input level, you can determine the level at which overloading occurs by noting when wave form distortion first appears on the screen. The oscillogram in Fig. *14A* represents a pure sine wave, such as will be obtained when a sine wave signal is fed into the amplifier and there is no amplitude distortion. That in Fig. *14B* has slight irregularities on the peaks of each cycle, these being flattened somewhat. This could be due to an excessive flow of grid current in a class A amplifier stage, and since both positive and negative peaks are flattened, it is probably due to a push-pull stage. This distortion is not apparent on the ear and hence is not extremely objectionable.

When the grid circuit of a push-pull or push-push stage is overloaded, the wave form may be distorted in the manner shown in Fig. *14C*. The quality of the tone emitted from the reproducer will be fuzzy or hashy in this case.

When one tube of a push-pull or push-push amplifier has low emission, or when the center-tapped transformers in the stage are defective, the wave form will be distorted as in Fig. *14D* when the grid circuit of the stage is overloaded. A single tube which is overloaded and which also has transformer core saturation on one-half of each cycle will give a similar distorted pattern. This type of amplitude distortion causes harsh and unpleasant tones.

The pattern in Fig. *14E* shows a flattening out of both peaks of each cycle, with no current or voltage existing between alternations. This break between half-cycles is due to excessive negative C bias in a push-push stage. The flattened peak may be due to grid current flow in a class

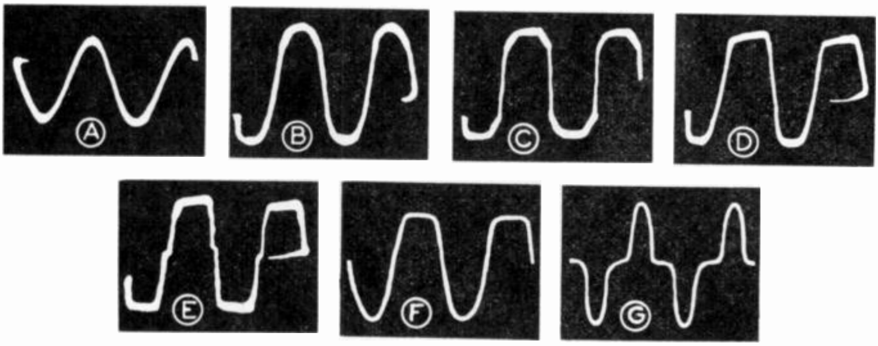


FIG. 14. Typical wave form patterns as seen on the screen of a cathode ray oscillograph connected to various points in an audio amplifier. Pattern *A* indicates satisfactory operation, while the others indicate various types of trouble. These are actual photographs of patterns produced on a cathode ray tube screen, retouched somewhat for reproduction purposes.

A amplifier or to a low-emission tube in a driver stage. This type of trouble can be traced to poor C bias voltage regulation. The reproduced sound will be very mushy, and speech will be almost unintelligible.

As you become familiar with audio amplifier ailments and learn to associate them with the different wave forms which you see on a C.R.O. screen, you will become able to recognize and identify distortion and trace it to the trouble-making stage, simply by viewing the patterns on a C.R.O. screen.

Amplitude distortion which is due to incorrect electrode voltages or defective parts will be eliminated by correction of the defect. When this is done, the maximum undistorted output level for the amplifier will be much higher.

Calculating the Output Power. Knowing the ohmic value of the resistor connected across the output of an A.F. amplifier and knowing the voltage across this resistor when maximum undistorted power is being handled by the amplifier (by measurements with a vacuum tube voltmeter or copper-oxide rectifier type voltmeter), we can estimate the power developed by means of the formula $P = V^2 \div R$. For example, if the load resistance is 3,500 ohms and the maximum allowable output is 30 volts the power developed will be $30 \times 30 \div 3{,}500$, or .257 watt.

CHECKING A TYPICAL AUDIO AMPLIFIER

As a review of the material just studied, I will now go through the process an expert technician would follow in checking a typical audio amplifier like that represented by the circuit diagram in Fig. *15*, to determine if there is amplitude distortion. First of all, the A.F.S.G. and its matching circuit are connected to terminals *1* and *2* of the amplifier, and the vertical plate terminals of a C.R.O. are connected across load resistor *R* in the amplifier (terminals *3* and *4*). Set the amplifier gain control *R1* for maximum gain, then advance the output of the A.F.S.G. slowly (using a reference frequency), until the voltmeter across the amplifier output indicates full output or until wave form distortion just begins to appear. The gain control on the C.R.O. must, of course, be adjusted to give a pattern which corresponds to the size of the screen on the C.R.O. tube.

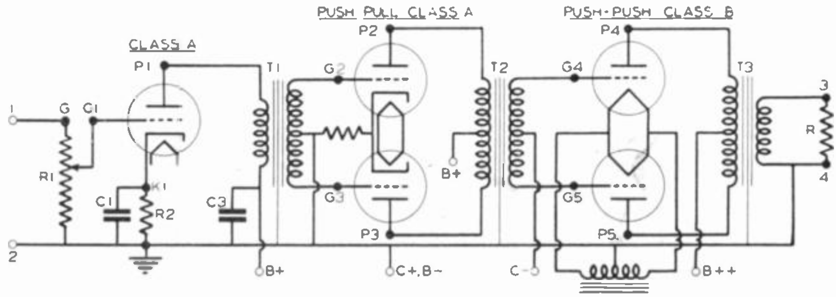


FIG. 15. Circuit diagram of a typical three-stage audio amplifier.

If a pure sine wave output pattern like that shown in Fig. *14A* is obtained at full output, it will not be necessary to make further tests on the amplifier with a C.R.O. If distortion appears before rated output, and a check-up shows that all tubes are in good condition and are receiving rated filament, grid and plate voltages and rated plate currents, then the stage which is causing the distortion must be located and the trouble corrected. The C.R.O. can be used for locating the trouble. Sometimes an analysis of the output wave form may tell us immediately what is causing the trouble, but in other cases we will have to use the following stage-by-stage check-up.

Disconnect the C.R.O. from the amplifier output terminals, connect the grounded vertical C.R.O. terminal to point *2* in Fig. *15*, and connect the other or hot vertical C.R.O. terminal to point *G* in order to check the wave form of the audio signal as it is across resistor *R1*. The pattern should be a sine wave similar to the output pattern of the A.F.S.G. Now move the hot C.R.O. terminal to point *G1*; again a sine wave pattern should be obtained.

Before proceeding farther, make sure that the C.R.O. which you are using employs a condenser as a coupling device to its input gain control.

If there is none, then insert a 1 mfd., 600-volt paper condenser in series with the hot vertical lead of the C.R.O. in order to keep direct current out of the C.R.O.

Now connect the hot vertical C.R.O. terminal to point *P1*, the plate of the first tube. If this tube is functioning properly, it will be necessary to reduce the gain on the C.R.O. in order to keep the picture on the screen. If little gain is observed, then condenser *C1* may be open. You can check this condenser by connecting the C.R.O. across it; with the condenser open, an appreciable A.F. voltage will be indicated, but with a good condenser the A.F. voltage observed will be negligible. In the latter case, a shorted winding in transformer *T1* may be the cause of low gain.

If one peak of the wave observed when the C.R.O. is connected between *P1* and *2* is flattened out, as indicated in Fig. *14F*, then the C bias for this single tube stage is either too high or too low. Check the ohmic

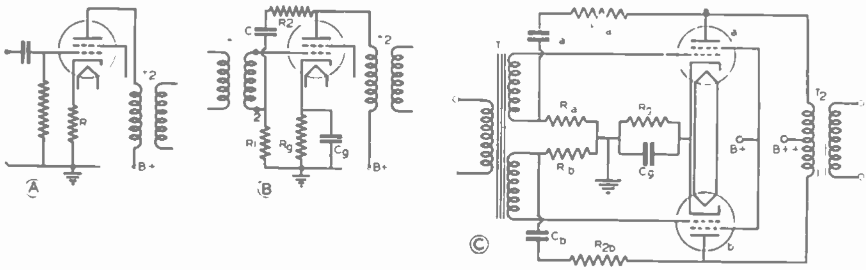


FIG. 16. Three different applications of inverse feed-back in audio amplifier circuits.

value of *R2*, putting in a new resistor of the proper value to eliminate the flattening if necessary.

Assuming that the wave form at point *P1* was good, we next apply the hot vertical C.R.O. lead first to point *G2* and then to *G3*. The voltages obtained here should be equal to each other and should be greater than that obtained at *P1*, because transformer *T1* has a high step-up ratio. If these two voltages are not equal, then one side of the secondary of transformer *T1* may be defective, and the transformer will have to be replaced.

Now move the hot vertical C.R.O. connection first to point *P2* and then to *P3*. Any indication of distortion is a sign that a defective part exists before the point at which a measurement is being made. You will note that the waves for *G2* and *G3* are 180 degrees out of phase with each other, and likewise the waves for *P2* and *P3* will be opposite in phase.

Assuming that the source of distortion has not yet been located, points *G4* and *G5* are next connected in turn to the C.R.O. Again there should be a step-up in voltage since *T2* is a step-up transformer. A variation of more than 10 per cent in the voltages at *G4* and *G5* indicates a defective transformer at *T2*. Repeat this procedure for points *P4* and *P5;* if a wave form like that in Fig. *14G* is obtained, the C bias is too high and requires adjustment.

INVERSE FEED-BACK CIRCUITS

If amplitude distortion is traced to the output stage and cannot be satisfactorily reduced by making voltage adjustments, a considerable amount of this distortion can be eliminated by the use of an inverse feed-back circuit.

Harmonics introduced by a conventional audio amplifier output stage may be reduced as much as 50 per cent by employing an inverse feed-back circuit, while still obtaining rated power output from the tube. This reduction in harmonic distortion is secured by feeding back an inverse voltage whose peak value is less than or equal to the C bias voltage of the tube in the stage to be corrected. This reduces the power sensitivity of the stage 50 per cent, making it necessary to apply twice as much power to the grid circuit of the stage. With amplifiers which have more than about 6 db of gain to spare, this is no objection.

The simplest method for obtaining inverse feed-back or degeneration is that illustrated in Fig. *16A*. This method simply involves omitting the by-pass condenser which is usually connected across cathode resistor *R;* this causes degeneration at all frequencies being amplified. The amount of degeneration introduced is dependent upon the value of *R*, but since this resistor is also used to obtain automatic C bias, its value cannot be varied to control the amount of feed-back. The amount of degeneration available by this method is thus definitely limited.

A somewhat better arrangement is that shown in Fig. *16B*, where condenser *C* and resistor *R2* are introduced for the specific purpose of providing inverse feed-back from plate to grid. R_g and C_g serve their normal function of providing automatic C bias, while *R1* provides a return path to ground for the grid and at the same time acts in connection with *R2* as a voltage divider for the A.F. plate voltage which is being fed back to the grid. The values of *R1* and *R2* control the amount of inverse feed-back, assuming that *C* has negligible reactance at the lowest audio frequency being handled.

In a push-pull or push-push stage the inverse feed-back system must be of the form shown in Fig. *16B*, but both tubes must receive independent feed-back voltages. The circuit in this case will be as in Fig. *16C*.

The inverse feed-back circuit in Fig. *16B* can also be used to correct frequency response, but doing this may partially cancel its primary function of reducing amplitude distortion. When a greater response is desired at higher audio frequencies than at low and intermediate frequencies, a coil can be connected in series with *R2*. The reactance of this coil increases with frequency, serving to reduce the feed-back current and thus reduce degeneration. This gives the desired increase in gain at high frequencies. Placing a condenser across *R2* gives increased degeneration at high frequencies, thus serving to cut down the gain at high frequencies.

If the inverse feed-back voltage is too great, the stage may become unstable or go into oscillation. There is, therefore, a limit to the amount of equalization and reduction in distortion which may be secured with this method.

When servicing audio amplifiers which employ inverse feed-back circuits, it is well to measure the inverse feed-back voltage with a high resistance copper-oxide rectifier type voltmeter. The peak value of this feed-back voltage should never exceed the applied C bias voltage at any frequency in the range over which the amplifier is to be operated.

HUM AND NOISE LEVELS

The level of the signals which originate in an audio amplifier itself is known as the *hum and noise level.* All amplifiers have hum and noise levels; in fact, this is often the first thing to be measured when checking the performance of an amplifier. These undesired signals originate in the amplifier through the use of conventional coupling devices and electronic tubes.

Measuring Hum and Noise Level. The hum and noise level of an audio amplifier is always given as the number of db difference between the full power output level of the amplifier and the output level when there is no input signal. To determine this value, you must first adjust the amplifier for rated undistorted power output (by measuring the output voltage with a voltmeter connected across the load resistor) when an A.F.S.G. is feeding the amplifier with power equal to the output power of the pick-up unit. Next, turn off the A.F.S.G. without disturbing any of the amplifier gain controls, and again measure the voltage across the load resistor. Whatever voltage is now present will be due to both hum and noise. You can determine which predominates by connecting a C.R.O. across the output resistor; a pattern which is practically constant in shape indicates hum, while a continually changing and very irregular pattern is caused by noise.

The combined hum and noise level is determined by measuring the output voltage across the load resistor when there is no input signal, computing the output power in watts for this case, and then converting this wattage value into decibels by means of a suitable table. The resulting decibel value is then the noise and hum level in db.

The technician is more interested in the difference between the hum and noise level and the full power output level than in the actual value of the hum and noise level. To get this difference, simply measure the output voltage at full power, compute the power output in watts, and convert it into decibels. The difference between the decibel level for full output and the noise and hum level is then the number of db down that hum and noise are heard. For amplifiers delivering less than 10 watts, the hum and noise level should be at least 35 db down below the full output power level. The higher the output level of the amplifier, the lower must be the hum and noise level, for otherwise people near the loudspeakers would hear hum and noise when the amplifier is idling. For amplifiers above 10 watts, the hum and noise level should be down 50 to 60 db.

TEST QUESTIONS

Be sure to number your Answer Sheet with the *number* appearing on the front cover underneath the title of this text.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your Course, and you will receive the best possible lesson service.

1. Are the same general procedures followed in servicing audio amplifiers as in servicing radio receivers?
2. Why will the replacement of a bad tube not always clear up trouble in an A.F. amplifier?
3. How would you reduce noises which were inherent in the circuits and tubes used in the first stages of a high gain A.F. amplifier?
4. What method of measuring the input impedance of an A.F. amplifier is represented by the circuit in Fig. *4*?
5. Give the two distinct reasons for equalizing an A.F. amplifier.
6. When equalizing an A.F. amplifier, would you use a loudspeaker as a load?
7. State briefly the two fundamental methods of equalizing an audio amplifier.
8. Which of the equalizer circuits shown in Fig. *11* (A, B, C, D, or E) would cut down gradually the response of an A.F. amplifier at the higher frequencies?
9. Which of the instruments available to servicemen is valuable for checking amplitude distortion in A.F. amplifiers?
10. Why are inverse feed-back circuits sometimes used in the output stages of A.F. amplifiers?

1. Yes.

2. Because certain defects in A.F. circuits will cause a tube to "go bad" and will ruin a new tube inserted in its place.

3. By using a sound pick-up device which has greater output than that originally used, thus permitting a reduction in the gain of the first stages.

4. The substitution method.

5. (1), To obtain a flat electrical frequency response; (2), to obtain a flat acoustical frequency response.

6. No.

7. (1), Raising or lowering the gain of the amplifier in those range of frequencies where the db variation from the reference level is excessive; (2), noting the lowest db response in the entire frequency range and reducing the gain at all other frequencies to within 2 db of this lowest level.

8. The equalizer circuit shown in Fig. 11A.

9. The cathode ray oscillograph.

10. To reduce amplitude distortion.

HOW THE CATHODE RAY OSCILLOGRAPH IS USED IN RADIO SERVICING

49RH-1

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

FACTS OR FICTION—
THE VALUE OF AN INQUIRING MIND

A newspaper story describes a powerful radio receiver which operates without vacuum tubes; magazine articles tell how a man flew through the air by blowing into a queer-shaped box; a Sunday newspaper supplement tells of a man who lived for several weeks frozen inside a solid block of ice—all sheer nonsense, yet, there are countless persons who *believe* stories like these—who believe that everything appearing in print must be true. An alert person believes only those things which appear reasonable to him; doubtful statements raise question marks in his mind, and start a search for the truth.

Take things with a grain of salt; in other words, inquire into the truth of statements which you hear or read, and look for hidden meanings in phrases.

When the cathode ray oscillograph was first offered to radio servicemen, many claimed that it was indispensable to servicing. Others, more inquiring and cautious, studied the subject carefully and found that the possession of an oscillograph *did not* spell the difference between success and failure as a serviceman, but that it *was* invaluable for certain specialized types of servicing. This lesson text describes these important uses, and in addition tells about a lot of jobs which you can do better and faster with a cathode ray oscillograph than with ordinary instruments.

J. E. Smith.

NATIONAL RADIO INSTITUTE

WASHINGTON, D. C.

1942 Edition

A LESSON TEXT OF THE N. R. I. COURSE
WHICH TRAINS YOU TO BECOME A
RADIOTRICIAN & TELETRICIAN
(REGISTERED U. S. PATENT OFFICE) (REGISTERED U. S. PATENT OFFICE)

NCP2M242 Printed in U. S. A.

How the Cathode Ray Oscillograph Is Used in Radio Servicing

INTRODUCTION

The cathode ray oscillograph* technique of servicing radio receivers fills a definite need, and is not merely the result of a vogue. We want to make clear, however, that a cathode ray oscillograph is *not* an indispensable device in radio servicing. It can improve the quality of servicing you do, and in many cases help you to do a job in less time, but for the great majority of servicing tasks your regular test equipment will prove entirely satisfactory and by far the more economical as regards time.

There are, of course, tests you can make with a cathode ray oscillograph (C.R.O.) which are direct checks on a radio circuit defect; oftentimes you would be able to identify these defects by the patterns which show on the C.R.O. screen. For example, when the vertical plates of a C.R.O. are connected across a bias resistor in the audio system and an abnormally high amplitude wave pattern appears on the screen, we have definite proof that the by-pass condenser is open. But the effects that would lead you to make this test would also tell you what is wrong. In this case, a low audio output could indicate degeneration, and when accompanied by no low note reproduction would indicate an open bias resistor shunt condenser. Connecting a condenser across the various bias resistors would be a definite check, for good quality would be obtained when the open condenser was shunted by a good unit. Why then use a C.R.O., when the *effect to cause* analysis required before we could use a C.R.O. indicates the trouble? The answer is obvious—the C.R.O. would be useless.

Other defects like this can be located just as easily, after a reasonable amount of experience in servicing, by listening to the type of sound emitted by the loudspeaker and using our old standby, the *effect to cause* reasoning. The C.R.O. can, of course, be used as an additional check.

Frankly, the cathode ray oscillograph is a specialized instrument, finding its greatest application on the radio work-bench, just as the X-ray machine belongs in the medical laboratory rather than in the doctor's car. Like the X-ray machine, the C.R.O. helps the Radio-Trician to check defects which makes themselves apparent by confusing and oftentimes contradictory effects.

On calls to homes of customers the C.R.O. becomes a bulky, fragile and unwieldy device, unsuited for efficient work. Far more rapid servic-

---

* Strictly speaking, an *oscillograph* is an instrument which *records* permanently the wave form of a voltage or current, An instrument which only lets you *see* the wave form on a screen is an *oscilloscope*. The term oscillograph is often used when *oscilloscope* is intended, as is done throughout this lesson.

ing can be done on the job, in most cases, with simpler devices such as the portable signal generator, multimeter, socket analyzer, adapter and tube tester.

What, then, are the special advantages of this C.R.O. as a servicing instrument? This lesson will show you that for the band-passing of high fidelity radio receivers and for the adjusting of audio stages of public address amplifiers to give better quality, the C.R.O. should be used if possible. At the same time you will be shown how to do some of these jobs with ordinary servicing tools.

Undoubtedly, as service men become more familiar with the possibilities of the C.R.O., more and more uses will be found. But in the light of economical use of one's time, the different methods of doing each servicing job should be carefully considered.

CHECKING AND ALIGNING THE R.F. SYSTEM

One of the most reasonable servicing uses for the C.R.O. today lies in the aligning of a receiver for definitely desired selectivity (fidelity) and sensitivity characteristics. While the alignment and peaking procedures are best performed with an ordinary signal generator and an output indicator, the band-pass adjustment is best done with a cathode ray oscillograph and a *frequency wobbulated* (automatic frequency modulated) signal generator.

You realize, of course, that when we consider both selectivity and sensitivity we must refer to a frequency-output response curve. We can use the C.R.O. as a curve-tracing device to produce this curve on the screen if we use a special signal generator to feed into the receiver under test a constant output voltage of a freqeuncy which varies within certain desired values. The varying output of the receiver, fed into the oscillograph, appears on the screen as the resonance curve. Simple measurements of the height and width of this curve determine whether further adjustment of the receiver is necessary. The experienced service man can analyze this curve at a glance; what he sees suggests what is to be done to the receiver. We can form a mental picture of the same resonance curve, or plot the curve on graph paper, by noting the readings of an output indicator while the frequency of a signal generator is varied, provided we have the time and patience.

From what has been said in the earlier part of the Course, it should be clear that in general two types of response curves are important. They are: *1*, Sharp or peaked resonance curves, which give high sensitivity for distant reception; *2*, band-pass or flat-top resonance curves, which give high fidelity.

The question naturally arises: "When shall peak or band-pass adjustments be considered?" Unless the service manual on the receiver states definitely or implies by the aligning procedure that band-passing is necessary you must be governed by personal experience. As a rule T.R.F. receivers with four or less tunable stages, and superheterodynes with one and two I.F. transformers require *peak* adjustments to obtain acceptable sensitivity and selectivity.

Band-passing will be required most often in superheterodyne receivers. There should be no question that band-passing is intended when four I.F. transformers are used (the use of four is rare). Where three I.F. transformers are found, the advisability of band-passing rests with your good judgment. If the receiver when peaked has plenty of "pep," enough to sacrifice for good fidelity—if the receiver is capable of delivering five or more watts of undistorted power (push-pull 45 or 47 tubes or tube arrangements with higher output), and the loudspeaker is housed in a large compartment (no table or mantel models), band-passing was probably intended.

So-called high fidelity receivers must be band-passed, and those with variable fidelity must be aligned by the procedure suggested by the maker. Usually the variable coupling (between a tunable primary and secondary) or a third winding shunted by a variable resistor permits the set owner to vary from a peak to a flat-top resonance response. A control on the panel is provided in either case. *Loose* coupling or *high* resistance here gives a *peaked* response.

To be sure, many receivers not intended for high fidelity can be adjusted to have flat-top resonance. Only those stages with tuned primary and secondary or with band-pass filters can be so adjusted. This usually limits the procedure to the I.F. stages of supers. Band-passing should be considered only if you are certain the customer prefers better quality to distant reception.

With this fact in mind let us turn to the two methods of creating flat-top resonance, first by the older and more tedious method employing a portable signal generator (S.G.) and output indicator (O.I.); and finally with a C.R.O. and a frequency wobbulated signal generator. As the superheterodyne receiver is practically the only type you will be called upon to band-pass, our main discussion will be limited to it.

BAND-PASSING WITH A PORTABLE SIGNAL GENERATOR AND OUTPUT INDICATOR

It is always wise to peak the response of an R.F. system before attempting any band-pass adjustments. In most cases there will be no difficulty in adjusting the receiver to high gain, but should regeneration or oscillation appear, peak up to this point of "spill-over."

After peaking the receiver you may begin the band-pass procedure. If you vary the frequency setting of the S.G. from a value below the frequency setting of the receiver, through resonance, and above, you will probably notice that the reading on the output meter starts with a low deflection, increases to a maximum and decreases again to a low value.

Let us assume that the receiver is set to 1,000 kc., and the S.G. is varied from 995 kc. to 1,005 kc. If you were to plot the output meter readings for each kilocycle of change, as at 995, 996, 997, 998, 999, 1,000, 1,001, 1,002, 1,003, 1,004 and 1,005 kc., the resultant curve would be the response of the R.F. system. You will probably get a response curve similar to curve *A* in Fig. *I*.* In this case the audio system of the receiver can be temporarily neglected, for it is merely being used as an amplifier for the output indicator.

In order to get higher quality reproduction, assuming that the audio amplifier will reproduce high audio frequency signals, a response curve similar to curve *B* in Fig. *I* should exist.† Tunable R.F. and I.F. circuits should be adjusted, usually by varying the trimmer condensers until this type of response is obtained or at least approached.

Band-Passing A T.R.F. Receiver.—Do not attempt to introduce band-pass resonance into a T.R.F. receiver unless high frequency trimmers and serrated rotor plates are included in the gang of variable condensers. It is important that you peak the receiver first at 1400 kc. with the trimmers, then peak at other dial positions by bending the rotor plates at every dial position where a segment of a serrated (split) rotor meshes fully with the stator. With the peaking completed, return the receiver and S.G. to 1400 kc., turn half the trimmers *in* (more capacity) and half the trimmers *out* (less capacity), so that as you tune the modulated S.G. from 1,395 to 1,405 kc., a practically constant output is indicated on the O.I. It is a good plan to tune the first stage to a frequency below resonance, the second stage above resonance, the third stage below, and so forth. At dial positions where a rotor segment meshes fully with the stator, band-pass by bending the rotor segments, one in, one out, etc. Vary the S.G. frequency at each such position to check for band-pass.

Band-Passing a Superheterodyne.—Again, before you can introduce a flat-top resonance characteristic, the I.F. must be peaked and the oscillator made to track the preselector by the I.F. value. As a rule, band-passing can only be introduced in the I.F. amplifier of superheterodyne sets, for other sections will not have tuned primary and secondary transformers.

To band-pass a super, connect the modulated signal generator to the input of the first detector. (Several connections will be shown later.) Connect the output indicator in the usual manner. Assume you want 10 kc. band width in a receiver having a 260 kc. I.F. frequency. Set the S.G. to 260 kc.‡ To avoid confusion follow a definite procedure each

* The curves here show gain with respect to the maximum gain in each case. Actually the maximum gain is reduced by band-passing.

† When changing any amplifier having a curve *A* characteristic to one with a curve *B* characteristic, amplification will be reduced. The circuit must originally have considerable gain; in designing a receiver extra stages would be added to offset losses in gain caused by band-passing.

‡ Stop the action of the receiver's oscillator stage, either by removing the oscillator tube or, in the case of pentagrid converters, by shorting the grid coil of the oscillator.

time you adjust an I.F. transformer. For example, turn all primary trimmers *in* ⅛th turn, all secondary trimmers *out* ⅛th turn. Watch the output meter. Continue to turn trimmers in and out as indicated, ⅛th turn at a time, until the output drops to about ⅓ the peak value. Now swing the S.G. from 255 to 265 kc. and observe the variation in output. If the resonance curve is still too sharp, increase the output of the S.G. and repeat the band-passing procedure. If normal flat-top resonance is observed between 255 and 265 kc., the job of flat-topping the I.F. amplifier is complete. If the frequency spread is too great to give the desired selectivity, turn the trimmers back, ⅛th turn at a time, until a satisfactory compromise setting is obtained.

It is a good plan to swing the S.G. frequency from 255 kc. to 265 kc. after each complete adjustment of I.F. trimmers to determine whether critical (beginning of double peak) resonance response is obtained. If

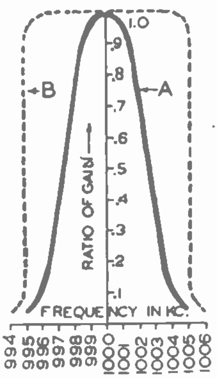


Fig. 1

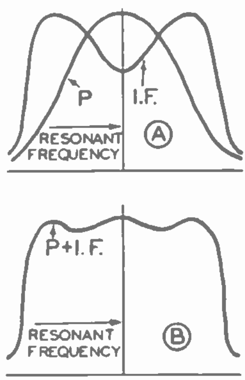


Fig. 2

two peaks are obtained, one higher than the other, tune the S.G. to the highest peak frequency and adjust either the primary or secondary trimmers to reduce its height. If the peak frequency is higher than the I.F. resonance frequency (260 kc. in this case) turn the secondary trimmers *out;* if the peak frequency is lower than the intermediate frequency turn the primary trimmers *in.*

Where the preselector R.F. transformers are of the usual tuned secondary type, no band-passing can be obtained in the preselector, so adjust for single peak resonance. Under such conditions it is wise to adjust the I.F. amplifier to get double hump resonance as shown by curve *I.F.* in Fig. *2A,* leaving the preselector in its original peaked condition, with a resonance curve like that shown by curve *P.* The I.F. and preselector curves combined will then give the triple hump curve shown in Fig. *2B,* which closely approaches the ideal band-pass curve. If the preselector response is too sharp, it may be necessary to broaden it by shunting resistors across the secondaries of the tuned transformers.

Try one watt resistors of 100,000, 75,000, 50,000 and lower ohmage, until the desired response is obtained when the S.G. is set to some frequency in the broadcast band (perhaps 1,000 kc.), the receiver is tuned to this frequency, and the S.G. is swung from 10 kc. below to 10 kc. above the first setting. In this test the S.G. is connected to the ANT and GND posts of the receiver

Bear in mind that any band-pass adjustments will reduce the gain of the R.F. stages, and thus reduce the over-all sensitivity of the receiver. In fact, you may have to increase the output of the S.G. several times before you can approach the desired flat-top characteristic; it may even be necessary to increase the sensitivity of the output indicator. When these adjustments are complete be sure to test the receiver for sensitivity by using a standard outdoor antenna. You will note the improvement in quality, especially if you have had musical training. If the sensitivity is now too low, even though quality is better, readjust to peak resonance throughout and consider the receiver unfit for high fidelity adjustments.

Special Precautions and Hints.—When the receiver has AVC and the long method of band-passing is used, it is important that the S.G. output is set sufficiently low to operate the receiver below the threshold of AVC (the point where increased S.G. output does not materially increase the output). If you find that the S.G. output cannot be reduced sufficiently, remove the AVC tube, if possible; or remove the AVC C bias voltage and substitute a fixed bias. The latter is easily done by opening the common grid return (of the controlled tubes) to the AVC bias resistor. Connect the common lead to the movable contact of a potentiometer connected across a C battery, and ground the + terminal of the battery. Tune the receiver to any broadcast band station and adjust the potentiometer for normal output.

The signal generator used for flat-topping should not be self-modulated (grid leak-condenser modulation). Use a signal generator in which an audio oscillator (extra tube) is used to modulate the R.F. oscillator. Self-modulated oscillators will not produce constant output over any reasonable change in frequency, and the carrier may be over-modulated, which is undesirable.

If you are aligning a high fidelity receiver with variable fidelity control, always peak and align the receiver with the coupling in the band-pass circuits set to the least value (coils separated or at right angles), or to maximum resistance in the circuit of the third coil. When you are ready for band-pass adjustments, set the coupling to maximum (resistor to minimum) and swing the S.G. (connected to the input of the receiver) through 20 kc. Study the response. If it is not flat-top, connect the S.G. to the first detector (if a super) and proceed to balance the two humps. Now connect the S.G. to the receiver input, and check the over-all response on the O.I. Check for peak response when the fidelity control is set for the lowest fidelity.

You will probably find it difficult to swing the average type of S.G. about 20 kc., because this band occupies only a small portion of the tuning dial. This can be overcome by shunting the variable condenser in the S.G. by a midget variable condenser, which can be externally mounted. Run the two leads from the S.G. variable condenser to two plug-in pin jacks mounted on the S.G. panel. Mount the midget condenser on a bakelite strip and connect to pins also mounted on the strip, which are spaced to slip into the jacks provided on the S.G. A 0 to 50 mmfd. midget condenser will be needed for the I.F. band; a 0 to 20 mmfd. midget will be best for the broadcast band. Mount a 180 degree dial, marked from 0 to 100, on each midget condenser shaft, and place on the condenser frame an indicator mark or wire pointing to 100 on the dial when the rotor plates are all in. It is a good plan to place each midget condenser in a shielding can, connecting the can to a third pin. This pin plugs into a panel jack which is grounded to the S.G. shield; space the three pins in such a way that the midget trimmer can be plugged into the S.G. in only one position.

It is necessary to recalibrate the signal generator when a midget condenser is attached. Set the modulated S.G. to the desired frequency (with the trimmer condenser out of the jacks) and tune an all-wave receiver (A.W.R.) to this frequency and to maximum output. Set the midget condenser to 50, and plug it into the S.G. Leaving the A.W.R. setting fixed, tune the S.G. until you hear its signal again in the receiver. Record this S.G. setting, for you must tune to that setting instead of to the original calibrated setting whenever you use the midget condenser. Twice the frequency difference between the two S.G. settings will then be approximately the band width covered by the midget condenser as it is varied from 0 to 100.

As the band width for each midget condenser will vary with the frequency setting of the S.G., it is a good plan to determine the band width for different broadcast and I.F. settings of the S.G., and plot (for each plug-in condenser) new calibration curves for each S.G. range in which that condenser will be used. These curves, which may be placed on the same graphs as the original S.G. calibration curves, should show: *1*, The frequency produced at different S.G. dial settings when the plug-in condenser is set at 50; *2*, the band width produced by the plug-in condenser at various S.G. dial settings.

BAND-PASSING WITH A WOBBULATED FREQUENCY GENERATOR AND CATHODE RAY OSCILLOGRAPH

Preliminary Concepts.—In the previous explanation covering the procedures for band-passing you noticed the necessity of shifting the frequency over a band width of more than 10 kc. while noting the output readings on the meter from an A.F. modulated signal generator. If you remove the A.F. modulation, leaving the R.F. signal unmodulated, you will get no deflection on the output meter while it is connected to the audio system. However, if a D.C. milliammeter is connected into the plate circuit of the audio demodulator (as for example the second detector of a superheterodyne receiver), variations in the strength of the signal produced by the S.G. or variations in the response of the R.F. system of the receiver produce a varying current which is indicated by the meter. In fact, you could flat-top a radio receiver with this simple output indicator.

For an alternate flat-topping method which is preferable in many circuits, especially in those using a diode detector, you can connect a D.C. voltmeter across any device in the detector circuit which has an appreciable resistance. The D.C. current in the plate circuit of the detector, and consequently the D.C. voltage across any part in the circuit, will depend on the type of detector used, on the supply voltage (fixed) and on the effect produced by feeding an unmodulated R.F. signal into the detector. Where diode detectors are used the voltage

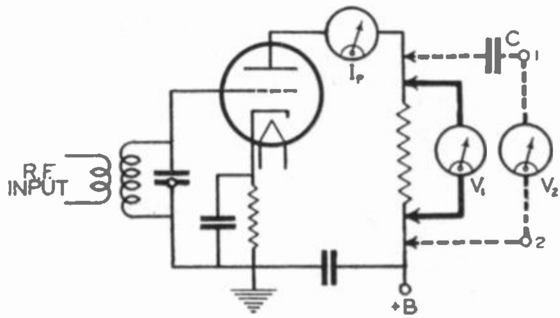


Fig. 3. If V_2 gives a reading for an unmodulated r.f. signal, connect an r.f. by-pass condenser between the plate and ground to keep r.f. out of the meter.

across the diode load resistor will vary *only* with the R.F. signal in the circuit; no initial drop will exist.

To further clarify this explanation, refer to Fig. *3*. Assume that the tube is automatically biased for detection. If no *R.F.* is fed to its input, the current meter I_p and the voltmeter V_1, both D.C. instruments, will show readings, their steady values depending on the tube used and upon the plate and C bias voltages. Meter V_2 (a rectifier type A.C. voltmeter) will not indicate, as condenser *C* blocks the current in this circuit. Now suppose an *unmodulated R.F.* signal is fed steadily to the grid circuit. Since the tube is connected as a C bias detector, a grid signal will cause the readings of I_p and V_1 to increase, a normal condition. Meter V_2 will still remain at zero. If this unmodulated R.F. signal is now *audio modulated* at a constant percentage of modulation, I_p and V_1 will not change, as they read average values. V_2, a rectifier meter, will indicate, as the audio signal passes through *C*. This is essentially what we did in the previous long procedure of flat-topping a receiver, for there the O.I. (a rectifier type A.C. meter) was really connected across the detector output, as is done here. The audio stages simply serve as an amplifier for the output indicator.

Going back to the condition where an unmodulated R.F. signal is fed to the receiver, let us wobble * the R.F. signal frequency. As we do this the plate current will vary, these variations reaching V_2 through condenser C. If V_2 is a D.C. milliammeter and the wobble is not taking place too rapidly meter V_2 will follow the change. If the change is too rapid for a D.C. meter then an A.C. meter will be required. Fortunately, the cathode ray oscillograph will follow any frequency of wobbulation.

When we connect the vertical plates of a C.R.O. to terminals *1* and *2* (Fig. *3*), the fluorescent spot will move up and down on the screen in step with the speed of wobbulation, for frequency changes send current changes through the C.R.O. input resistor in the same way that these changes caused the meter V_2 to indicate. For example, assume the S.G.

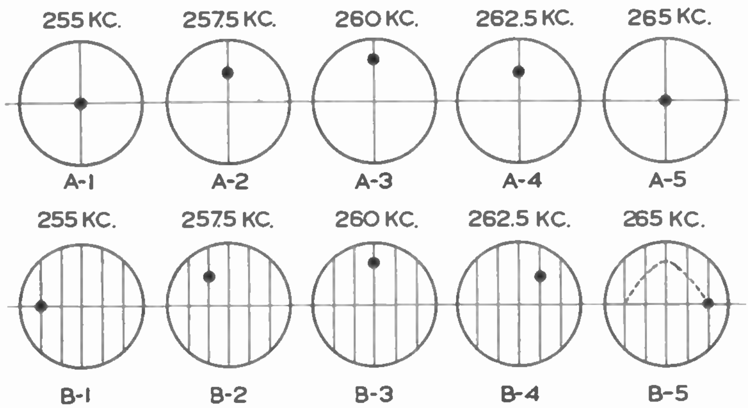


Fig. 4

is connected to a 260 kc. I.F. amplifier and the vertical plates of a C.R.O. are connected as shown to *1* and *2* in Fig. *3*. When the S.G. is set to 255 kc. and no signal gets through the I.F. amplifier, the C.R.O. spot will be at the center of the screen (Fig. *4A1*). As we sweep the S.G. from 255 to 265 kc., the spot will take the positions of Figs. *4A1* to *4A5*, in the order shown. In fact, if we were to wobbulate rapidly from 255 to 265 and from 265 to 255 kc., we would observe a vertical line instead of a moving spot.

On the other hand, if we could arrange to have the spot appear as shown in Fig. *4B1* for 255 kc., and move progressively *to the right* as it moves up and down with frequency changes, as shown by Figs. *4B1* to *4B5*, the path taken would be that shown by the dotted line in Fig. *4B5*.

* Vary the setting of the S.G. tuning condenser dial repeatedly back and forth by one or two divisions—or the wobbulator condenser from 0 to 100 and 100 to 0 alternately.

We could see on the C.R.O. screen this resonance curve for the I.F. amplifier if the wobbulation from 255 to 265 kc. was made faster than about 8 sweeps per second. All this is possible in a modern cathode ray oscillograph, in which the sweep circuit, controlled by the rate of wobbulation, feeds the horizontal plates with a sweep voltage which moves the spot across the face of the C.R.O. screen. We shall now study in greater detail how this is accomplished, and how different sweep conditions produce different curves on the screen.

The Wobbulator.—Service men who use the C.R.O. provide themselves with a special signal generator constructed to shift or "wobbulate" the frequency automatically and regularly over a given band width. The width of this band varies with different oscillators, and is usually between 15 and 30 kc. This is accomplished by connecting a special variable trimmer condenser in parallel with the main tuning condenser in the

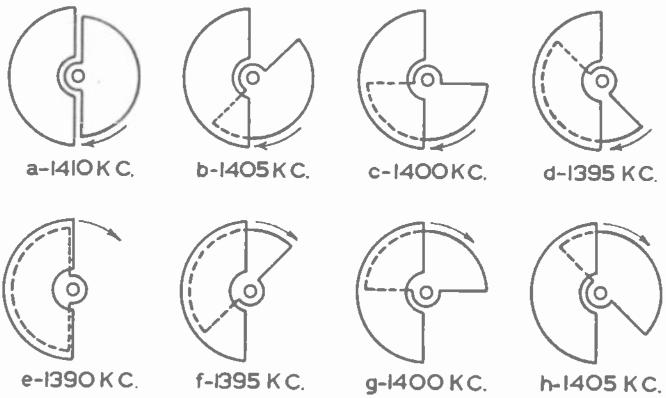


Fig. 5

signal generator, then rotating this trimmer condenser by an electric motor. The rotating trimmer with its driving motor is built into some oscillators. It is also supplied separately to permit attaching to any ordinary unmodulated signal generator. The rotor of this trimmer condenser usually is fastened directly to the shaft of the electric motor, so that as the trimmer rotates 360 degrees the rotor starts at zero capacity, reaches maximum capacity in one-half turn (180°) and then decreases to zero capacity again in the second half turn. If the oscillator used with this trimmer is adjusted so that exact resonance with the circuit under test occurs when the trimmer rotor meshes *half way* with its stator, two resonance peaks will occur for each complete rotation. This can be understood by referring to Fig. *5*, where it can be seen that when the rotor turns from *a* to *h*, the S.G. frequency is swept from 1,410 to 1,390 and then from 1,390 to 1,405, to return finally to 1,410 in position *a*. This assumes that the S.G. is originally set at 1,410 kc. Note that the positions of the rotor in *c* and *g* each will give signals of 1,400 kc. The frequency produced by the wobbulated S.G. with the rotor meshed half way (as in *c* or *g*) is called the "periodic frequency." * This periodic frequency is determined by the setting of the S.G. tuning control.

The electric motor driving the trimmer condenser rotates with constant speed, the usual value being somewhere between 900 and 2,400 r.p.m. A speed of 2,400 r.p.m. would be 40 revolutions per second, and the "periodic frequency" of 1,400 kc. (referring to the preceding example) would occur 80 times per second, because the periodic frequency occurs twice for each revolution of the wobbulatör condenser. If we now set the wobbulated signal generator to a 1,400 kc. periodic frequency, set the receiver to 1,400 kc., and connect the vertical plates of our oscillograph to the output of the receiver's second detector, the spot on the screen will rise to a maximum 80 times per second for a simple single peak resonance characteristic.

Let us first connect to the horizontal plates of the C.R.O. a linear sweep voltage which has a frequency corresponding to the r.p.s. speed

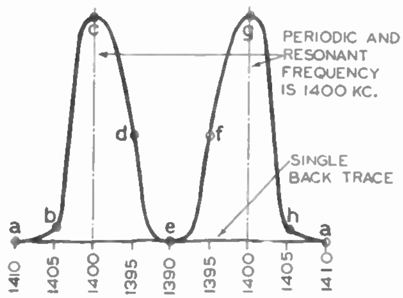


Fig. 6

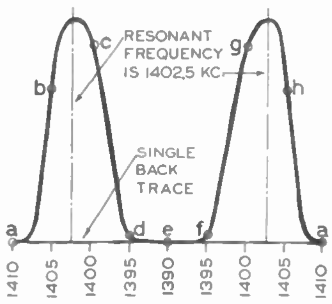


Fig. 7

of the motor, namely 40 cycles per second. (How this sweep circuit is synchronized with the aid of a synchronizing voltage delivered by the wobbulator is discussed later in this lesson.) Bear in mind that the periodic frequency will be obtained 80 times per second. Therefore, if our receiver is tuned to resonance at the periodic frequency of 1,400 kc., we can expect a double-humped (twin resonance) curve like that shown in Fig. *6*. Notice that we have purposely chosen a circuit which tunes sharper between 1,405 and 1,400 kc. than between 1,400 and 1,395 kc. This is done to bring out the fact that the left-hand hump of the double response curve is the inverse of the right-hand hump. The positions of the spot on the screen of the oscillograph which correspond to the rotor positions shown in Fig. *5* are indicated.

If we now detune the receiver so it is resonant to a frequency of

* When the wobbulator trimmer condenser, which is always of the straight line capacity type, is set at mid-capacity (to produce the periodic frequency), we have the "periodic capacity." As a rule the periodic frequency equals the mid-frequency of the band we desire to sweep across, or the peak frequency if a single hump resonance curve is desired.

1,402.5 kc., then the two humps will separate (space *d* to *e* to *f*) as shown in Fig. *7*. It is rather difficult to estimate or even notice the change unless a carefully marked scale has been prepared and fastened over the screen of the cathode ray tube. We will now show how to overcome this difficulty by using a linear sweep frequency which is twice the r.p.s. motor speed.

When we use a linear sweep frequency of 80 c.p.s., with the receiver set to 1,402.5 kc., the two humps of Fig. *7* will form an overlapping double image like that shown in Fig. *8*. The letters again indicate where the spot will be for each of the rotor positions in Fig. *5*. Notice that spots *a* and *b*, *b* and *c*, *c* and *d*, etc., are now twice as far apart horizontally, making the curve in Fig. *8* twice as wide as that in Fig. *7*. Also notice that there is only one position of the periodic frequency of 1,400 kc., *c* and *g* overlapping. The fact that the two curves do not fit exactly over one another shows that the receiver is not in resonance with the periodic frequency. If we now retune the receiver to 1,400 kc., then the tops of the patterns will overlap as in Fig. *9*. In other words, in Fig. *9* we have an advantage over Fig. *6* in being able to tell just when we are tuned

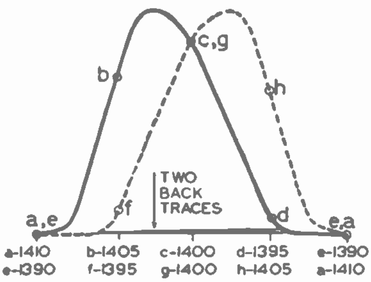


Fig. 8

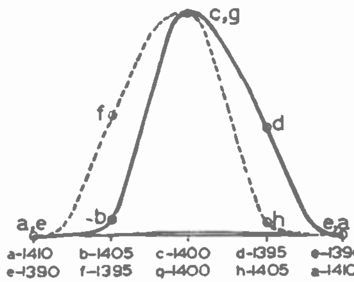


Fig. 9

to resonance with the periodic frequency, because then the tops of the curves will overlap each other.

The fact that the bottom portions of the patterns in Fig. *9* do not overlap shows us that the receiver response at 1,405 kc. is not the same as that at 1,395 kc. By adjusting the trimmers in the receiver we can make the two curves overlap entirely, to give the appearance of a single pattern. We will know then that the response above 1,400 kc. is identical with the response below 1,400 kc. This is an important adjustment in receivers, if we want equal amplification of the side-band frequencies. Further adjustment of the trimmers will allow us to spread the tops and sides of the curves in Fig. *9* until they have the appearance of the dotted band-pass curve in Fig. *1*, provided we have enough tuned stages to work on.

Need for Synchronizing Voltage.—The patterns of Figs. *6*, *7*, *8* and *9* require careful control of the frequency of the linear sweep voltage. A separate sweep frequency control is built into the average C.R.O., unless some other method is used to keep the sweep frequency in step with the sped of the wobbulator motor. If this frequency of the linear sweep voltage does not correspond to the speed of the motor, then these patterns will drift continually to one side of the screen. This drift is not serious with the double type of overlapping pattern, for even though the two curves are drifting slowly across the screen, you can tell when they overlap and can stop them at any time by readjusting the sweep frequency control. To hold the patterns stationary at all times, the manufacturers of motor driven wobbulator condensers have arranged for the generation of a separate voltage to be fed into the grid of the sweep circuit Thyratron (gaseous triode) tube. Even if the frequency control knobs are not set exactly to the correct frequency, or if the rotating condenser changes its speed slightly, this synchronizing voltage will stop movement of the pattern.

The synchronizing voltage is generated by attaching a permanent bar magnet to the shaft which rotates the wobbulating condenser. This rotating magnet induces in a pick-up coil (mounted near the shaft as in

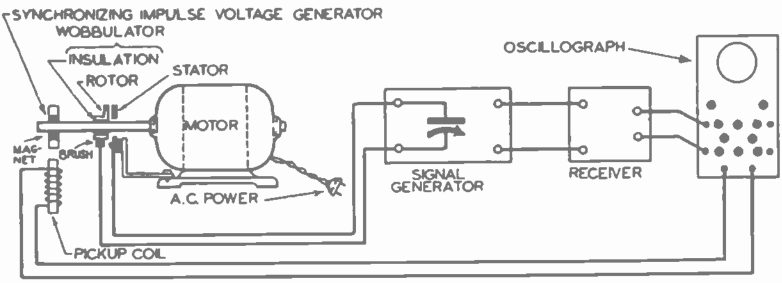


Fig. 10

Fig. *10*) an A.C. voltage having a frequency which is twice the frequency of rotation, this being the frequency required to hold the double patterns stationary.

The manufacturers' instructions covering cathode ray oscillographs will specify the location of the input terminals for such a synchronizing voltage. As a typical example we have shown in Fig. *10* how the RCA type TMV-128A wobbulator condenser with its synchronizing voltage connections is connected to the RCA type TMV-122B oscillograph.

An arrangement similar to the above, shown in Fig. *11*, is used for the National Union Type 3-5 oscillograph.* The synchronizing voltage from the pick-up coil is here amplified by a built-in one-tube amplifier (input V_1 and G) before being fed to the grid of the Thyratron tube. The output of the receiver under test is fed to the other one-tube C.R.O. amplifier (input H_1 and G), and the amplifier output is connected to the

* On a later model, type B3-5, a single selector switch on the front panel gives any desired connection between amplifiers, plates and sweeps, eliminating all back panel terminals.

vertical deflecting plates V_p by connecting A_R to V_p. The linear sweep voltage, generated with the aid of the Thyratron tube inside the C.R.O., is fed to the horizontal deflecting plates by connecting S to H_p.

In Figs. *10* and *11* the wobbulator is connected across the main tuning condenser of the signal generator. It is apparent that the addition of the wobbulator condenser will change the calibration of the signal generator; for this reason it will be necessary to recalibrate the S.G. because of the change produced by the wobbulator condenser. Earlier in this lesson you were told how this was done and what band width would exist. It is also apparent that the band width will vary for various settings of the signal generator tuning condenser.

In order to overcome the inconvenience of working with a variable band width, the Clough-Brengle Company has developed a special signal generator using two R.F. oscillators feeding into a 6A7 mixer tube. The general arrangement of the parts is shown in block form to the left of Fig. *12*. The output of a variable frequency R.F. oscillator is mixed with

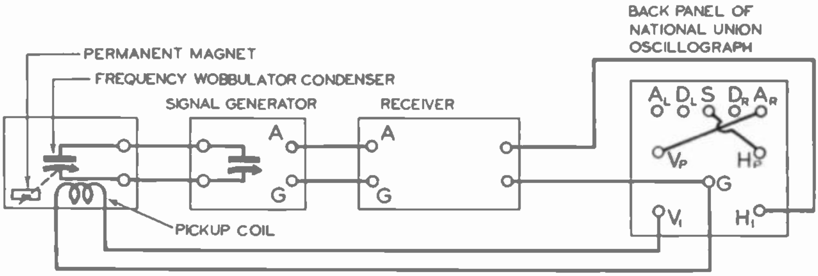


Fig. 11

the output of an oscillator having a *fixed frequency* of 670 kc., which can be varied 30 kc. by a motor-driven wobbulator condenser. When the wobbulator is used the periodic output frequency will be the sum of or difference between the frequency of each oscillator, the band width always being 30 kc. If the wobbulator condenser motor is stopped and the wobbulator condenser set to periodic capacity, the output frequency will be constant and equal to the periodic frequency when wobbulation was used.

In the RCA and National Union cathode ray oscillographs, the sweep voltage for synchronizing the horizontal deflection when wobbulating the signal frequency is produced in the C.R.O. itself, using an impulse voltage from the wobbulator to control it. In Clough-Brengle equipment, a special sweep voltage produced by an interlocked wobbulator mechanism is used, and is supplied if an external D.C. supply is used. Their signal generator has a cable ending in a 4-prong plug, which fits into a 4-hole socket in the C.R.O., automatically draws a D.C. voltage from the C.R.O., and feeds the horizontal plates of the C.R.O. with a sweep voltage.

This special sweep voltage is produced in a very simple manner. A commutator is placed on the shaft driving the wobbulator condenser. One-half of the revolving commutator is insulated, so a brush makes contact through the commutator for only one-half of each revolution. A condenser, a resistor and the commutator are connected in series, the condenser shunting the horizontal plates of the C.R.O. The C.R.O. plates are fed with a D.C. voltage through an adjustable resistor of high ohmic value. When the commutator is shorted, very little voltage is fed to the horizontal plates, the spot moves to the left of the C.R.O. screen, and there is no horizontal movement of the spot for one-half revolution of the wobbulator. When the commutator opens, the condenser starts to charge through the resistor in the supply line, this increasing (linear sweep) volt-

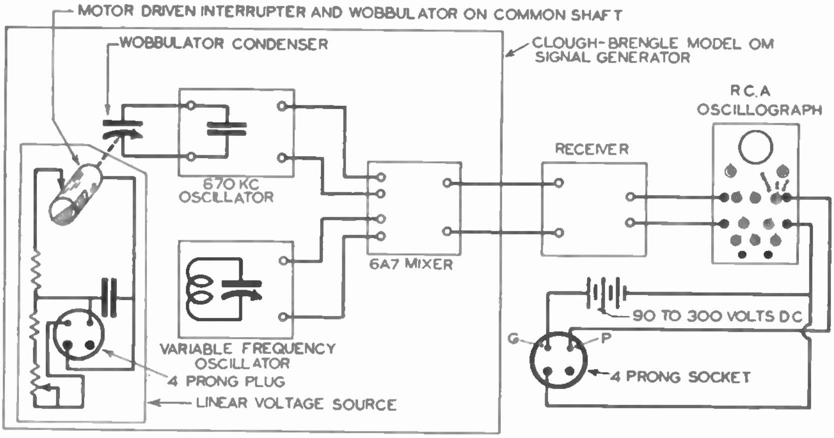


Fig. 12

age being fed to the horizontal plates to sweep the C.R.O. beam to the right, producing the resonance characteristic.

The Clough-Brengle Company claim certain advantages for their special type of linear sweep voltage, which produces a pattern (C.R.O. image) like that shown in Fig. *13*. In reality this is similar to the curve in Fig. *7*, with the sweep voltage stopped at position *a* while the vertical deflections are produced by the wobbulator condenser, compressing (or folding) the left-hand curve into a vertical line on the screen. After the first resonance hump is completed the sweep voltage comes into play, sweeping the spot across the C.R.O. screen to produce a regular resonance curve like that at the right in Fig. *7*. The advantage claimed for the curve in Fig. *13* is that the height of the left-hand "folded curve" always remains in one position, simplifying height (gain) measurements, while the right-hand curve can be gauged for band width.

It should be noted that the band width is shown in Fig. *13* as 20 kc. for purposes of comparison to Figs. *6* and *7*, while in actual practice the type OM Clough-Brengle band width is 30 kc., or 15 kc. on each side of the periodic frequency, no matter what this latter value may be.*

In the RCA or National Union oscillographs a double hump pattern is obtained by making the sweep frequency equal to the speed of rotation (in revolutions per second) of the wobbulator condenser; an overlapping double pattern is produced when the sweep frequency is twice the speed of the wobbulator condenser. For example, if the wobbulator condenser is driven at 40 r.p.s., a 40 c.p.s. sweep will produce a double hump pattern, and an 80 cycle sweep frequency will produce an overlapping double pattern. With an 1,800 r.p.m. wobbulator driving motor (30 r.p.s.) the correct sweep frequency for an overlapping double pattern would be 60 cycles. If the third type of pattern (semi-folded) is desired in addition to the other two, connect a model OM Clough-Brengle signal generator to an RCA oscillograph in the manner shown in Fig. *12*. Now, when the horizontal plate switch of the RCA oscillograph is set to the "TIMING" position either the double hump or overlapping double patterns can

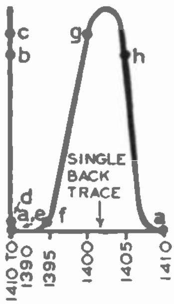


Fig. 13

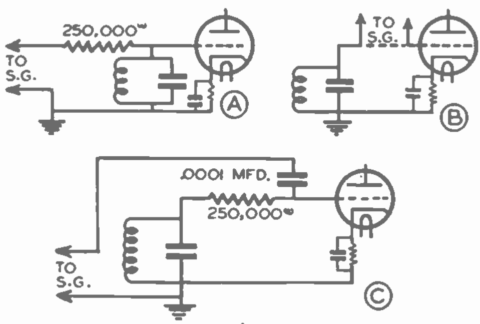


Fig. 14

be obtained by changing the sweep frequency; with this switch set either to the "OFF" or "ON" positions the folded pattern is produced.

Connecting the C.R.O. and S.G. Properly.—It is highly important that the cathode ray oscillograph and the wobbulated signal generator be properly connected to the receiver under test, if false resonance curves are to be avoided. Whatever connections are made must not disturb the characteristics of the receiver.

First consider the wobbulated frequency generator. A direct con-

* In a later model Clough-Brengle signal generator, the type OM-1, a synchronous motor, operating from a regular 60 cycle A.C. power source, drives a variable inductance (a metal disc mounted eccentrically on a shaft inside a fixed inductance), which is connected into the 670 kc. oscillator circuit. The band width created by this variable inductance is 40 kc. A 60 cycle A.C. or a 120 cycle voltage obtained from the full-wave rectifier of the S.G. is used as a sweep voltage on the C.R.O. This procedure is feasible because a sine wave is practically linear over the major part of the curve; the deviations from the linear or saw-tooth wave, occurring at positive and negative peaks, crowd together the lower parts of the resonance curve when a 60 cycle sweep is used, and with 120 cycles one side of the curve is distorted. This is not objectionable because only the central portion of the resonance curve, including the two resonance peaks, is of value in servicing. Unlike the earlier model, this S.G. has no provision for folding up one of the resonance curves.

nection to the aerial and ground terminals of the receiver will as a rule be satisfactory; it is well, however, to determine first if the manufacturer's service manual covering the receiver you are aligning gives definite instructions for signal generator connections. Generally it is considered good practice to place a 250 mmfd. mica condenser in series with the antenna posts on the receiver and the signal generator.

If the input is to be made to some other stage, such as is often done to adjust an individual R.F. transformer or the I.F. stages in a superheterodyne, the connection should be made in such a way that the electrical characteristics of the circuit are least affected. Several recommended connections are shown in Figs. *14A, B* and *C*. The first is the simplest and will generally suffice; that in Fig. *14B* is possible only if a conductive path exists through the signal generator used, in order that the grid bias will not be removed by a series condenser in the S.G.; the

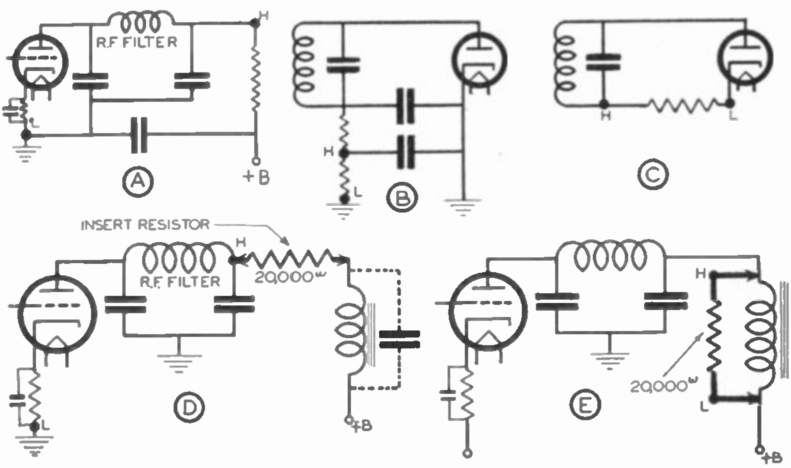


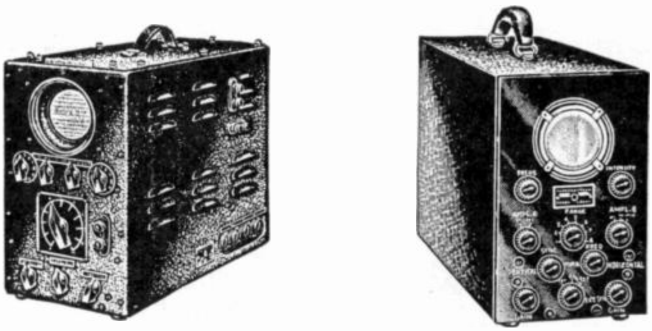
Fig. 15

method shown in Fig. *14C* is generally most effective at high frequencies. Always connect the grid to the *HIGH* R.F. terminal of the signal generator.

A little more thought should be given in making the connection to the vertical plates of the oscillograph. The low or ground terminal of the vertical plates (marked on the C.R.O. as *O* or *L*) is generally connected to the receiver chassis. Frequently, however, this terminal is connected to a point in the circuit which is not at ground potential, as in Fig. *15E*. If the low potential terminal (*L*) on the C.R.O. already is at a ground potential and the grounds of both devices are common, an undesirable current will flow, perhaps burning out some receiver part. Most service men first connect a D.C. voltmeter and then an A.C. voltmeter temporarily in series with this lead. If a deflection is obtained in either case, a 1 mfd. or larger condenser is connected in series with the lead; if there is no deflection a direct connection may be made.

The high side of the deflecting plates is generally connected to a point in the circuit whose potential will vary with respect to the chosen ground. Different methods of connecting the vertical deflecting plates of a C.R.O. to a receiver are shown in Fig. *15*, *H* representing the high potential deflecting plate terminal of the oscillograph, and *L* the low potential terminal.

Here it is necessary to point out that a form of distortion known as phase distortion will generally appear in the C.R.O. curves, unless the vertical plates are connected to a resistance load right at the detector. This phase distortion, originating in the audio stages, does not detract from the operation of the receiver as far as sound reproduction is concerned because the ear cannot detect a phase shift. The distortion does affect the C.R.O. resonance curves, often sufficiently so they cannot be



Two Typical Cathode Ray Oscillographs—Left: Clough-Brengle Model CRA; Right: RCA Model TMV-122B. Both have built-in amplifiers and linear sweeps.

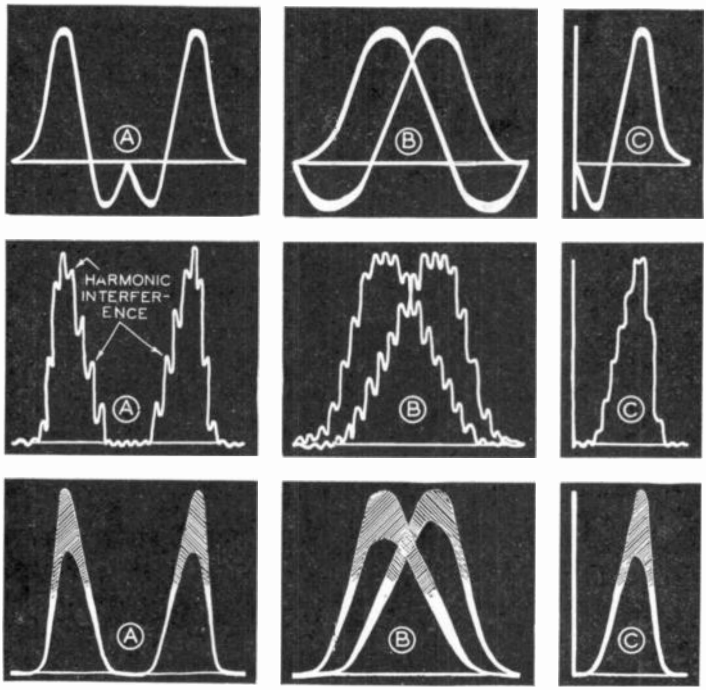
used in making adjustments. As the amount of distortion may cause an inaccurate adjustment, it is recommended that C.R.O. connections always be made to the output of the detector (second detector of a superheterodyne). Connect the C.R.O. plates across a resistance load here, or supply this load artificially if necessary, as is done in Fig. *15*, *D* and *E*.

In the case of grid control detectors which are followed by resistance coupling (Fig. *15A*) the high potential connection is the plate after the R.F. filter choke or resistance. In the case of diode detectors, the connection is made across the diode load, as shown by Figs. *15B* and *15C*. When an impedance or transformer load exists, as shown by Fig. *15D*, avoid distortion by inserting a 20,000 ohm resistor in the plate lead after the R.F. filter, connecting the high side of the vertical plates to the plate side of the resistor, and shunting the choke or primary of the transformer with a 1 or 2 mfd. condenser. Another alternate method is given in Fig. *15E*.

You will have no trouble in recognizing phase distortion if you compare Figs. *7*, *8* and *13*, which show no phase shift, with Figs. *16A*, *16B* and *16C*, which have phase distortion. The back trace here is at the center of the screen, the pattern forming both above and below this trace.

If the pattern is entirely above or below the back trace, phase distortion is absent.*

Summarizing the foregoing, it is highly important that the vertical deflecting plate be connected to a load which has no appreciable capacitive or inductive effects, for otherwise phase distortion would bring a portion of the curve below the back trace. Removing the reactive components by using artificial resistance loads eliminates this difficulty. Of course, anything you do should not alter the voltages and currents you are analyzing.



Top Row: Fig. 16 *Middle Row: Fig. 17* *Bottom Row: Fig. 18*

Figure *15E* shows how a resistor is connected temporarily across the primary of a transformer to remove the inductive effect, this being the most usual connection for a transformer load. When a phase distorted resonance curve is observed, reduce the value of the resistor to which the vertical plates are connected; this eliminates enough of the phase distortion to give a symmetrical resonance curve.

* Some C.R.O. connections may give confusing patterns. If connections to the vertical plates are reversed the spot will first move down instead of up, and the patterns will appear as Figs. *16*, *17* and *18* would be if viewed with the page upside down. If the spot is swept from *right* to *left* by the sweep voltage applied to the horizontal plates, the sweep voltage being reversed, you would see mirror images of the patterns shown here. A combination of both conditions can also exist, but these patterns, if recognized, are just as valuable in cathode ray technique.

The receiver *must* be operated below overloading, unless you are particularly interested in studying overloading effects. This means that patterns *must* be formed with a normal signal from the signal generator, yet the signal should be strong enough to "over-ride" tube noises and the interference which comes with high amplification in the receiver. Figure *17* shows how a C.R.O. reproduces mild interference from noise or a heterodyne with a broadcast signal. Remember that noise produces irregular wavy patterns, whereas the wavy patterns are more regular where heterodyne action takes place. Working with a stronger signal will generally eliminate the wavy portions in the curves. If the wavy lines become more prominent when signal strength is increased, cross-modulation is indicated. This may in turn mean that the R.F. tube bias voltages are low in stages which are not intended to cross-modulate.

Receivers which are thrown into self-oscillation or regeneration when a signal is tuned in will produce patterns like those shown in Fig. *18*.

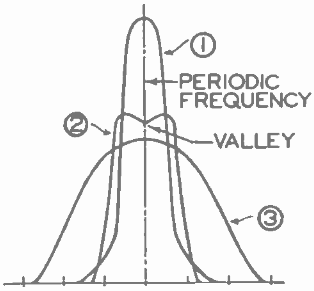


Fig. 19

Corrective measures for cross-modulation, regeneration or oscillation are considered elsewhere in the Course. Here we are merely interested in recognizing these defects by means of a C.R.O.

In order to get representative results the receiver under test should be operated at normal signal level. If the receiver has AVC and a wobbulated frequency generator is used to supply the signal, it is not necessary to remove the AVC feature, inasmuch as the average AVC could never follow the speed of frequency change. You could remove the AVC and introduce fixed C bias, but it is better to allow the AVC to show its effects. The input signal should be sufficiently great to operate the receiver above the AVC threshold point.

General Line-Up Procedure.—Once the wobbulated S.G. and C.R.O. are connected to a receiver, make those adjustments of the C.R.O. controls which are necessary to get a pattern of proper height, representative of the true conditions of the receiver. The receiver adjustments for band-passing are identical with those previously given for the output indicator method. If undesirable effects not due to poor alignment are present, service the receiver for these first. Although the aligning procedure should be perfectly obvious now, a review will show how simple it can be with the proper equipment.

Assume a receiver with three I.F. transformers and a band-pass preselector. If you are definitely planning to flat-top the R.F. system, use the cathode ray oscillograph as an output indicator. Set the apparatus exactly as you would for bandpassing; use a horizontal C.R.O. sweep and a wobbulated frequency signal. The sweep is set for double overlapping images. Peak the I.F. and align the oscillator with the preselector at a high and low preselector frequency, using the peak of the resonance curve as a guide. A curve like *1* in Fig. *19* should be observed.

Now connect the wobbulated S.G. to the first detector, turn the primary trimmer of each I.F. transformer *in*, the secondary trimmer of each transformer *out* in 1/8th turn steps until the pattern becomes broad and round at the top, then proceed slowly until the double hump appears, like curve *2* in Fig. *19*. Continue until the response curve width is of

A Typical Test Oscillator—RCA Model TMV 197-C, with 90 to 25,000 kc. R.F. frequency range and 400 cycle audio output signal.

desired value, about 10 to 15 kc. if ordinary good audio quality is desired, and 15 to 20 kc. if higher fidelity is wanted. If the valley gets too deep but the band width is satisfactory, load one or more intermediate transformers with a resistor across the secondary or primary, choosing a value that drops the humps to a satisfactory level. Another procedure involves peaking slightly one of the I.F. transformers, so as to get three humps and raise the valley. Unless the I.F. transformers have been designed to have optimum coupling the double hump may not appear, and a response like curve *3* of Fig. *19* will be obtained. Always adjust to maintain the original symmetry of the curve.

Having band-passed the I.F. section, connect the signal generator to the receiver ANT and GND posts. Set the receiver and S.G. to 1,400 kc. and to 600 kc. and check for perfect preselector and oscillator alignment. You will probably find that the pattern on the C.R.O. has now lost its flat-top or double hump appearance. By band-passing the preselector the double hump will return. Starting with a 1,400 kc. wobbulated signal, proceed exactly as with the I.F. transformers, turning one preselector tuning circuit trimmer *in* 1/8th turn or less and the other *out* an equal amount, until the double hump reappears. Again loading with a resistor may be necessary. Now turn the gang of variable condensers until the first segments of the serrated rotor plates mesh fully with the stators. Adjust the S.G. until the patterns on the C.R.O. screen overlap, then adjust the split segments for the desired band-pass characteristic. Repeat for each segment. Flat-topping the R.F. system is now complete.

If the preselector cannot be band-passed, a slightly different procedure should be used. Adjust the I.F. for a double hump with a fairly deep valley. Peak the preselector so this valley is filled in. If the triple hump is too obvious, shunt the tuning coil in the preselector transformer secondary with a resistor high enough to remove sharp humps. As the effects of each adjustment show immediately on the C.R.O. screen, you can readily experiment and make such changes as you see fit.

Remember that in any double resonant circuit, no matter what type of coupling is used, increased coupling rounds out and eventually double-humps the resonance curve. Loosening the coupling tends to peak the response. Adding a shunt resistor has the same effect as increasing the coupling; decreasing the size of the shunt resistor gives greater width to the resonance characteristic curve. Quite often it is necessary to use both methods, tuning the primary and secondary and inserting shunt resistances to get the desired effect. The use of a third winding with variable resistor control on the coupling transformer has the same effect as varying a shunt resistor.

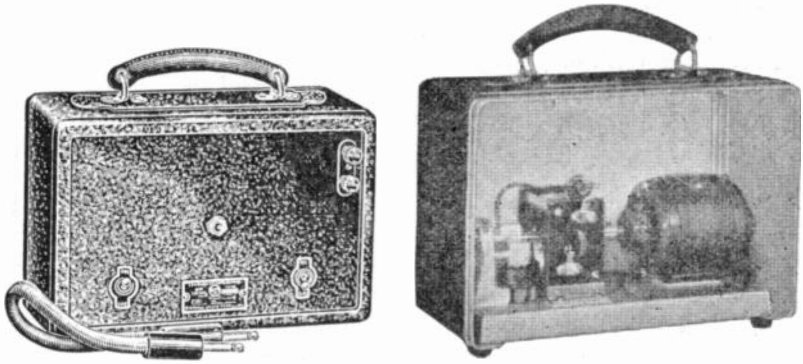
CHECKING AUDIO AMPLIFIERS

Introducing flat-top resonance into the R.F. system of a radio receiver does not necessarily mean that the sound emitted will be of high fidelity; the audio amplifier and the loudspeaker will in many cases determine the quality of the receiver output. As a rule the audio amplifier is able to handle higher audio frequencies than those fed to it by the R.F. and detector systems; flat-topping the R.F. system will then have the immediate effect of improving the response. However, it is wise to check the response of the audio system, especially where band width sufficient to handle over 5,000 c.p.s. is desired.

Conclusive fidelity tests on an audio amplifier, and this includes amplifiers used in radio receiver and public address systems, must include: *1*, A check for amplitude or wave form distortion; and *2*, a check for equal response over the desired band of frequencies.

A simple audio channel distortion *check* is made by comparing the wave form of a signal produced by an audio frequency generator before and after the signal has been sent through the audio system. The audio oscillator should preferably produce a sine wave of a single frequency somewhere between 400 and 1,000 c.p.s. The S.G. output should be controllable, a potentiometer being placed in its output circuit if there is no volume control. The audio signal generator is first connected to the vertical plates of the cathode ray oscillograph, and adjustments of the

C.R.O. and S.G.* are made to produce on the screen a single cycle stationary pattern of a reasonable size. The curve is then traced on tissue paper or any other semi-transparent paper which can be placed over the screen. Now the signal of the audio generator is fed to the input of the audio system. Reduce the gain of the cathode ray oscillograph amplifier and the output of the generator until the new pattern is the same size as the original. Compare the pattern on the tissue with that now on the screen. Double humps or single central peaks in each half cycle or alternation indicate *third harmonic* distortion; a slight dip in one-half of each half cycle indicates *second harmonic* distortion. An output wave with a gap between each alternation indicates excessive negative C bias on a class B push-push amplifier in which regular triodes are used at cut-off bias.



A Typical Frequency Modulator for oscillograph work, the RCA unit having two sweep ranges (15 and 30 mmfd.) is shown at the left. Back view (right) shows the 1,550 r.p.m. motor which drives the sweep condenser and synchronizing voltage generator.

With experience many other defects will be observed on the screen and identified; knowing these defects, corrective measures may be applied.

Although checks of A.F. distortion can readily be made with a C.R.O. and an S.G. producing only one audio frequency signal, the second check, of uniform response, requires a variable range audio oscillator. This type of oscillator is usually found only in laboratories or at those service benches where the most conclusive tests are considered essential. An audio beat frequency signal generator producing sine wave signals of various amplitudes (level control) within a frequency range of 30 to 10,000 or more c.p.s. is generally used. This A.F. signal generator is connected to the input of the audio amplifier, the receiver output is fed to a C.R.O., and the wave form is traced on the screen. Signals of equal strength but different frequencies are fed to the amplifier and the amplitude and wave form checked in each case. A chart made by plotting frequency against amplitude provides you with a frequency response characteristic which tells whether the audio amplifier will satisfactorily pass

* Under no conditions should the audio generator signal be so strong that it would overload the amplifier if it were fed into the audio stages.

the desired band of frequencies. Incidentally, many radio laboratories have built frequency wobbulated beat frequency audio signal generators, in order to show the entire response curve on the screen of the C.R.O. With this type of S.G. the effects of audio amplifier changes are seen immediately on the screen.

OVER-ALL RESPONSE

When a simple over-all distortion check (aerial to loudspeaker input) is desired, an R.F. signal modulated with an audio sine wave is fed to the input of the receiver and the output voltage at the voice coil is reproduced on the cathode ray tube screen. Deviations from a sine wave are easily detected and the defect located by making a stage by stage check of the receiver. Audio signals are fed to the audio system and audio modulated R.F. signals to the R.F. section, the R.F. frequency depending upon the stage (I.F. or preselector) under test.

By using a signal generator giving constant R.F. output and fixed percentage modulation for a number of audio frequencies, an over-all fidelity check is possible. By comparing the sine wave input patterns to the output patterns at each audio frequency, wave form distortion can be spotted; by comparing input and output amplitudes (with constant input) at each frequency, unequal frequency attenuation is checked.

IMPROVING AUDIO FIDELITY

If the audio channel is unable to reproduce the audio signals fed to it by the R.F. system, it is foolish to consider the high fidelity adjustment complete without further work on this section of the receiver. Improvements in A.F. fidelity are likely to increase hum output, A.F. regeneration and oscillation, but these defects can be removed by methods considered elsewhere in the Course.

Now we will consider a few methods of improving the audio channel, which includes: *1,* The detector (audio demodulator); *2,* the A.F. amplifier; and *3,* the loudspeaker.

Detector.—The C.R.O. should be connected to the input of the *first* A.F. amplifier tube, and a signal generator modulated with a sine wave A.F. signal should be connected to the input of the *receiver.* Analyzing the wave form of the A.F. signal at the output gives definite information on wave form distortion; checking the amplitude of the A.F. output for various A.F. values tells us what frequencies are discriminated against.

Consider first, adjustments on diode detectors. If the *wave form* is distorted try increasing the ohmic value of the diode load. If you find that low or high frequencies suffer attenuation, increase the capacity of the condenser shunting the load to reduce the highs, and vice versa. No adjustment should be made at the expense of wave form distortion. If any control exists in the diode circuit it must be so connected that its variation will not disturb materially the load or capacity value and affect the wave form.

Distortion in C bias detectors is observed in the same way. Always be sure that the plate voltage is at the recommended value. The C bias voltage may be varied (vary the ohmic value of the cathode to —B resistor) for minimum wave form distortion. Increasing the C bias shunt capacity will improve low frequency response. Quite often increasing the plate load's ohmic resistance will increase the lows; decreases will raise the highs. Be sure to check the output R.F. filter. If a single shunt capacity is used, increasing its value will tend to drop the highs and lowering its capacity will tend to raise the highs. The latter will be necessary in most cases.

Audio Amplifier.—In the case of a radio receiver, checking of the A.F. amplifier may be done with the audio modulated R.F. signal generator connected to the input of the receiver; the C.R.O. should be connected to the voice coil terminals. In a straight A.F. amplifier (as used in P.A. systems) the input must be a variable frequency A.F. signal generator.

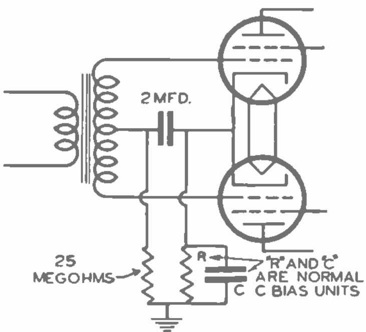


Fig. 20

Of course, the latter may be used in a receiver, connected to the input of the first A.F., if the detector is considered properly adjusted. Distortion is determined by analyzing the wave form, and frequency discrimination by comparing the output amplitude for various A.F. frequencies.

In the case of resistance or impedance coupled stages, increasing the capacity of the coupling condenser will bring up the lows. If a resistor in shunt with a condenser is placed in series with a coupling condenser (a condenser connected between a plate and a grid) the lows will be reduced and flat response will be obtained at the sacrifice of over-all gain. Resistors from .1 to 1 megohm and condensers between .0001 and .1 mfd. may be tried.

Shunting the secondary of an audio transformer with a 50,000 to 500,000 ohm resistor will raise the highs; shunting the secondary with a .001 to .01 mfd. condenser will raise the lows. If the response shows a rapidly falling characteristic at low frequencies, shunting the C bias resistors of the amplifier tubes with a 1 to 20 mfd. condenser will raise the lows; a circuit to prevent degeneration, shown in Fig. *20,* may also be used. Should the response characteristic curve show peaks or valleys, try various condenser and resistor shunts across the secondaries of transformers. If wave form distortion exists when maximum allowable signal is fed to the amplifier input, set each plate and screen or suppressor grid voltage to normal value, then vary the C bias until minimum distortion is obtained.

Loudspeaker.—It is a good plan to vary the A.F. signal frequency when the C.R.O. is connected to the voice coil. If the voice coil is floating (loudspeaker is reproducing the simple tone of modulation), a sharp increase in wave amplitude will appear when the loudspeaker is in resonance with the signal fed to it. Usually this occurs below 100 c.p.s. This causes the usual "boom-boom" so characteristic in some receivers. If this low-note distortion occurs when the loudspeaker is in the cabinet, line the inside of the loudspeaker chamber with rock wool pads, porous felt or wool pads, or even Celotex. Be sure the loudspeaker presses *gently* against the front face of the loudspeaker chamber. Incidentally this face or baffle should be backed up with a special baffle board at least one-half inch thick and of soft wood or Celotex. The felt on the loudspeaker rim should be soft. The depth of the loudspeaker chamber should not as a rule exceed *eighteen* inches. The back should be open, but if the cabinet is placed against a wall the back should have soft wool strips hanging from the top to the bottom. Strips of rugs with the fuzzy surface towards the loudspeaker may be used. If these measures do not correct cavity and loudspeaker resonance try moving the loudspeaker 1/32″ or more away from the front baffle.

Now let us consider the high frequency output. If the response of the A.F. amplifier is peaked at 4,000 to 8,000 c.p.s., no further loudspeaker correction will be necessary. If the response is flat or even starts to drop at 4,000 c.p.s., the addition of a tweeter loudspeaker is recommended. A crystal tweeter is ideal. Connect a 50,000 ohm potentiometer between the plates of the output tubes (push-pull or push-push will be the usual condition), protected by a .1 to .5 mfd. series condenser at each plate connection. With a single tube output stage, connect the potentiometer between the output tube plate and the chassis. Connect the tweeter to the movable and to one end contact of the potentiometer. Place the tweeter inside the dynamic speaker or above it on the baffle, in this case cutting a hole in the baffle. The potentiometer, mounted on the receiver panel, is adjusted for best treble * output. You can always check highs by tuning in a local station, preferably one known to transmit programs of high fidelity, and listening to the announcer and performers. When the receiver is set for normal audio output, you should be able to hear the letters *s*, *t*, *d* and *k* pronounced, hear the breathing of performers and hear studio noise and echoes, if the receiver gives good reproduction on the highs.

* High audio frequency.

QUESTIONABLE TESTS WITH A C.R.O.

Inasmuch as a cathode ray oscillograph is a voltmeter having a very high resistance, and will respond to any frequency, many technicians like to use it in checking the dynamic characteristics of radio parts. The receiver is excited with a modulated R.F. signal and the vertical plates of the C.R.O. are connected across the part to be checked. By comparing the observed wave form with that which is expected, defects in the unit are "spotted." Filter condensers in a power pack may be checked by viewing on the C.R.O. screen the ripple voltage across each unit; use power line frequency in the sweep circuit.

In testing the A.F. section of the receiver the C.R.O. and its usual built-in amplifier will suffice, for as a rule the amplifier will handle frequencies up to 90,000 c.p.s. When checking the R.F. and I.F. sections the amplifier built into the C.R.O. cannot be used, and an external radio amplifier is necessary. Many technicians use for this an all-wave receiver (150 kc. to 20,000 kc.). The part to be checked is connected to the ANT and GND posts of the receiver, with a resistor in series. The ohmic value of the resistor should be about ten times the

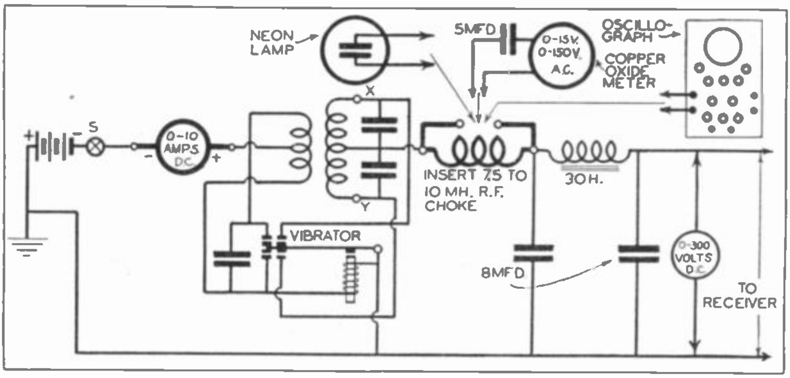


Fig. 21

impedance of the part under test. For example, when checking across a 500 ohm bias resistor † use a 5,000 ohm series resistor; when checking across the secondary of a tuned transformer whose impedance may be roughly considered 20,000 ohms, use a .25 megohm series resistor. The vertical plates of the C.R.O. are connected across the secondary of the last I.F. transformer of the A.W.R.; the trimmer condenser of this stage is adjusted to compensate for the capacity of the C.R.O.

The disadvantages of the C.R.O. for such tests are many. The C.R.O. tube is expensive and its life limited; why waste it on tests better done by other means? An effect to cause reasoning will as a rule isolate the defect; a stage by stage elimination test will isolate the defective stage, and a stage check will reveal the defective part. Dynamic tests can be made with a vacuum tube voltmeter or copper oxide rectifier voltmeter, instruments which are less expensive initially, less costly to operate and which give all the results wanted except wave form. Of course, if you are making a detailed study of certain defects or carrying out research work on the design of radio parts a cathode ray oscillograph will be invaluable.

---

† If a D.C. voltage exists, place a .1 mfd. blocking condenser in series with the extra resistor.

THE C.R.O. AS AN AID IN VIBRATOR ADJUSTMENTS

The vibrator, extensively used in auto, aircraft and farm radio receivers, often requires replacement or repairs. Although the C.R.O. is not absolutely necessary here, if you possess one it can be used with considerable success for checking vibrator repairs. As you already know, the vibrator contacts should first be filed smooth and parallel, and the gaps initially adjusted to a .003″ to .006″ clearance (about the thickness of this page).

A vibrator is best adjusted under actual operating conditions, preferably when connected to its receiver by a special extension cable, which can readily be made. A 0–10 ampere D.C. ammeter is inserted in the vibrator primary supply and a 0–300 volts D.C. voltmeter connected across the output of the filter, as shown in Fig. *21*.

The contacts are next adjusted (with the vibrator connected to its radio receiver) for minimum sparking when input current is a minimum (about 3 amperes), and D.C. output voltage is a maximum (about 180 volts or more). Manufacturers' specifications are well worth following.

Better adjustments can be made if an R.F. choke is inserted in the output, as shown in Fig. *21*. A neon lamp, an output meter, or a C.R.O. connected

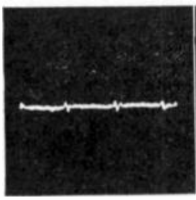


Fig. 22

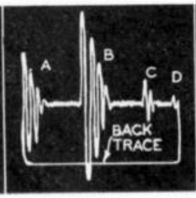


Fig. 23

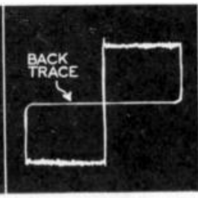


Fig. 24

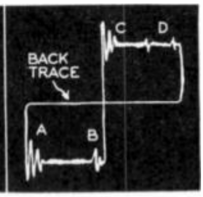


Fig. 25

across this choke will show minimum voltage when sparking at the contacts is a minimum. If the sweep is applied to the C.R.O., a pattern like Fig. *22* indicates good adjustment. The pattern shown in Fig. *23* indicates sparking and poor adjustment.

If the C.R.O. is connected across the secondary of the step-up transformer at points x and y in Fig. *21*, a pattern like that in Fig. *24* indicates good rectification; the pattern in Fig. *25* would then indicate excessive sparking. The wavy portions at A, B, C and D may not always be visible, especially if the C.R.O. screen has a slow response. Gaps in the pattern would then indicate poor adjustment. Each alternation should be alike—a flat top without gaps or variations.

TEST QUESTIONS

Be sure to number your Answer Sheet with the *number* appearing on the front cover underneath the title of this text.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your Course, and the best possible lesson service.

1. Should the cathode ray oscillograph (C.R.O.) be used in the customer's home?
2. Will band-passing an R.F. stage reduce its gain?
3. How many times does the periodic frequency occur for each revolution of the wobbulator condenser?
4. If a wobbulator condenser connected to an S.G. is rotated 40 revolutions per second, what horizontal sweep frequency should be used on the C.R.O. to produce an overlapping double pattern?
5. When connecting a C.R.O. to the plate of the second detector of a super, what feature of the pattern tells us that no phase distortion exists?
6. Is it necessary to remove the AVC action when a C.R.O. and motor driven wobbulated signal generator are used for band-passing?
7. What *two* fidelity tests on an audio amplifier must be considered?
8. What is indicated if the output wave from a *push-push* amplifier shows a gap between the alternations?
9. What will happen to the highs when an audio transformer secondary is shunted by a 50,000 to 500,000 ohm resistor?
10. What simple aural check when the receiver is tuned to a high fidelity broadcast indicates that the loudspeaker is reproducing the highs satisfactorily?

How the Cathode Ray Oscillograph is Used in Radio Servicing. No. 49 RH-1

1. No. The C.R.O. should not be used in the customer's home.

2. Yes.

3. Twice.

4. An 80 cycle sweep frequency will produce an overlapping double pattern.

5. The pattern is entirely above or entirely below the back trace.

6. No. The average AVC circuit could never follow the speed of frequency change.

7. 1, Check on amplitude or wave form distortion; 2, check for equal response over the desired band of frequencies.

8. Excessive negative C bias.

9. The resistor tends to raise the highs (high audio frequency notes).

10. You will be able to hear the letters s, t, d, k, pronounced; hear the breathing of performers; hear the studio noise and echoes.

IMPEDANCE MATCHING NETWORKS, PADS AND VOLUME CONTROLS

50RH

HOME STUDY RADIO SCHOOL
PIONEER
NRI

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

RULES FOR LIVING

The late King George V of England formulated six rules for living, each a masterpiece of wisdom in itself, which together form a challenge to every ambitious, red-blooded man.

Teach me to obey the rules of the game.

Teach me never to cry for the moon, never to cry over spilled milk.

Teach me to win if I can; if I cannot win, teach me to be a good loser.

Teach me to distinguish between sentiment and sentimentality—to esteem the first and to despise the second.

Teach me never to accept and never to offer false praise.

Finally, if I must suffer, may I be like a thoroughbred that goes away by himself in order to suffer in silence.

Friendship, politics, business, love, life itself is just as much a game as tennis or baseball—obey the rules if you would gain the respect of yourself and others. . . . They are truly happy who do not waste precious hours wishing for the impossible or worrying about disappointments of the past, but rather keep their eyes turned to the future, intent on building what can still be built. . . . A good loser blames not the umpire, the weather nor the opponent, but only himself. . . . Sentiment is a true feeling of our heart, while sentimentality is an affected expression of false sentiments; true sentiment is expressed discreetly, modestly, and often not at all. . . . Put aside that natural tendency to favor those who praise you instead of those who tell the truth about yourself, and likewise, never deceive others by false praise. . . . We all know how well misery loves company—but is it fair to make others endure your own physical or moral pain?

Such are the rules for living set up and followed by a great king; they can be your guide for living, too.

J. E. Smith.

NATIONAL RADIO INSTITUTE

WASHINGTON, D. C.

1941 Edition

A LESSON TEXT OF THE N. R. I. COURSE
WHICH TRAINS YOU TO BECOME A
RADIOTRICIAN & TELETRICIAN
(REGISTERED U. S. PATENT OFFICE) (REGISTERED U. S. PATENT OFFICE)

NCP17C1041

Printed in U. S. A.

Impedance Matching Networks, Pads and Volume Controls

FACTORS AFFECTING POWER TRANSMISSION

The subject of transmission lines is of such importance in connection with radio broadcasting and public address systems, that we are going to devote this lesson and a following lesson to a study of transmission lines themselves and the factors involved in the transmission of signal power.

A transmission line might be only a few feet in length, as in the case of a broadcasting studio which is located right next door to the transmitter. Here the transmission line merely carries the sound signals from the microphone to the transmitter.

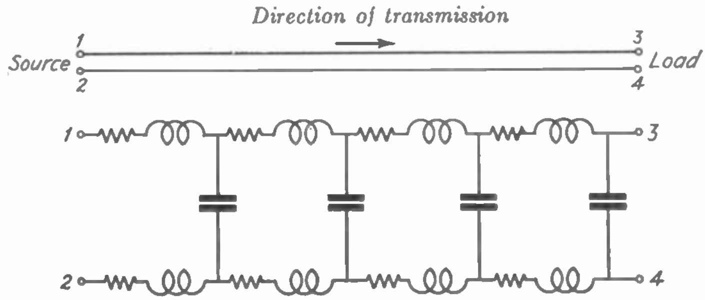


FIG. 1

In other cases the transmission line might be several miles long; for example, where a program originates at some remote point as in chain broadcasting. In public address systems, transmission lines connect the microphones to the amplifying system, and connect the amplifying system to the loudspeakers. In sound recording, transmission lines connect the microphones to the amplifying apparatus and the recording devices to the amplifier.

Now let us suppose we have a transmission line several miles long consisting of two parallel wires, run either like ordinary telephone wires in the open (open wire lines) or in a single lead covered cable. Let us consider a certain length of this line, let us say one mile. There will be a definite capacity between the two wires, a definite amount of resistance in the two lengths of wire, and there will be line inductance due to the length of the wire.

In Fig. 1 we have represented graphically 4 miles of a transmission line. Notice that the line is equivalent to a number of inductances in series with a number of resistors, shunted by a number of condensers. In case we were to measure the impedance at the source—that is, across terminals *1* and *2*—we would find that it would be possibly 500 ohms.

Now if we were to connect across terminals *3* and *4* an impedance of 2000 ohms, we would find that we would obtain much less power from the line than if we connected across *3* and *4* a load impedance of 500 ohms. This goes back to the principle we learned when we studied loudspeakers—that for maximum power output of any device or line, we must match the impedance of the load with the impedance of the source. And here we have

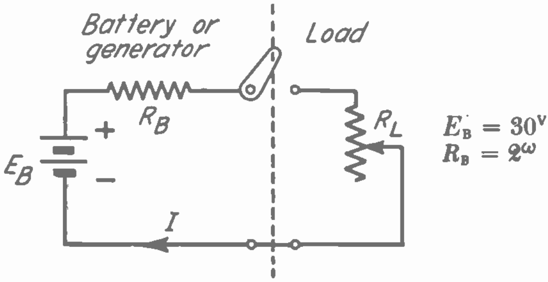


Fig. 2a

one of the most important factors in connection with transmission lines—the proper matching of impedance for maximum power output.

Thus it can be seen that, if the impedance of the load is not matched to the impedance of the source, a power loss will take place. This loss is referred to as a "reflection loss" because the effect of transferring power from a circuit of one impedance to a circuit having a different impedance is as if a part of the power were reflected back and lost. When the variation in impedance is large, the loss is great.

However, the power is not actually "reflected back." What really happens is that maximum power is not delivered by the source unless the two impedances match. Suppose an ordinary generator is the source—it will not work at maximum efficiency unless its impedance is matched by the impedance of the load.

The difference between the maximum power the source is capable of delivering and the actual power delivered to the load is called the "reflection loss."

The fundamental purpose, then, of matching impedances in an electrical circuit is to reduce this reflection loss to a minimum and thus to obtain the greatest possible transfer of power from one circuit to another. A very simple experiment can be made which will demonstrate the importance of matching impedances for maximum output power. Take a regular battery having a known voltage E_B and a known internal resistance R_B which we can consider in series with E_B. Connect it to an external load resistance R_L. Now we want to find out what value of R_L is necessary for the greatest possible transfer of power from the battery to the load.

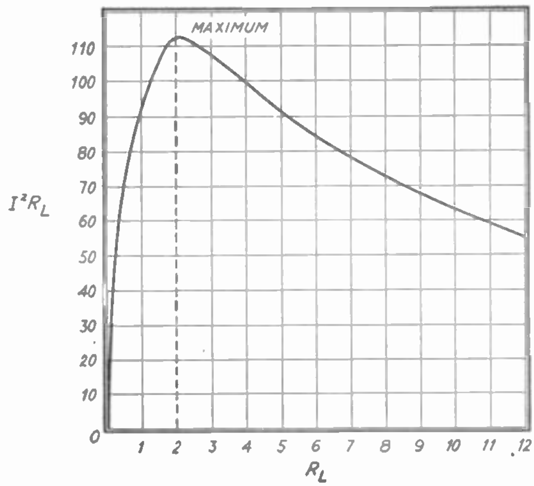


FIG. 2b. Curve for circuit shown in Fig. 2a

The set-up is shown in Fig. 2a. When the circuit is closed, current will flow. We know from the familiar formula that the power absorbed by R_L will be equal to I^2R_L. Now, if the value of R_L is increased, the current through it will decrease. But as both the current I and the resistance R_L determine the power in the load, it is evident that there must be a balance between the two somewhere, when the product of the two together, representing the power absorbed by the load, will be maximum.

Substituting for R_L a number of resistors of various values, we can plot a curve, because for each value of R_L, I^2R_L will change. Having plotted a curve, it is a simple matter to find out at what point the transfer of energy is greatest. A curve of this sort is shown in Fig. 2b. Notice that the peak of the curve is at the point where $R_L = R_B$. This is true whether the source is a battery, a generator, a vacuum tube, a phono-pickup —or any source of power.

Fig. 3a shows a vacuum tube connected to a load resistance R_L. A voltage E_g (from a preceding tube or from any voltage source) is impressed on its grid. This voltage appears in the plate circuit of the tube and is stepped up by the amplification factor (μ) of the tube. Now the tube acts as a source of power which it delivers to the load R_L. The tube resistance which corresponds to the internal resistance of the battery in Fig. 2a is the plate resistance R_P.

The equivalent circuit of Fig. 3a is shown in Fig. 3b. The stepped-up voltage μE_g in series with the resistor R_P feeds the load R_L, and we say that the load resistance "faces" or "sees" the source and its internal resistance.

From Fig. 3b we can see that this circuit is essentially the same as our battery circuit, and knowing this we can realize that maximum power will be obtained from the generator when R_L is equal to R_P.

The load resistance R_L is usually called the terminal impedance, or "sink," in audio frequency circuits. It is the place where the audio frequency power undergoes a change from one kind of energy to another kind. In a broadcast transmitter, the sink is the input to the modulator tube. In sound recording it is the galvanometer, the light valve, or the cutting head. In public address systems, the loudspeakers are the sink. The power source is usually called either the generator or just simply the source.

Now that we have seen why it is essential to match the sink to the source we are ready to consider the ways in which this can be accomplished.

IMPEDANCE MATCHING TRANSFORMERS

It seldom happens that the impedance of a source will match that of its sink without the use of some correcting device. When we were studying loudspeakers we learned that impedance matching transformers were used to correct for differences in impedance. You will remember also that in coupling a loudspeaker to the power output of a receiver we used a transformer that would give us maximum *undistorted* output and that a transformer of this type would result in some reflected loss but that this was unavoidable due to the fidelity requirements.

Fig. 4 will give you an idea of the amount of reflected loss due to a mismatch of impedances. Losses are given in decibels for convenience.

We start out with R_G (the resistance of the source) equal

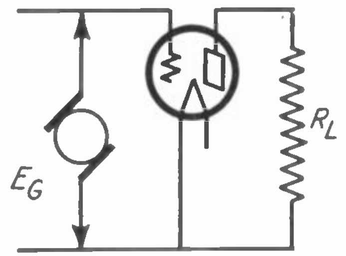


Fig. 3a

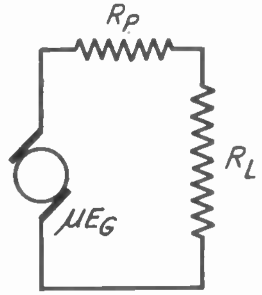


Fig. 3b

to R_L (the load impedance). Notice there is no power loss. Suppose R_L is twice the resistance of R_G. Reading up from 2 on the bottom line we find that there is a loss of ½ db. There will be the same loss if R_G is equal to $2R_L$.

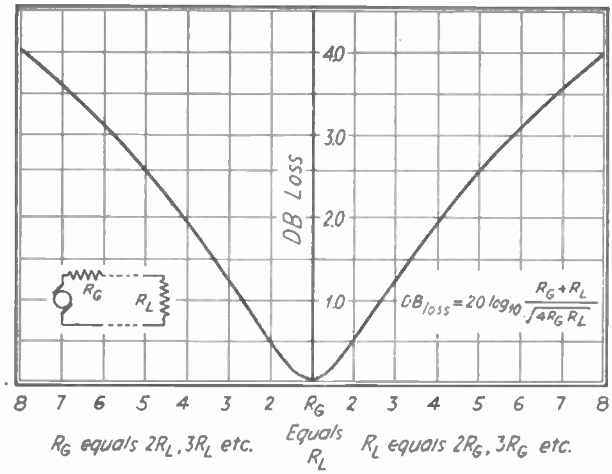


Fig. 4

Let us take a practical example. Suppose a push-pull amplifier consisting of two '50 tubes which have a total plate impedance R_G of 3600 ohms, is connected to a bank of magnetic speakers having a net impedance of 600 ohms. What is the db. loss? It is obvious that the generator impedance is six times that of the load. We read up from 6 on the horizontal scale, on the left side of the graph to a point where the curve intersects the vertical line from 6. We find that the db. loss is 3.1.

For maximum undistorted output we would use an impedance matching transformer which would bring the load impedance up to about twice the plate resistance of the tubes, that is, about 7200 ohms. Of course this would involve a loss of ½ db., but, as previously stated, this is unavoidable if we want minimum distortion.

When we match a load impedance to a source impedance for maximum power output, in effect we change the load impedance so that it appears to the generator as an impedance equal to itself. Or as we commonly say, the generator "sees" an impedance equal to itself.

Another method of matching a sink impedance to a source impedance is by the use of what is called an impedance tapering

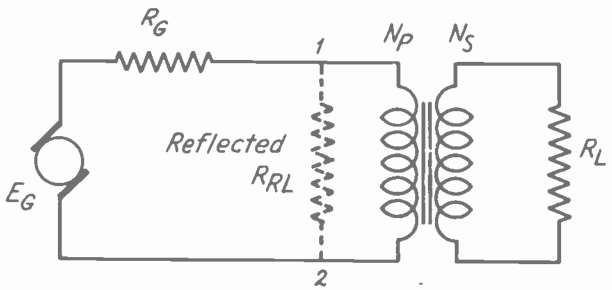


FIG. 5

network. We shall consider this method later on in this lesson. The transformer method however, is by far the most efficient way of matching impedances and is the most generally used.

In Fig. 5 is shown an impedance matching transformer connected between a generator having a definite impedance R_G and a load R_L. N_P represents the number of turns on the primary or source side of the transformer, and N_S, the turns on the secondary side. With the secondary of the transformer connected to R_L, this impedance will be reflected back into the primary. This reflected impedance can be represented by the resistance shown in dotted lines across terminals *1* and *2*. Then, as far as the generator can "see," the load will appear to it as an impedance across *1* and *2*.

The impedance of this reflected load is not R_L but $R_L \times \left(\frac{N_P}{N_S}\right)^2$. that is, the load resistance multiplied by the square of the turn ratio of the transformer. If the reflected impedance is equal to the generator impedance, no reflection losses will occur between the generator and the transformer primary, and $R_G = R_L \times \left(\frac{N_P}{N_S}\right)^2$. From this equation we get the statement:

$$\frac{N_P}{N_S} = \sqrt{\frac{R_G}{R_L}} \qquad (1)$$

This equation tells us that the ratio between the primary and the secondary turns of an impedance matching transformer shall be equal to the square root of the ratio between the primary (source) and the secondary (terminal) impedances.

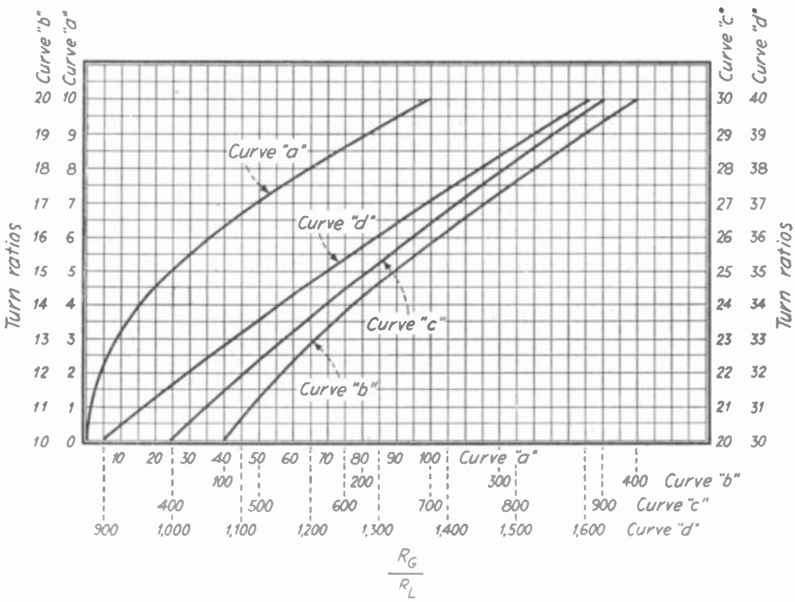


FIG. 6

With the use of this formula, knowing the impedance of the source and the impedance of the load, it is a simple matter to calculate the ratio between primary and secondary transformer turns to make the load impedance equivalent to that of the source.

The same facts can be expressed in graph form so that the proper transformer turn ratio can be obtained without going through any mathematical processes. A graph of turn ratios plotted against impedance ratios is shown in Fig. 6. Let us say as in a previous example that a 2000 ohm source is feeding into a 500 ohm load. We divide R_G by R_L ($2000 \div 500$) to find that

R_G is four times R_L. Knowing this, all we have to do is to read off the turn ratio from the curve in Fig. 6 and find that a step-down transformer having a ratio of 2 to 1 will be needed.

You might wonder what to do if the load resistance were actually larger than the source resistance. Follow the same procedure—divide the larger impedance by the smaller, determine the turn ratio as before, but then, when connecting the transformer into the circuit, connect the winding with the least number of turns to the source and the winding with the greater number of turns to the load.

If there were no loss at all in a transformer of this type, we should get all of the power in the primary transferred into the secondary and thence to the load. As a matter of fact, this is not possible because of some unavoidable eddy current and hysteresis losses in the transformer iron, and another loss due to the resistance of the copper wire windings. All of these losses go into heating up the transformer. They are so small, however, that the heating is not apparent in the relatively low-power circuits used for sound transmission. The actual efficiency of a correctly designed transformer will be between 80 and 90 per cent.

A few very common uses of the impedance matching transformers are in coupling phonograph pickups, carbon button microphones, or vacuum tubes to a line, or a tube to a loudspeaker.

The impedance of a telephone line, in ordinary practice, is very close to 500 or 600 ohms. On the other hand, the impedance of a high impedance phonograph pickup is often around 2000 ohms. If the pickup were worked directly into the line without any coupling device, there would be a resulting reflection loss of nearly 2 decibels. Also, the performance of the pickup would probably be affected by working into an impedance which is too low, causing a distortion in the tone quality of the pickup by discriminating against the low frequencies, thus emphasizing the high frequencies. Both of these troubles can be eliminated by the use of the proper impedance matching transformer. The impedance ratio in this case is: $2000 \div 500 = 4$.

We know that:

$$\frac{N_P}{N_S} = \sqrt{\frac{R_G}{R_L}} = \sqrt{\frac{2000}{500}} = \sqrt{4} = 2^*$$

* This may be verified from Fig. 6.

Therefore, our transformer must have twice as many primary as secondary turns.

From the standpoint of quality of reproduction, the importance of matching a single or double button microphone to the line is not so great as in the case of the phonograph pickup, because a microphone will show very little frequency discrimination when worked into an incorrect impedance; but, of course, the reflection loss due to the mismatch will be present. Since a transformer is always required in a carbon microphone circuit in order to provide a coupling to the amplifier and a path for the polarizing direct current, it is universally considered good practice to design this transformer to match the impedance of the microphone to the load impedance.

COMMERCIAL IMPEDANCE MATCHING TRANSFORMERS

Actual impedance matching transformers involve a number of various design factors which we will consider briefly. The primary and secondary coils

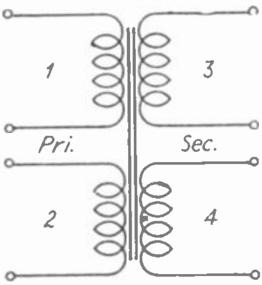


FIG. 7

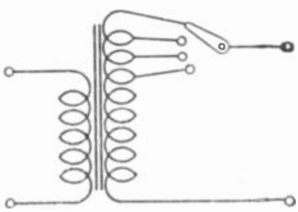


FIG. 8

are wound closely together on a closed iron core which makes the coupling between them perfect except for a very small leakage. By the proper choice of good magnetic iron for core material and a good winding structure, the transformer windings themselves can be made almost purely inductive with very little resistance. Suppose that this has been done and that the secondary of our transformer has been temporarily open circuited by removing R_L, in Fig. 5. The generator then "sees" an almost pure inductance whose value is determined by the number of turns on the primary, the permeability of the iron core, etc.

The reactance of the winding can be found from the formula, $X_L = 2\pi fL$, where X_L is the reactance in ohms, f is the frequency in cycles and L the inductance in henries. In order to fix the number of primary turns, the reactance X_L at 1000 cycles is taken as the reference value and it should be about twenty times the generator resistance, R_G.

Having found the number of turns for the primary that will give an inductive impedance twenty times that of the generator, the number of turns on the secondary is found from formula (1). The size of wire is chosen so that the primary and secondary windings occupy about an equal amount of space. While other less important factors must enter into the design of matching transformers, the above procedure is fundamental.

These transformers are often made with both the primary and the secondary windings divided into two equal sections, and eight terminals brought out, four on the primary and four on the secondary side as in Fig. 7. This is done so that the same transformer may be used for matching a number of different impedances.

Suppose that a transformer has the proper number of turns in sections 1 and 2 in Fig. 7, with the primary windings in series, to be connected with a 2000 ohm device. Each half of the winding will have an inductance equal to one-fourth of the total, for, as you know, with tight coupling and with 1 and 2 connected in series, the inductance will be four times that of one section. By connecting the two windings in parallel, the effect is the same as if the number of turns is the same as one section but the wire size doubled. This reduces the resistance, of course, but does not affect the reactance. With such a connection, the primary will be correct for connecting to a 500 ohm source.

The same reasoning applies to the secondary or load side of the circuit. Thus, a transformer as in Fig. 7 designed for operation between 2000 and 500 ohm impedances, with the halves of each of the windings in series, may be used with equal efficiency for impedance matching as follows:

Pri-Sec. Load	*Connections*
2000–500	1 series 2; 3 series 4
500–500	1 parallel 2; 3 series 4
500–125	1 parallel 2; 3 parallel 4
2000–125	1 series 2; 3 parallel 4

Although a matching transformer is made to work from 2000 to 500 ohms, it should be clearly understood that it also can be used to work from 500 to 2000 ohms. The method is obvious, in that the primary and secondary connections are interchangeable. Again, if the transformer works from 2000 to 500 ohms, the same transformer may be used to match 500 to 125 with 1 in parallel with 2, and 3 in parallel with 4.

Quite often when a source feeds a load whose impedance may vary—as for, example, a power amplifier feeding first one, then two, then three banks of loudspeakers in parallel—a tapped secondary is used for impedance matching as in Fig. 8. Naturally fewer turns are used on the secondary as the load impedance is decreased.

The selection of a transformer to work from some lower impedance—as, for example, a double button carbon microphone—into the grid of a vacuum tube is a somewhat different problem than any we have so far considered. In this case, the secondary does not feed into any definite load impedance of a comparatively low value but is left almost open, because the impedance of a tube from the grid to the filament may be anywhere from one million to twenty million ohms at audio frequencies.

In considering this type of transformer, we must first study the factors that determine the frequency response of a transformer. We are all familiar with response curves, like the one shown in Fig. 9, in which the amplification or gain of an audio frequency transformer is plotted against frequency.

Curves of this type are in very common use because, by them, one can tell at a glance how efficient a transformer is at all the frequencies at which it is designed to work. The effect of a loss of some of the frequencies (in Fig. 9 these are the very low and very high ones) is called frequency discrimination.

As we observed above, in an audio transformer, the turns of wire of the windings are wound very closely on a good closed magnetic iron or alloy core. This is done to give the windings a high inductance and to provide a close coupling between the primary and secondary sections. But besides the inductance there is, unavoidably, a very small capacity between each turn and each layer of the winding. The net result of all these little capacities is a fairly large total capacity across the whole winding. It is almost insignificant in comparison with the large inductance of the windings, but its effect shows up very decidedly at higher frequencies, and it is this so-called "distributed capacity" that determines the limit of the high frequency response of a transformer.

The total distributed capacity of either the primary or secondary winding shunted across the inductance causes each winding to have a natural frequency or resonant peak just like any ordinary tuned circuit.

At frequencies below the resonant point the coils are, of course, inductive and the signal in one coil will be transferred to the other through the iron core in

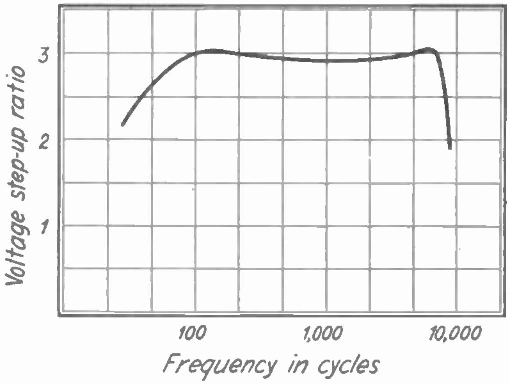


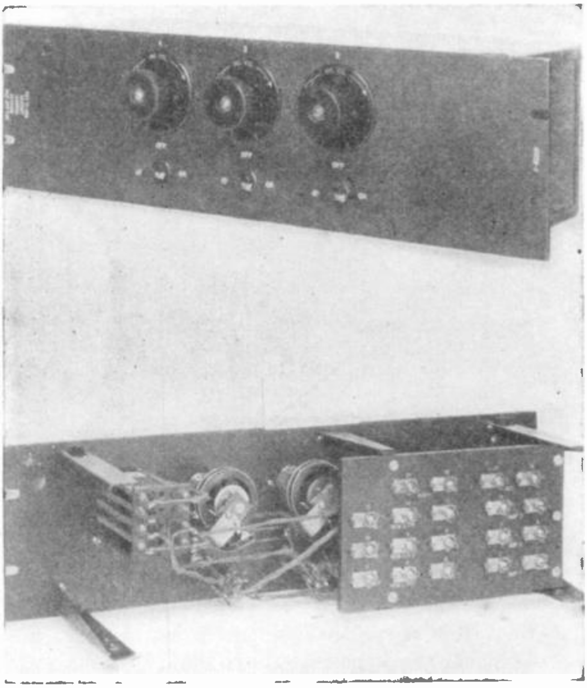
Fig. 9

the normal manner. But above the resonant point the coils begin to act as capacities, and the higher the frequency above that point the greater is the bypassing effect, with the result that these frequencies are largely lost.

Several schemes are in common use to reduce this distributed capacity in good transformers. One is to wind the coils in "pie" sections, thin washerlike sections, and to place them together side by side on the core with spacing between them. Another is to divide the secondary into two sections separated by the primary. Still another is to space the layers, one from the other, by fairly thick paper.

Both windings are proportioned so that the best voltage step-up or turns ratio is secured with the lowest possible distributed capacity. Transformers in high quality audio amplifying systems have voltage step-up ratios of 2–1 to 5–1 for a 10,000 ohm plate to a grid, 5–1 to 15–1 for a 500 ohm line to a grid, and 10–1 to 25–1 for a 200 ohm microphone to a grid. When a transformer works into the grid of a vacuum tube, it is not an impedance matching device, because it would be almost impossible to attain a match with such a high impedance but it acts merely as a voltage step-up device. Its design is not determined by the impedances that we are to match but by the frequency response requirements the coils must meet.

The same factors as those discussed above also limit the high frequency response of impedance matching transformers. In the usual types of such transformers encountered in audio systems, the impedances to be matched are of a rather small magnitude, usually not more than 20,000 ohms. Consequently their frequency response characteristics will be somewhat better than for transformers working into a grid circuit. It is not uncommon to find these transformers with a practically flat response characteristic from 30 to 10,000 cycles.



Front and Rear View of a Western Electric Mixer Control Panel of Three Positions. This Type is widely used in Talking Motion Picture Recording Studios.

We have learned what limits the highest frequencies that a transformer will respond to, and now, with the aid of Fig. 10, we will study the low frequency limitations. E_g is some A.C. voltage source, and for convenience we will assume that its frequency is variable from a very low to a high value. R_G is the generator resistance. The generator is connected to a transformer working into the grid of a tube, and we are interested in the voltage E_S across its secondary. The primary, N_P, is almost a pure inductance, and its reactance to the alternating voltage will, therefore, increase with frequency. At extremely low frequencies, its reactance is low as compared to R_G and very little of the voltage, E_g, will be developed across it. The voltage, E_S, across the secondary, being dependent upon the primary voltage, will also be attenuated at the low frequencies. As the frequency increases, the reactance of N_P will become greater and greater until it is so large that the effect of R_G can be neglected. Then all of the voltage E_g will be impressed across the high reactance of N_P and the voltage will all appear at E_S, stepped up by the turn ratio between N_P and N_S.

In voice or music transmission, the lowest frequency in which we are interested is about 40 cycles; therefore, the primaries of the transformers used should have a high enough inductance so that nearly all of the generator voltage will be across the transformer and not too much across the resistance of the generator. That is why we say that the primary reactance of the transformer at 1000 cycles should be at least twenty times the resistance of the source from which it is to work. This gives us ample leeway for the lower frequencies.

The core material used in audio transformers is usually a good grade of soft Swedish magnetic iron, or an alloy of nickel and iron called permalloy or "A" metal, that has been specially heat-treated.

When a direct current is passed through windings on a magnetic core, the permeability of the core will decrease with an increase in current beyond a certain point. That is to say, up to a certain point, as the current in the windings is increased, the magnetic flux in the core will increase by a proportional amount.

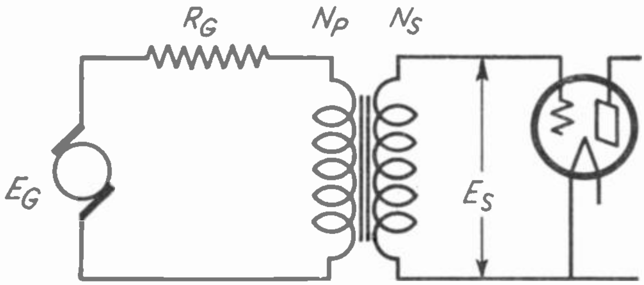


FIG. 10

But when the core is carrying all of the flux lines that it is able to—i. e., at its saturation point—increases in current cannot effect an increase in flux. This is the limit of the permeability of the core and the practical limit of the inductance of the windings.

It is for this reason that the direct current flowing in an audio transformer must be kept at a low value unless special precautions are taken.

The push-pull arrangement is used extensively to prevent core distortion. This system has been studied before, and we have seen it used with double carbon button microphones.

Sometimes when a saving in tubes is necessary, or suitable transformers are not available, another circuit is used to provide a by-pass for the direct current in the plate circuit of the tube, and at the same time to provide a means of transferring the audio frequencies from the tube to the circuit following it.

Fig. 11 shows this circuit. The inductance L is such that its impedance, with the plate current flowing through it, is very high with respect to the plate impedance of the tube. As in audio transformers, this might be ten or twenty times the plate impedance at 1000 cycles. Practically all the alternating current voltage of the tube, E_g, will then be impressed across the inductance. The condenser, C, is very large, so that even low frequency voltages will not be reduced appreciably at the output of the circuit. The inductance, in practice, has a value upwards of 15 henries and the capacity is more than two microfarads. You will recognize this as a method of coupling a power tube to a speaker but in that case the load is preceded by a matching transformer.

ATTENUATION SYSTEMS

We have discussed in some detail the transformers and coupling devices used in audio frequency circuits, and now we come

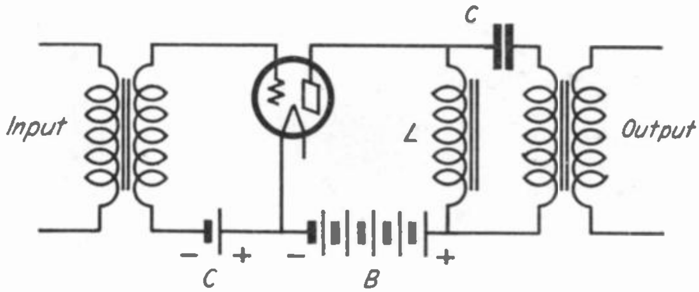


FIG. 11

to the various types of resistive networks that are commonly used. By a resistance network we mean a group of ordinary resistance units connected together in some special way in order to perform a particular service. The various types of networks are generally given the names, L, T, or H, because of their similarity, when shown in schematic circuit diagrams, to these letters. These connections are shown in Fig. 12. Each one has its own uses, and we will consider them all in detail later.

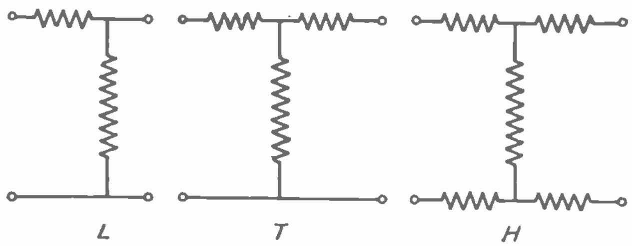


FIG. 12

Except for the so-called impedance matching network or "taper pad" which has an L type of circuit and is used for the same purpose as the impedance matching transformer, the principal use of all of these networks in voice circuits is to regulate the power level by reducing it as required.

When the network is introduced into a circuit, it is evident that some of the current will flow across the shunt branch and thus the signal will be partially short circuited before it reaches its destination; and the remaining current that flows through the series or horizontal branches will be impeded by the resistance of that part of the circuit. Thus there will be a loss of current and power in the network. This loss is called "attenuation."

Attenuation is just exactly the reverse of the amplification or gain of an amplifier. When an amplifier is inserted in some circuit, it causes an increase of the power that is being delivered to a load. An attenuation network similarly inserted will cause a decrease or loss of power in the load.

VOLUME CONTROLS

The development of circuits and apparatus for controlling the volume or power level in voice transmission circuits has been a gradual and an interesting one. In the modern broadcasting

Construction of a Balanced-H Type Volume Control made by the General Radio Company

station, in sound transcription and talking motion picture studios, the control of the power level in practically all of the audio frequency circuits is accomplished by some form of attenuation network built up of resistive branches. It is possible, of course, to regulate power level by changing the efficiency of a circuit element such as the microphone or one of the amplifiers. An effect of this sort can be realized by varying the biasing voltage of a condenser microphone, by a change in the direct current through a carbon button microphone, or by regulating the plate and grid voltages of some of the amplifying tubes. This, however, is obviously not good practice because all such elements are designed to perform most efficiently, to distort least, to operate at a lowest noise level, etc., with fixed electrical values.

Resistive networks can be designed so as to introduce no distortion of themselves and to make possible precise and almost noiseless control of the power level.

As distinguished by mechanical construction, there are two general types of volume controls in use, one in which the resistance is made continuously variable by sliding switch contacts across wire wound resistors in the manner of the familiar potentiometer, the other in which there is a number of small fixed resistors connected to suitable contacts. A switch arm connects these contacts in the proper circuit arrangement and changes the attenuation in definite steps. Fig. 13 illustrates a balanced H network of the latter type. Each construction has its own particular advantages. In general, the contact type has a lower noise level. It has a larger contact surface for the switch, and a switch

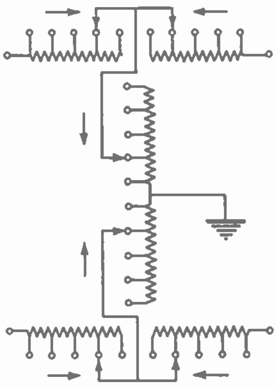


Fig. 13

properly designed will wipe the contacts clean of accumulated dust. This is of particular advantage in high fidelity sound broadcasting where every effort is made to reduce extraneous noise to the absolute minimum. The calibration of a step-by-step control can be made very accurate without difficulty, and settings can always be exactly repeated. This is important when the over-all efficiency of the system is checked frequently. It is also valuable to be able to do this so that the change in efficiency of the system may be accurately checked when any alteration is made in one of its units.

A step-by-step attenuator should have a considerable number of definite steps in order to allow for accurate adjustment of the power level. The average ear can just detect a volume change of between 2 and 3 decibels. It is reasonable then that a change per step of this value or a little less should be about correct for a control in a sound circuit.

The step-by-step type is almost universally used as what is called a master gain control. A relatively complicated H or T type network (see Fig. 12) is sometimes used in this position. It is of the greatest importance that no failure occur in this circuit, since such an accident would probably put a bank of microphones and a speech amplifier out of commission. For this reason, this control should be of the most fool-proof construction possible.

Fig. 14 shows a generator with an internal voltage E_g and an impedance R_G connected through a T-type attenuation network. The various resistive branches can be simultaneously varied by means of a properly designed switch so that the attenuation of the network may be set to any value desired. In this way, the amount of the power which is delivered from the source to

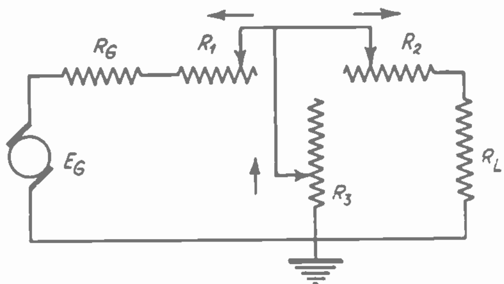


FIG. 14

the sink can be changed. At the same time, by selecting certain relative values of the series branches, R_1 and R_2, and the shunt branch, R_3, we can keep the impedance of the volume control attenuator absolutely constant at both its input and output regardless of the setting of the switch. The switches move together. The arrows show the direction of movement for a decrease of attenuation, that is, a decrease of the series resistance and an increase of the shunt resistance. On the last tap the series arms are at zero resistance, the shunt arm open, and at this setting the control has, of course, no attenuation and all the available generator power is delivered to the load.

In practice, the input and output impedances of this type of network are always made equal and if either the generator or load impedance does not match the attenuator impedance, a proper impedance matching transformer or impedance tapering network is used.

Both the T and H networks are also used as fixed attenuators. In some places, the power level may be consistently too high in which case a simple fixed network is put into the circuit to hold the power level down to the desired value. This often happens when a phonograph pickup and a carbon microphone are being worked, either one or the other, or both together, into a speech amplifier. The output from the pickup is usually at least 10 decibels above that of the microphone, so a fixed T network is placed in the pickup circuit to effect an equalization of the powers.

Other conditions may demand that one circuit be partially isolated from another so that undesirable changes in one will not too seriously affect the other. Isolation is sometimes accomplished by the insertion of fixed attenuation between the two circuits. The T or H networks are used so that the impedance conditions will not be upset.

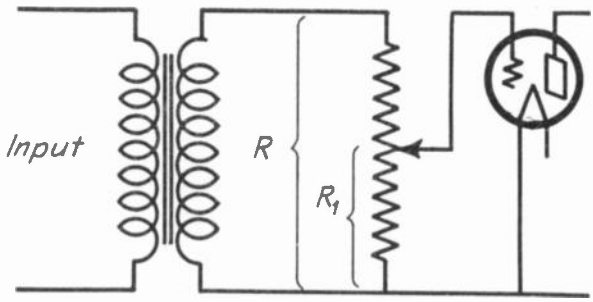


FIG. 15

There are several other types of attenuators in general use and one of the most valuable and simple of these is the common potentiometer voltage divider. In Fig. 15 a potentiometer is shown across the secondary of an input transformer with its variable switch connected to the grid. This is the normal way to operate such an attenuator.

Its operation is very simple. The entire voltage at the secondary of the transformer is impressed across the two ends of the potentiometer resistance, one end (the grid side) being at the highest potential, and the other end at the filament or lowest potential side. The voltage drop is evenly distributed across the unit and thus, if the grid lead is connected to the switch as shown, any desired potential from zero to the maximum available may be obtained.

The grid of a vacuum tube used as an amplifier draws no current, and consequently the position of the switch makes no difference to the voltage distribution in the resistance. For this reason, the percentage of the total voltage which is on the grid is proportional only to the position of the switch.

The ratio of the total voltage across the potentiometer and the voltage on the grid is, of course, R_1/R (see Fig. 15). Thus the voltage attenuation of a potentiometer expressed in decibels is,

$$DB = 20 \log R/R_1$$

If we wish to find values of R_1 for various attenuations, knowing our total resistance, the formula is:

$$R_1 = \frac{R\ *}{\log^{-1} \frac{DB}{20}} \qquad (2)$$

Taking a practical example, let us assume that we wish to

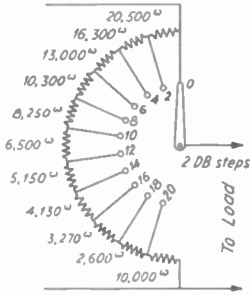


FIG. 16

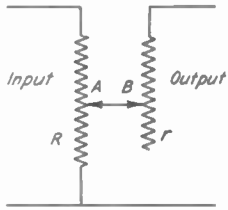


FIG. 17

find a point where the voltage on the grid is six decibels less than the total voltage, when the total potentiometer resistance is to be 100,000 ohms, then:

$$R_1 = \frac{100{,}000}{\log^{-1} \frac{6}{20}} = \frac{100{,}000}{2} = 50{,}000 \text{ ohms.}$$

We would thus locate our point at just half way on the potentiometer or at 50,000 ohms.

Fig. 16 shows a typical potentiometer with taps arranged for 2 db. variations.

If a potentiometer is working into a circuit which is not

* $\text{Log}^{-1} N$ is only a short way of saying "a number whose logarithm is N"; in this case N is DB divided by 20. Suppose N was .5. What number would have a log equal to .5? From an ordinary log table, you would find the number is 3.16. In other words $\log^{-1} .5$ is 3.16.

open, that is, one having a definite impedance, the current drawn would affect the voltage distribution in the potentiometer and the simple equations would no longer hold. However, in practice, if we keep the impedance of the output circuit high with respect to the potentiometer, say five or ten times its total resistance value, the error is so slight that it can be neglected. We must remember, however, that the impedance of the potentiometer, looking back into it from its output, varies from zero to the value of the shunt circuit consisting of the potentiometer and the transformer secondary to which it is connected.

This means that it would not be good practice to work a transformer, for example, from a potentiometer input because the change in the impedance that the primary of the transformer works from would cause serious changes in frequency discrimination. That is the reason that a constant impedance circuit such as a T or H network should be used for a volume control preceding a transformer if the best quality of reproduction is required.

There is a sort of compromise circuit which is widely used in volume control work where approximately constant impedance is required, but where it is not necessary to have the precision of a T network. This circuit is shown in Fig. 17. In this circuit, one slider, *A*, moves along a shunt resistance across the input in the manner of a potentiometer. At the same time a series resistance is introduced into the circuit by a second slider, *B*, which helps to compensate for the decreasing impedance as seen from the output side as the switches move downward toward zero output. The series resistance also puts some additional attenuation into the circuit. This circuit, or a variation of it, has been in use as a volume control for a long time and has proved to be reasonably satisfactory.

It has a special application in what are called "mixer" circuits. In nearly all broadcasting, public address, or talking motion picture installations, there are many times when one microphone is not sufficient. Suppose a dialogue is being carried on between two actors and a background of music is to be maintained. When the actors pause in the speaking, the music should be brought in somewhat louder, and when they resume talking, the music must again be reduced to the background. This would mean that two microphones, at least, would be needed—one for the speakers, the other for the music. Their volume of output must be variable and independent of each other. In order to accomplish this, two volume controls are used, one in each microphone circuit. Their combined outputs work into a common speech amplifier.

In practice, the conventional set-up often has four of these microphone volume controls. The whole unit, because it combines (mixes) the outputs from several sound sources, is called a "mixer."

Suppose it is desired to control the power output of three studio microphones and an incoming telephone line so that any one of the group may be operated independently of the other, and so that two or more may be worked simultaneously into the high gain speech amplifier. This calls for a mixer control panel on which are mounted four resistive attenuation networks of

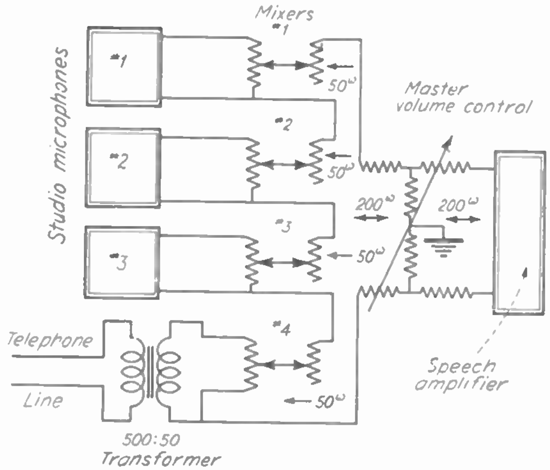


FIG. 18

suitable design. The circuit is shown in Fig. 18. These mixers must have two important electrical characteristics. One is that they have a constant impedance as seen from the output, and the other that they introduce no extraneous noise into the circuit.

It is obvious that if the output impedance of any one of the mixers did change very much with its setting, the combined output levels of all the controls would be affected.

In Fig. 18 the impedance of the controls is shown as 50 ohms, the four connected in *series* giving a total impedance of 200 ohms. It is nearly always necessary to have, in the circuit following the mixers, a master gain control, and this is followed by a master transformer integral with the speech amplifier to raise the voltage to a high value before it is impressed across the grid-cathode. This master control is to regulate the levels of all of the sound sources together. The customary network for the work is of the H type illustrated.

The H type is chosen because, with it, it is possible to obtain the balance to ground of the mixer circuit and the speech amplifier, which tends to eliminate to a great extent pick-up and cross-talk noises in the leads from the mixer circuit. It also has a constant output impedance which is important because the speech amplifier is designed to work from some fixed predetermined impedance. A change from this impedance is apt to cause frequency discrimination in the input transformer.

In another system that is in wide use, a high impedance

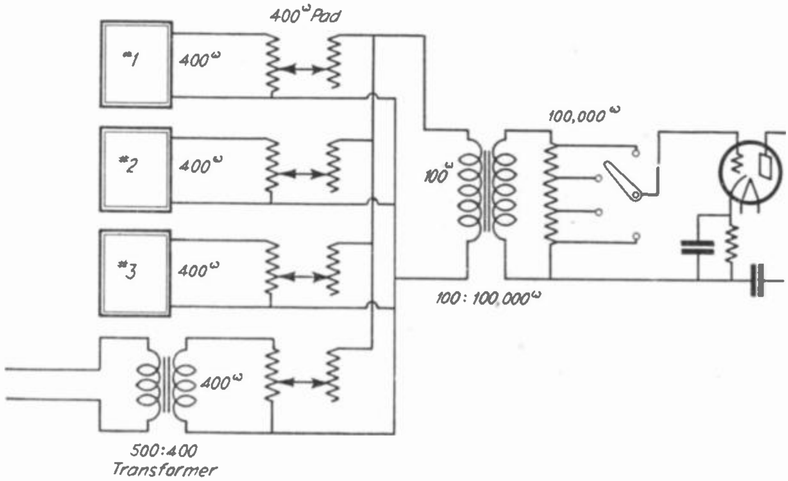
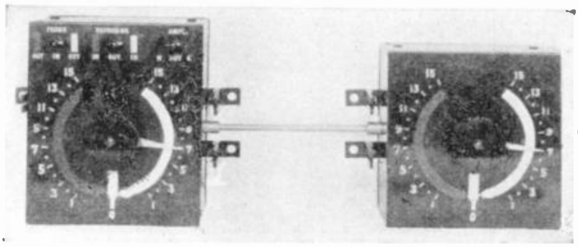


Fig. 19

potentiometer is connected across the secondary of the input transformer to the speech amplifier. The transformer will act as an impedance matching device going from 200ω to the resistance value of the potentiometer. As we know, this potentiometer may be calibrated in decibels and so can be made quite as satisfactory a master volume control as the H network at the input. It is, of course, possible to ground the center of the primary winding of the transformer and thus to maintain the balance to ground of the mixer circuit, provided a shielded input transformer is used so that the amplifier circuit itself does not affect the balance of the primary or mixer side.

Before we close the subject of mixers, let us look at another possible connection. Suppose the microphones have a resistance of 400 ohms each. Connecting the four in series would call for an H pad of 1600 ohms. High resistance circuits are not advisable because of extraneous noise pickup. In this case it would be advisable to connect the variable pads in parallel and make them feed into the master H pad for over-all level control. If each pad has a resistance of 400 ohms and they are all in parallel, the net terminal impedance will be 100 ohms. The main H pad would then be designed to have a constant terminal resistance of 100 ohms. This pad connects on one side to the parallel pads and to the load on the other side through an impedance matching transformer.

The connections for the four pads are shown in Fig. 19, but in this case they feed to the grid-cathode of an amplifier. The master control in this case is the $100,000\,\omega$ potentiometer and the matching transformer reflects the 100,000 ohms down



A Western Electric Fader with Dummy Control such as is used in Motion Picture Projection Booths.

to a value of 100 ohms to face the total pad impedance of 100 ohms.

This is referred to as *parallel* mixing as contrasted with *series* mixing illustrated in Fig. 18.

FADERS

We now come to the consideration of a resistive network used extensively in motion picture projection booths for transferring the sound from one projection machine to the other. The use of faders is not limited to this field, however, as they are used wherever one device is to replace another gradually and imperceptibly. For example, they are used extensively in broadcast studios to shift from one program to another, or from studio to announcer.

There are always at least two projection machines in the booth of a movie theatre. When one reel of a picture is about exhausted, arrangements are made so that the other machine can be quickly started and the new reel commenced just before the old reel ends. Thus, there is no discontinuity in the program that the spectator sees, and he is unconscious of any interruption. It is now necessary, since all motion pictures are with sound accompaniment of some kind, that the amplifiers and loudspeakers be switched simultaneously with the projectors so that there may also be no interruption in the sound. This can be accomplished in two ways. All Western Electric and many other types of installation use what is called the "fader." It is a two-sided or bilateral network constructed as shown in Fig. 20.

On inspection it will be seen that this network is somewhat similar to the one shown in Fig. 17 except that the series arm, r, is kept at a constant value instead of being variable. As the slider moves down in the direction of resistor R_2, the volume is

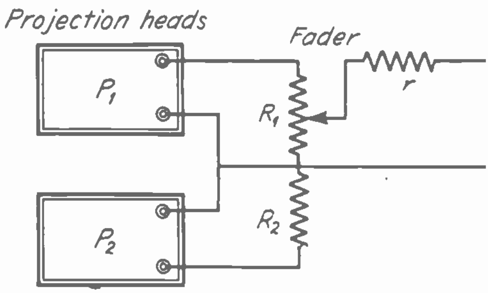


FIG. 20

decreased from the projection head P_1 (which contains a photocell pickup and its associated amplifier) and after crossing through zero begins to increase the volume from the machine P_2. In this way, the sound from one machine is gradually decreased to zero, and then the other sound track gradually brought up from zero to its maximum. The transfer of sound is thus smoothly accomplished without interruption. It will be noticed that the fader may also be used as a volume control, so that the level of the sound from either machine may be adjusted to suit any size of audience or any house. These faders are usually calibrated in ten or fifteen steps of three decibels per step. Although Fig. 20 shows a continuous variation, the actual theatre fader has definite steps of resistance arranged between taps.

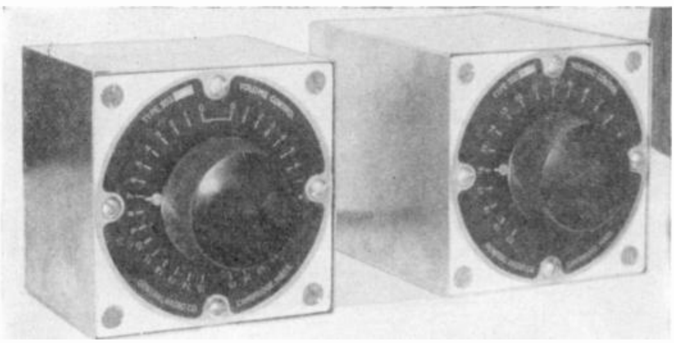
The impedance of the output of the machines P_1 and P_2 is usually made equal to the input impedance of the main amplifier. This impedance which we will call R, is usually of the order of 200 ohms.

In practice, it has been found that the best values for R_1, R_2 and r are approximately as follows:

$$R_1 = R_2 = 1.5R; \text{ and } r = 0.7R \qquad (3)$$

The impedance of the fader is not exactly matched, at all settings, to the impedance of the projection heads or of the main amplifier, but it has been found to be near enough for general use.

These faders are usually supplied with a dummy control which looks just like the regular fader and which has its adjusting handle or wheel tightly coupled mechanically to the



Left—A small Fader employing the Circuit shown in Fig. 20. *Right*—A T-Type Volume Control employing a circuit shown in Fig. 14.

main fader. The dummy and fader are placed so that one or the other can be easily reached from either projection machine, thus giving the operator complete control of the sound from both positions.

In the R.C.A. Photophone system the sound is transferred by means of a relay. It is arranged so that the sound track is transferred by the operation of a key. These relays also short circuit the speakers during the cross-over so that no objectionable click is heard by the audience. Both the fader and relay changeover systems usually are equipped with additional contacts which control the exciter lamps and other auxiliary apparatus in the projection heads. This is so that they will be turned off when their machine is not in operation.

IMPEDANCE MATCHING NETWORKS

The most efficient way in which to couple two circuits of different impedances together is, of course, the impedance matching transformer which we discussed at the beginning of this book. But sometimes this is inconvenient. Aside from the power loss that results from the mismatching of impedances, there are many other cases when correct operating conditions are obtained only when proper terminal impedances are used. For example, if a calibrated attenuation network is not properly terminated, its calibration is worthless, unless a correction term is applied. Loudspeakers, audio frequency amplifying transformers and such instruments are nearly all designed to give correct operating characteristics when working from a circuit of some definite impedance. For all of these uses, the right impedance matching transformer may not always be available, and to build one up may be a lengthy and tedious job. A most convenient substitute is available in the form of a simple resistive network called an impedance tapering network or "taper pad."

A taper pad has several definite advantages to offset its inefficiency. It has a fixed and known loss and it is not affected by frequency to the extent that a transformer may be.

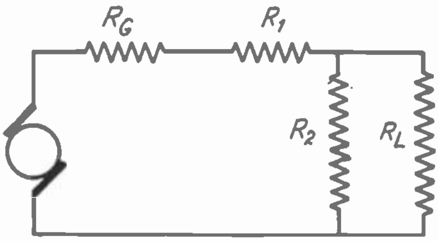


FIG. 21

Fig. 21 shows one of these taper pads connected across a generator whose impedance is of some definite value, R_G, and a load, R_L. In order to calculate the value of the series branch, R_1, and the shunt branch, R_2, so that both the generator and the load see their respective impedances R_G and R_L, looking toward the junction, the following formulas are used.

$$R_2 = \frac{R_L R_G}{\sqrt{R_G(R_G - R_L)}} \tag{4}$$

and

$$R_1 = \sqrt{R_G(R_G - R_L)} \tag{5}$$

Here are two general equations which permit the calculation of an impedance tapering network to match any two impedances.*

Such a network always introduces considerable loss in the circuit.

---

*When R_G is smaller in ohmic value than R_L, resistor R_1 should be connected in series with load R_L. These formulas (4, 5 and the loss formula) apply if R_L is substituted for R_G and R_G is substituted for R_L.

The fact that this loss can be definitely calculated is often a great help when calculating the total gain or loss of a circuit. The loss using a resistive impedance network shown in Fig. 21 is found from the formula: db. loss = 20 $\log_{10} n$, where n equals $\sqrt{R_G/R_L} + \sqrt{R_G/R_L - 1}$.

APPENDIX

Standard Reference Levels.

6 mw. feeding 600^{ω} load—sound pictures.
10 mw. feeding 500^{ω} load—radio broadcasting.
12.5 mw. feeding 500^{ω} load—N. B. C. System.
2.4 mw. feeding 600^{ω} load—telephone.

Formulas for db. gain and loss when powers are known.

(1) $$\text{db. gain} = 10 \log_{10} \frac{\text{output power}}{\text{input power}}$$

(2) $$\text{db. loss} = 10 \log_{10} \frac{\text{input power}}{\text{output power}}$$

Formula for db. gain when voltages are known and source and load impedances are equal.

(3) $$\text{db. gain} = 20 \log_{10} \frac{E_L}{E_S}$$

where E_L is the load voltage, E_S is the source voltage, and the impedances of L and S are equal.

Formula for db. gain when voltages are known but impedances differ.

(4) $$\text{db. gain} = 10 \log_{10} \frac{E_L^2 R_S}{E_S^2 R_L}$$

where R_L and R_S, the impedances of the source and load, are different.

Formula developed from formula 4.

(4a) $$\text{db. gain} = 20 \log_{10} \frac{E_L}{E_S} + 10 \log_{10} \frac{R_S}{R_L}$$

where the expression $10 \log \frac{R_S}{R_L}$ is the correction factor.

Formula for db. gain when currents are known and impedances are equal.

(5) $$\text{db. gain} = 20 \log_{10} \frac{I_L}{I_S}$$

Formula for db. gain using current values, when impedances differ.

(6) $$\text{db. gain} = 10 \log_{10} \frac{I_L^2 R_L}{I_S^2 R_S}$$

Formula developed from (6) showing impedance correction factor isolated.

(6a) $$\text{db. gain} = 20 \log_{10} \frac{I_L}{I_S} + 10 \log_{10} \frac{R_L}{R_S}.$$

In calculating the resistance values to be used in a fixed T pad as shown in Fig. 14 you would use the formulas:

(7) R_1 and $R_2 = R_0\left(\frac{K-1}{K+1}\right)$ where R_0 and $R_S = R_L$, $K = \log^{-1}\frac{N}{20}$
where N is the db. attenuation desired.

(8) $R_3 = 2R_0\left(\frac{K}{K^2-1}\right)$

For example: To design a pad to have a 20 db. loss, this pad to be placed between a source and sink of equal impedances of 200^{ω} each:

$$K = \log^{-1}\frac{20}{20} = \log^{-1} 1 = 10$$

$$R_1 \text{ and } R_2 = 200 \times \frac{10-1}{10+1} = 200 \times \frac{9}{11} = 163.6^{\omega}$$

$$R_3 = 2 \times 200 \times \frac{10}{10^2-1} = 400 \times \frac{10}{99} = 40.4^{\omega}$$

A variable T pad can be constructed by calculating values of R_1, R_2 and R_3 for equal db. steps and using three resistors having taps controlled by three switch arms operated simultaneously.

An H pad can be designed by computing for a T pad as shown and placing half the resistance in the upper section and the other half in the lower section. An H variable pad is wired so that all six arms move simultaneously, and the center of the shunt arm (R_S) is grounded.

TEST QUESTIONS

Be sure to number your Answer Sheet with *the number* appearing on the front cover underneath the title of this text.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your Course, and the best possible lesson service.

1. What is meant by reflection loss?
2. If a '10 type tube having a plate resistance of 5000^{ω} is connected to a load having a resistance of 1000^{ω}, what will be the reflection loss in decibels?
3. How would you connect up the transformer shown in Fig. 7 if you wanted to match a 125^{ω} load to a 2000^{ω} source, assuming that the transformer was originally designed to couple 2000^{ω} to 500^{ω}?
4. If a 500^{ω} generator were connected to a 500^{ω} load, what would be the reflection loss?
5. What two devices are used for impedance matching?
6. What three types of resistance networks are there?
7. Show by a schematic diagram how three 50^{ω} microphones and a 500^{ω} transmission line would be connected through a mixer and master volume control to an amplifier.
8. What type of volume control would you use if you wanted to keep noise at a minimum?
9. Why is a fixed T network used with a phono-pickup and not with a carbon microphone when both feed into the same amplifier?
10. Why is it that faders are designed to vary the signal intensity in steps of two or three decibels?

Impedance Matching Networks, Pads and Volume Controls. No. 50RH

1. The difference between the maximum power a source is capable of delivering and the actual power delivered to a load, is the reflection loss.

2. From Fig. 4, the loss will be approximately 2.6 db.

3. Connect 1 in series with 2, and 3 in parallel with 4.

4. There would be no reflection loss and the generator would deliver maximum power to the load.

5. The impedance matching transformer and the impedance matching resistance network.

6. The L, T, and H types.

7. See Fig. 18.

8. You would use the contact type rather than the ordinary potentiometer type control.

9. To reduce the output of the phono-pickup to the level of the microphone output.

10. Because a two or three db. change in sound level is just barely perceptible, and if the sound level is varied in steps of two or three db., the individual steps will not be heard, and increases and decreases will be smooth and gradual.

TRANSMISSION LINES AND FILTERS

51RH-1

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

SEVEN DEFINITIONS OF HAPPINESS

Happiness is a habit—cultivate it!

Elbert Hubbard

Happiness—a good bank account, a good cook, and a good digestion.

Jean-Jacques Rosseau

It's pretty hard to tell what does bring happiness. Poverty and wealth have both failed.

K. E. Hubbard

A man's happiness is to do a man's true work.

Marcus Aurelius

The best way to secure future happiness is to be as happy as is rightfully possible today.

Charles W. Eliot

He is not happy who does not think himself so.

Publius Syrus

Happiness is a by-product of an effort to make someone else happy.

Gretta Palmer

NATIONAL RADIO INSTITUTE

WASHINGTON, D. C.

1942 Edition

A LESSON TEXT OF THE N. R. I. COURSE
WHICH TRAINS YOU TO BECOME A
RADIOTRICIAN & TELETRICIAN
(REGISTERED U. S. PATENT OFFICE) (REGISTERED U. S. PATENT OFFICE)

NCP15C542 Printed in U. S. A.

Transmission Lines and Filters

SIGNAL TRANSMISSION OVER LINES

With the introduction of chain broadcasting, where widely separated stations are inter-connected by telephone lines, the interest of radio invaded the telephone field. As radio technicians developed a working knowledge of the telephone art, they applied the acquired technique more broadly to radio's growing needs.

The practicing technician appreciates the importance of a knowledge of the principle and actions of transmission lines, level indicators, equalizers and filters. Why? Because he is primarily concerned in transmitting intelligence signals or carrier currents modulated with voice or picture signals with the least attenuation, distortion and interference. And this applies equally to radio receiving, audio amplifying and radio transmitting equipment. Let us enumerate a few practical examples where these problems show up.

A microphone picks up a voice or musical performance. It may be transmitted a short distance to an amplifier as in the case of public address systems; to a radio transmitter; or over land lines (telephone or modified telegraph lines) to a remote public address amplifier or a radio transmitter. Where a wide range of audio frequencies are to be reproduced over long lines the following factors must be compensated for: loss of signal strength; unequal attenuation of the frequency components; and the interfering noises. Of course, when the inter-connecting lines are short, up to 500 feet, and audio power is being transmitted, frequency attenuation may be relatively unimportant. But, when high fidelity is desired or where picture signals (as in television) are transmitted, even a line of 20 feet, unless properly treated, may introduce distortion. It is perfectly clear that a real understanding of transmission lines and associated devices is needed when operating radio transmitters and P.A. systems; yet many of the problems encountered there also exist with home receivers when extensions to a high fidelity receiver are made.

Sound signals are very often transmitted on a carrier current, which may be some frequency from 5 to 50 kilocycles. This is frequently done where a telegraph line is leased for broadcast station interlocking, for municipal P.A. systems, or where a monitoring signal is transmitted over the regular communication channel. In these cases filters play an important part; as do repeaters (amplifiers), monitoring or power level indicating devices.

Even radio frequency currents (.1 to 10 megacycles) are transmitted over wires in both receiving and transmitting systems. A transmitter may feed its antenna when widely separated; there are cases where R.F. energy has been conveyed 7 miles. The noise-reducing antenna clearly shows how transmitting technique has invaded the receiver field. All-wave receiving antennas are nothing more than regular single band transmitting antennas modified with equalizers. Indeed, transmission lines are more and more becoming important in radio.

Before we go into this phase of the radio art, let us first inspect the services and frequencies that are met in practice.

Sound Current Transmission.—The normal band of voice frequencies range approximately from 250 to 3,000 c.p.s. It may take a line over one mile long before distortion makes its appearance. When this frequency range is to be transmitted the only precaution needed is to keep the input level high enough to override line noises. If the line is used in a P.A. system to connect a power amplifier with several loudspeakers, attenuation may be serious in a line 1500 feet long.

For normal musical program transmission (100 to 5,000 c.p.s.) frequency attenuation or distortion shows up in a line of 4,000 feet; while for high fidelity an even shorter line introduces these effects. Transmission over telephone lines is only satisfactory when equalization of the attenuation of all frequencies is provided for.

Carrier Currents.—For ordinary telephone purposes the carrier frequency may be any value from 5 to 50 thousand cycles per second. If each channel is modulated with intelligence signals up to 3,000 c.p.s., the channel must be at least 6,000 c.p.s. wide. If suitable separation is included, about 6 channels may be employed. Filters are important in order to prevent interference between channels. Unequal transmission of the side band frequencies (the carrier + or — the intelligence signal) in each channel will exist, but not to the extent present when the original intelligence signal is sent by itself over the line.

When high frequency currents, which may be any value over 20,000 c.p.s., are transmitted, attenuation is without doubt the most vital problem. A low resistance line, having negligible radiation (pickup in the case of receiving systems) is needed. This ideal is approached by using large conductors or litz wire properly insulated, and twisted or transposed. In transmitters the two conductors may be concentric, as, for example, a metal conductor within a metal tube. Then, too, the line must be properly matched at the input and output if reflection losses are to be kept at a minimum. Either impedance matching devices must be employed or the lines must be of a definite length. The exactness of this match, for reasons of power economy, becomes more important as the current transmitted becomes greater. Transmitter feeders are treated with greater care than receiver feeders.

Visual Program Transmission.—As this art progresses, transmission lines will receive greater attention. The range of frequencies normally run from 24 to 250,000 c.p.s., but there is every belief that the upper range will be nearer 1,000,000 c.p.s. Not only is frequency attenuation important, but phase distortion (the relative position of maximum and minimum current for the various frequency components shifting in transmission) may alter the fidelity of the transmitted intelligence. Much is yet to be done in this field, but no one doubts that it will be an extension of the present art which found its origin in telephone research.

Obviously a course in radio would be incomplete without a study of transmission lines and associated equipment. A detailed study of this phase of the field requires an advanced mathematical analysis, beyond the scope of the ordinary engineer. A simple treatment must, as far as you are involved, suffice. We will merely consider in a general way some of the principal terms and phenomena. Do not feel disheartened if you find the subject hard going. And it will be wise not to question the derivations of even the simple formulas given, as they could not be explained without the use of complex mathematics.

FUNDAMENTALS OF TRANSMISSION LINES

Broadly speaking, a transmission system consists of:

a. *A source of power.* It may be a generator of radio or audio frequency currents, or it may be a point in a network where the R.F. or A.F. power at that point is to be transmitted to some other remote point.

b. *A load.* This load may be a device which uses the power supplied or it may be the input to some other network, device or amplifier which is influenced by the transmitted power. The load is also called the sink or the receiver.

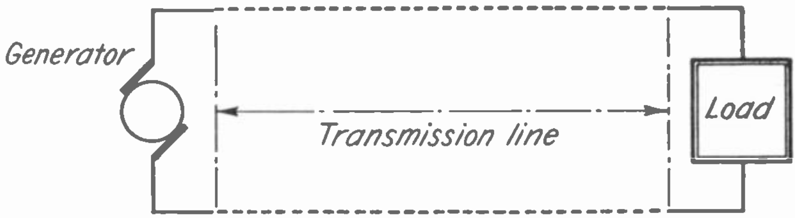


Fig. 1

c. *A transmission line.* This is the connector between the source and the load. Its action on the conveyed energy may or may not be of great importance, depending a good deal on the frequency of the current, the length and other dimensions of the line.

A transmission system is schematically indicated in Fig. 1. Remember that we are just as much concerned with the load and source as the line.

A transmission line is said to be *balanced,* when both of the conducting wires are equally distant from the ground, as it would be if they were twisted together or run in a metal sheathing. A line is *unbalanced* if the two conducting paths are not symmetrical to the ground. Of course, every attempt is made in practice to keep transmission lines in a balanced condition; otherwise noise is picked up, cross talk appears; and in the case of transmitters radiation, and in the case of receivers pickup make their appearance, if the frequency of the conveyed signal is high enough.

But a simple transmission line is more than two conductors. As we shall shortly realize, a line has so-called distributed resistances, inductance, capacity and leakage associated with it. First each lead has its resistance; so many ohms per foot, per 1,000 feet or per mile. A line has a definite amount of inductance per running length. When current flows there is a magnetic field around each wire (that produced by one lead which is not cancelled by its parallel running lead), thus producing self-induction. Clearly the two wires form a condenser which appears to be in shunt with the source and load. Actually this capacity is also distributed over the entire length and we should break up the capacity into smaller units and associate each unit with the running resistance and inductance in this unit. The smaller we choose the length the nearer correct our assumption of running or distributed capacity becomes. And, finally, there is some leakage resistance between the conductors. This leakage may be equally distributed along the line if ordinary insulation is used, as in the case of twisted or parallel leads; or located at points of mechanical support, as in the case of transposed or pole supported wires. From a practical viewpoint we may look on leakage as being distributed.

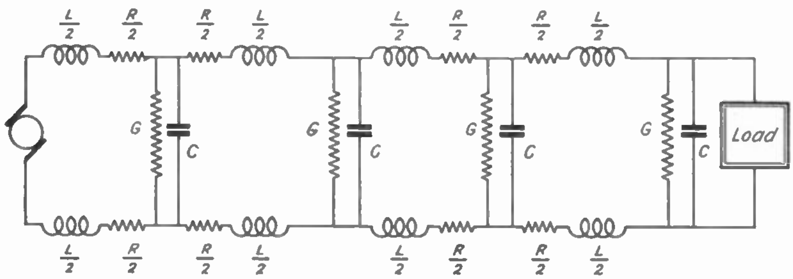


Fig. 2

These important concepts of a transmission line are schematically shown in Fig. 2. Here R represents the resistance per unit length of line, a mile, 1,000 feet or a foot long. In telephone engineering the mile is the unit length and the resistance is referred to as so many ohms per *loop* mile, meaning the two conductors. Since the resistance is equal in each conductor only one half or $R/2$ ohms exist in each conductor per unit length. In a like manner the inductance is $L/2$ henries or microhenries per unit length of a conductor. Each unit length has G leakage conductance, which you know is the reciprocal of the leakage resistance. It is measured in mhos or micromhos. Finally each unit length of transmission wire has C capacity, measured in microfarads.

You may look upon these factors as being distributed over the entire line, or you may isolate them into small units. Four are shown in Fig. 2, yet you may well think of 100, 1,000 or a million such units. When you consider the unit lengths small enough you approach the true idea of distributed constants, as L, C, R, and G are called.

It would tax the ability and ingenuity of a well-trained communication engineer to handle lines involving the constants of L, C, R, and G. Fortunately for every-day radio work we need not go to such details. In a well-designed audio line we may neglect G. For high frequencies, the effects produced by R are negligible and only L and C are considered. And at low frequencies and with short lines only R matters. We will, therefore, only consider here: *1*, low frequency high power comparatively short lines where R is important; *2*, high frequency lines of any length where the factors L and C are important; and *3*, high fidelity audio lines where R and C are important. We will consider them in this order.

A SHORT LOW AUDIO FREQUENCY POWER LINE

In laying out a public address system, or making a loudspeaker extension to a radio receiver where the audio frequencies are below 10,000 c.p.s., the line is less than 1,000 feet long, and power is being transmitted; it is frequently essential to know how much loss is experienced in transmission. Under these conditions, it is safe from a practical viewpoint to neglect all line constants except R, the running resistance.

To begin with, no good technician would couple a source and a sink unless their impedances were equal. You already know how this is done. When a low frequency power line connects a source and a load this cardinal rule should not be violated. We always assume, as portrayed in Fig. 3 (insert of Fig. 4), that the line connects devices with equal or matched impedances. X is the impedance of the load and the source; $R/2$ is the resistance of one wire of the line, R the total line resistance, or its loop resistance. The loss introduced by R is the loss due to mismatch. Analyzed closely the load is not X, but $X + R$.

If you know the length of the line and the wire gauge, you can quickly find the resistance R of the line from a wire table. Table No. 1 may be more convenient, as it gives the total resistance of a transmission line for various twin conductors in terms of 1,000 feet long. In this case both wires are considered. Only information for practical copper wire sizes is given.

TABLE NO. 1

Wire Size B & S Gauge	R-Ohms Per 1000 Loop Feet	Wire Size B & S Gauge	R-Ohms Per 1000 Loop Feet
10	2.0	18	12.8
11	2.5	19	16.5
12	3.2	20	20.3
13	4.0	21	25.6
14	5.2	22	32.4
15	6.2	23	40.8
16	8.0	24	51.4
17	10.1		

Assuming that the source and the load have been matched in the conventional way, the loss in decibels that is contributed by the line is easily found from Fig. 4. First the loop line resistance (found from Table No. 1) is divided by the source or load resistance, X. Using this ratio we find from Fig. 4, the db loss. Suppose, for example, the loop line resistance is 100 ohms, and the source has a resistance of 200 ohms. Then 100 divided by 200, that is, the ratio R/X is 0.5. Figure 4 tells us that this is equivalent to a 2 db loss—transmission line loss.

Here is another very practical example. Suppose a 24 watt amplifier—that, is an amplifier supplying 36 db above the reference of .006 watt—is to be connected to a 15 ohm load, 500 feet away. What is the minimum size wire that could be used to keep the loss to 2 db? We assume at once that the source has a resistance of 15 ohms. From Fig. 4 the ratio R/X is 0.5; that is, the loop resistance of the 500 foot line must not exceed 7.5 ohms. Table No. 1 tells us that 1,000 feet of a No. 18 B & S gauge twin conductor wire would have a resistance of 12.8 ohms; a No. 19 B & S gauge wire a resistance of 16.5 ohms. Obviously 500 foot lines would have resistances of 6.4 and 8.3 ohms. Hence for practical reasons No. 18 wire would be chosen.

Try to remember, that when audio power is transmitted over short lines, the source and load impedance should be high with respect to the line resistance to obtain low line loss.

HOW A HIGH FREQUENCY LINE BEHAVES

If you were to analyze a line fed with high frequency current one wavelength long,* either open or shorted at the far end, for voltage and current at various points along the line, you would be surprised to find that the current and voltage did not decrease

* For a 1,000,000 cycle signal a one-wavelength line would be 300 meters or about 985 feet. For a 10,000 c.p.s. signal a one-wavelength line would be 30,000 meters or about 98,500 feet or 18.5 miles.

regularly from the source to the end. You would find that there were three points of minimum current and at each of these points the voltage was at maximum. What happens is best explained by saying that the current is forced down the line under the influence of the voltage, is reflected from the end back to the source, reflected from the source to the end, back and forth until the above stable condition is reached. In fact a line that is terminated in a load behaves in a similar manner, with less minimum current points. It is worth remembering that reflections take place at terminal points, at the source, at the load, along the line where a device is inserted, where two dissimilar lines are joined; but never along a continuous line.

This condition might in some cases be tolerated if only a signal of one frequency is to be transmitted. But where several frequencies are involved, each signal would call for its own wavelength

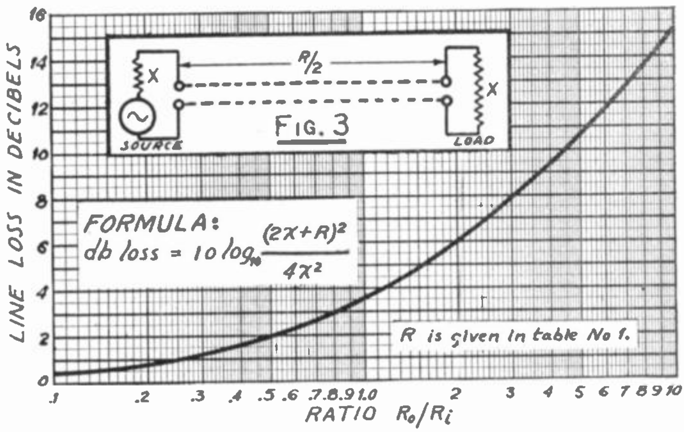


Fig. 4

line, otherwise chaotic terminating conditions would exist. What has been said of a one-wavelength line is also true for shorter or longer lines, although the current and voltage distributions may be quite different.

On the other hand, should you analyze a very long line, many many wavelengths long, you would find that the current and voltage decreased regularly from the source to the end, the voltage, of course, being almost zero at the end. This appears to be a more reasonable situation, except for the fact that we want a reasonable amount of voltage at the end to feed a load.

If you were to measure the input impedance of a long line, you would get a value that would remain substantially constant even if the line was made longer or shorter, but was always at least a few wavelengths long. Going one step further we come upon a very vital fact; the input impedance of the line will always remain at this input value *no matter how long or how short* the line is made—if you connect a load equal to this long line input impedance value. This impedance is called the *surge impedance** of the line and mathematically can be shown to be equal to:

$$\text{Surge Impedance} = Z_o = \sqrt{\frac{\text{Distributed INDUCTANCE}}{\text{Distributed CAPACITY}}} = \sqrt{\frac{L}{C}}$$

where: L is the distributed inductance as indicated in Fig. 2, and C is the distributed capacity as shown in the same figure. L and C must be in henries and farads, or in microhenries and microfarads, and the surge impedance will be in ohms.

Unless the source has an impedance equal to the surge impedance, a mismatch exists and a loss will be experienced. Furthermore, any line disturbance transmitted to the source will be reflected from the source and may reach a seriously objectionable value at the load. If the source is matched to the line, and the load is matched to the line, the line behaves as if it were a device with an input and output impedance of Z_o ohms—almost purely resistive. No reflections take place at the source or the load; the voltage and current decrease uniformly (due to line resistance) from the source to the load and line loss is reduced to a minimum. What really happens may be explained by saying that each terminal is matched and any voltages sent to the ends are totally absorbed by the terminating devices, hence no reflection. All this information is portrayed in Figs. 5a and 5b. Now we have the desired uniform condition with reasonable power supplied to the load.

THE DETERMINATION OF SURGE IMPEDANCE OF R.F. LINES

Lines of 1,000 feet or more when used for audio frequency current transmission or lines of any length when used for frequencies of 10,000 c.p.s. and more, except those lines which are of a specific length for definite needs,† should always have the source and the sink matched to the surge impedance of the line. In fact, regardless of the length of a line or the frequency of its current, if you are in doubt as to whether it will behave as a long or short line, it is always wise to match the input and output ends. The

---

* Strictly speaking, the input impedance of a very long line at any frequency is called its *characteristic impedance* and varies with frequency. It has a resistance and reactance component. At very high frequencies the line input impedance approaches a fixed resistive value and is called the surge impedance of the line.

†Considered later in this text.

surge impedance of the line you choose to use is, therefore, an important factor in transmission over wires.

We have already learned that Z_0 of high frequency lines depends on the distributed capacity and inductance. The surge impedance of two parallel wires, and this includes transposed wires, is readily computed from its layout. A wire within a metal tubing, called a concentric cable line, is quite often used for high frequency transmission. Its Z_0 is also readily computed from dimensions.

The surge impedance may be easily determined from the calculated loop inductance and capacity, or Z_0 may be calculated directly from simple formulas. Table No. 2 tells us what L and C would be for an open line. Z_0 may then be calculated from the formula: $Z_0 = \sqrt{L/C}$. In Table No. 2, D is the separation of the wires from center to center; d is the diameter of the wire used. If d is in mils, then D should be figured in mils. Where inches or centimeters are used for d, then the same unit of measurement

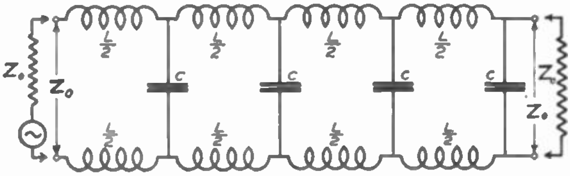


Fig. 5a

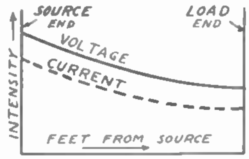


Fig. 5b

should be used for D. For example, a No. 14 B & S gauge wire has a 64 mil diameter (.064 inch). If the two wires are separated 3,200 mils (3.2 inches), D/d will be 50 and the surge impedance for the line will be 567 ohms.

TABLE NO. 2

PER MILE OF OPEN LINE WIRE

D/d	L (Henries)	C (Microfarads)	Zo (Ohms)
40	0.00298	0.01022	540
50	0.00313	0.00971	567
60	0.00324	0.00935	589
70	0.00334	0.00905	606

From a practical standpoint of determing Z_0, L and C are unimportant; so Z_0 may be computed directly from formulas or from a specially prepared graph, as given in Fig. 6. This graph permits you to readily determine Z_0 for various spacings of a definite gauge wire. For transmitter antenna installations, where lines are extensively used, you will find this chart quite helpful. Observe the curves for lines employing two separated pipes. We will shortly learn where such lines are used. Figure 7 permits you to determine the surge impedance of concentric conductors. If you know the radius R_i of the inner conductor, and R_o the inside radius of the surrounding tube, compute the value of R_o divided by R_i; and determine from the graph Z_o, the surge impedance.

The lines covered by Figs. 6 and 7 are extensively used in transmitters, but the so-called noise-reducing all-wave and broadcast antennas for receiving purposes generally employ twisted

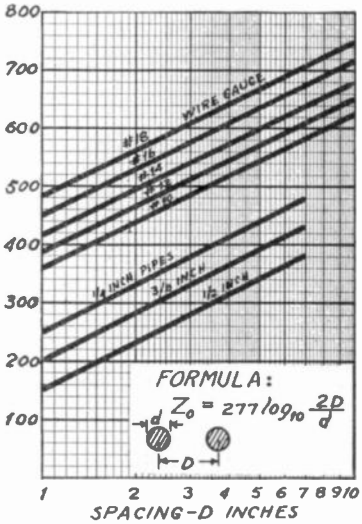


Fig. 6

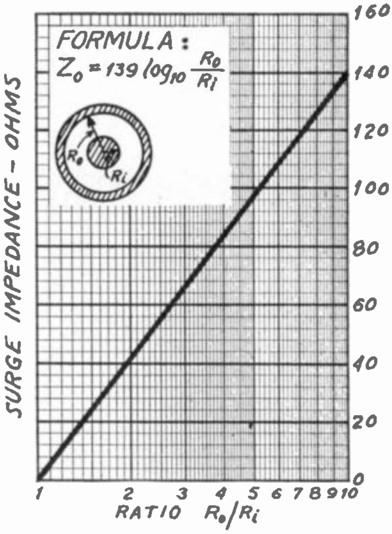


Fig. 7

wires set in rubber. Cable of this sort should be measured for its Z_o. A length of the cable is measured for input impedance Z_1 when the far end is open, and for Z_2 for the far end shorted. To find its surge impedance Z_o, multiply Z_1 with Z_2 and find the square root. ($Z_o = \sqrt{Z_1 \times Z_2}$). Experience with these lines shows that they vary from 15 to 150 ohms. It is best to have the maker give the exact value of Z_o.

MATCHING SOURCE AND SINK TO LINE

Once the surge impedance of the line that is to be used is known, the problem of its adaption to use reduces to one of matching the source and load to the line. Several methods in general use will now be considered, the six important ones shown in Figs. 8a to 8f.

Figure 8a is, of course, the most common of all matching devices, a low frequency transformer. It is used extensively in audio frequency circuits. The ideal transformer has a high primary and secondary reactance, negligible resistance, low distributed capacity, negligible core losses and negligible flux leakage. Fortunately, the modern audio matching transformer approaches this ideal. In audio frequency current transmission it is safe to assume for ordinary transmission that the source is purely resistive and it may be matched to the line by means of an iron core transformer. The load is also assumed resistive and again an iron core ideal

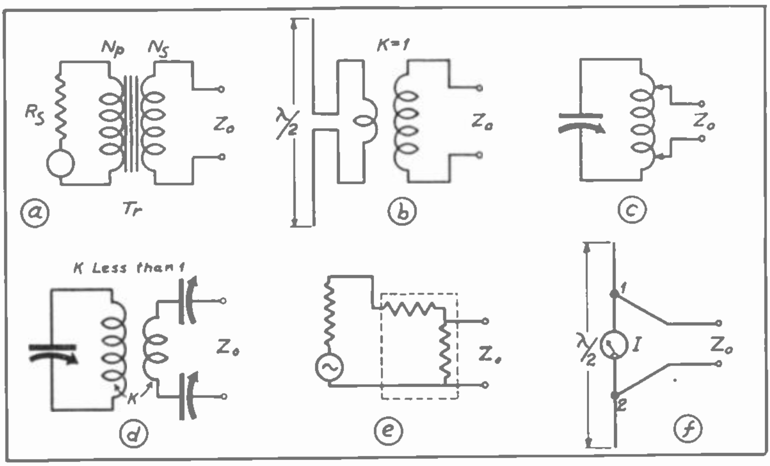


FIG. 8

transformer is used. The load and source resistance may be any value, the match created by the insertion of a suitable transformer.* The only problem involved is choosing a transformer with the correct turn ratio. This has been considered before in this course. Recall the fact that: $T_R = \sqrt{R/Z_o}$ where R is the source or the load resistance. Z_o is the surge impedance of the line and T_R is the turn ratio figured from the load or source to the line. If the source or

* For an exact match at audio frequencies not only must the impedance of the load or source be equal in value to the characteristic impedance of the line, but their reactance characteristic should be opposite and equal. A low frequency line has a capacitive component decreasing with increased frequency. The source and the load should be equally inductive. This is called conjugate match and the kind of match required for what is referred to as the max max power transmission. For ordinary needs a numerical match suffices.

load are not resistive, it is roughly correct to consider their impedance.

An air core transformer may be used at high frequencies, as shown in Figs 8b and 8d. In Fig. 8b, we show an air transformer coupled to the center of a half wave antenna (current fed). The current fed doublet has roughly an antenna resistance of 75 ohms (resistive) when fed at resonance. The transformer is then used to match this source or load, depending on whether a receiving or transmitting antenna is used to the surge impedance of the line. The transformer must have no leakage flux; that is, the coupling (K) should be unity (*1*). Quite often in antenna practice transmission lines consisting of cable or concentric conductors are used, because a line can be selected which will match the antenna resistance, usually 75 ohms.

The modern all-wave antenna broadly follows the coupling scheme shown in Fig. 8b. Of course, where a wide range of frequencies are to be received at the will of the set operator, an approach to ideal conditions must suffice. Fortunately, a half-wave antenna has a rather wide response. Hence if an antenna is used which resonates exactly to the mid frequency of the band, satisfactory pickup at off resonant frequencies will be obtained. For a very wide range of frequencies, such as we encounter in all-wave reception, two and perhaps three half-wave antennas are used in parallel, connected to the line with or without a single R.F. transformer. When no transformer is used, half-wave lines (for mid frequency) must be employed. In some cases the antennas are run at an angle to each other, to minimize their effect on each other. When space is limited a shorter antenna may be used, the length made up electrically; first by inserting coils in the antenna, or secondly by shunting the antenna side of the R.F. coupler with a condenser. When multiple antennas are used in parallel, the series coil scheme should be employed. The length of the wire on the coil should equal the length of wire needed to make a true half-wave antenna. In a number of all-wave antennas, all-wave response is accomplished with a single doublet, by inserting in each half of the antenna a parallel resonant circuit. Together with the straightaway it resonates the antenna at several frequencies in the band (harmonics of the lowest frequency), thus creating fairly broad response.

Figure 8c is a common direct coupling procedure where a line is connected to a tank circuit. Unity coupling exists and the taps are varied until the $V \div I$, the voltage across and the current to these taps, equals the surge impedance.

Where an inductive coupling to a tank circuit, a source or a load is to be made and unity coupling cannot be obtained, the leakage reactance is balanced out by a line capacity as shown in Fig. 8d. In this sketch two condensers are used, each twice the electrical value of the condenser calculated to neutralize leakage inductance. This twin capacity arrangement is common practice in obtaining a balanced line. In fact, the source or load device feeding the line is often connected to ground at its electrical center, to artificially produce a better balanced line. In a scheme of this sort, the condensers are varied until the line currents are maximum and equal.

Quite often, a source is to be connected to a line where the source power level is more than the line is designed to handle. Ordinary telephone lines are an example. The input must not exceed 2 db (above 6 milliwatts) to reduce cross talk and inductive noises. In such cases an attenuating matching pad, as shown in Fig. 8e, is used. This is only one of the many matching pads that may be used. You are already familiar with them.

Figure 8f shows a means of coupling a radiator to a line. Points *1* and *2* are chosen so the $V \div I$ is equal to the surge impedance. Where the separation is large in comparison to line wire separation, the $V \div I$ is greater than Z_0 to take care of the line flare. A practical coupling is accomplished when the antenna current at the center is a maximum. A thermal ammeter may be inserted in the center of the doublet and points *1* and *2* adjusted for maximum current value.

SPECIAL USES FOR R.F. LINES

In the radio art, lines quarter wave ($\lambda/4$) and half wave ($\lambda/2$) long are in general use. It is important to know how such lines behave. (λ is pronounced *lamda* and represents one wavelength, $\lambda/2$ is pronounced *lamda* over *2*, and is called a half-wave line.)

If a line one wavelength long * and open circuited at one end is excited with a sine wave voltage, the current distribution assumes the shape shown in Fig. 9, zero at both ends and the center. Of course, the voltage is a maximum when the current is a minimum, 90 degrees out of phase. Note that current is 90 degrees out of phase with the voltage. When you consider a half-wave and quarter-wave line you recognize the usual voltage and current distributions. The frequency of the voltage of a λ, $\lambda/2$, or $\lambda/4$ line

---

* If the frequency of transmission is known, one wavelength is determined by the formula: meters = 300,000 divided by frequency in kilocycles. Because the current is slowed up at high frequencies (less than 300,000,000 meters per second) a wavelength line is slightly shorter. Multiply the above calculated value by .96 when *f* is less than 3,000 kc.; by .95 for *f* between 3,000 and 28,000 kc.; and by .94 when *f* is above 28,000 kc.

which will give these current and voltage distributions is called the resonant frequency of the line.

Properties of λ/4 Lines: If a quarter wave line is shorted at one end, the other end has a very large impedance at resonant frequency. You should at once recognize that this is exactly how a parallel resonant circuit behaves. The fact is, that shorted quarter wave lines are extensively used in place of parallel resonant circuits.* The lower the line losses, the higher is its resonant resistance. Such a line causes negligible current to flow from its source, although its own current (at the shorted end) will be quite high. Quarter wave concentric conductor transmission lines have the highest input impedance, as the radiation loss is reduced to a minimum.

If a quarter wave line is open at one end, the other end has zero impedance at resonant frequency. In other words an open λ/4 line connected to a circuit behaves like a series resonant circuit. A large input current flows to the line at the source.

A quarter wavelength line is extensively used for matching purposes. When a λ/4 line is connected to a load having an impedance Z_L, the input impedance of the line is *not* Z_o, the surge impedance; but Z_o times the ratio of Z_o to Z_L, the load impedance. Expressed as a formula this becomes: (Z_I, the input impedance $= Z_0^2 \div Z_L$). This phenomenon is extensively used in transmitter antennas to couple a low resistance antenna to a high impedance line without the use of a matching transformer. The higher the frequency the more important does this scheme become. If Z_A is the antenna resistance and Z_B is the surge impedance of the line you wish to couple to, then if you use a quarter wave line as a matching device, its surge impedance must be found from the formula: $Z_o =$ *square root of:* Z_A *times* Z_B. Here is a very practical example. A 75 ohm current fed doublet is to be connected to a 440 ohm feeder (from Fig. 6 this is obtained by using two #10 wires separated 2 inches apart). The quarter wave matching line should then be equal to the square root of: 440 times 75. This figures out to be about 182 ohms. Clearly, either concentric conductors or parallel pipes must be used. If parallel pipes are used, Fig. 6 indicates that ½ inch pipes separated 1.2" should be used. This typical construction is shown in Fig. 10. If the antenna is radiating 20 meter waves, the matching line will be very nearly 5 meters or 16.4 feet long.

* A shorted λ/4 line is very often used as an antenna coupling device. It is connected to a λ/2 antenna at a voltage loop. A transmission line of any length connects to the shorted λ/4 line, at points where $V \div I$ equals the surge impedance of the extension line. Thus a complete match is obtained.

Properties of λ/2 Lines: Half wave lines are extensively used in radiation systems because of a very peculiar behavior. If a λ/2 line is connected to a load having an impedance of Z_L, the input of the line no longer has an impedance of Z_o, but the same impedance as the load, namely Z_L. You can readily imagine the value of this property. A remote inaccessible load is made to appear as it actually is at a more accessible point.

Lines Some Multiple in Length.—What has been said of λ/4 lines also holds true for lines that are 3, 5, 7, 9, 11, 13, 15 and so forth times as long. On the other hand, the property of a λ/2 line is exhibited by lines 2, 3, 4, 5, 6, 7, etc. times as long. This additional information is quite important as the distance between the source and the load may at times be many wavelengths long.

Efficiency of R.F. Lines.—In this discussion of the special prop-

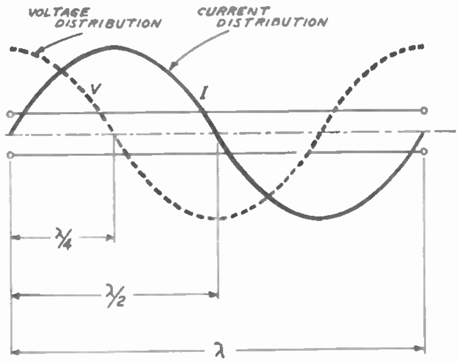


FIG. 9

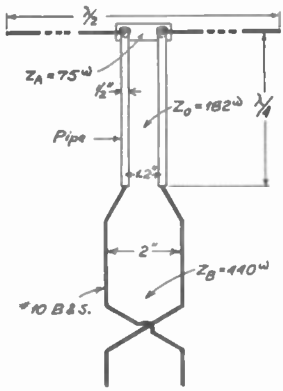


FIG. 10

erties of R.F. lines do not overlook the important fact, that *the line may be of any length just so long as the load and the source are made equal to the surge impedance of the line.* It has been estimated that the efficiency of an R.F. line roughly drops 2 per cent from the value of 100 for every wavelength used. Thus a line 4 wavelengths long will have an efficiency of 92 per cent.

LINES FOR CURRENT AND VOLTAGE FED ANTENNAS

Half wave antennas, or multiples thereof, and half wave antennas in a special array, are extensively used in radio transmission and reception. Each half wave antenna must be fed with power. Two procedures are generally followed. Either power is supplied at the center, or at one end. Note that in Fig. 11A, a transmission line feeds into the center, where the current in the antenna is the greatest. This is a current fed antenna. A slight modification of this is shown in Fig. 8f, which is a current fed antenna, the impedance of the connections matched. Again, in referring to Fig. 11B, observe that the feeder connects to the end where the current in the antenna is a minimum, or where the voltage is at maximum. This is a voltage fed antenna.

In either case the current at transmitter end of the line should, for reasons of efficiency, be at peak value, or at a current loop as it is called. In the case of a current fed antenna a $\lambda/2$ line should be used, and what was said about $\lambda/2$ lines, tells us that the source end of the line will have an impedance equal to the antenna resistance, about 75 ohms. Of course, the line may be any whole number times as long.

Referring to the voltage fed antenna, the Zepp antenna as it is often called, we find that a $\lambda/4$ or a line 3, 5, 7, etc., times as long must be used to obtain a current fed source and a very large load (antenna end) impedance. In this case the source end of the line has a very low impedance, below 75 ohms.

Tuned Transmission Lines.—In erecting a $\lambda/2$ or $\lambda/4$ line it is not always possible to get exact lengths, in fact, no matter how careful you may be, the length may be incorrect. In practice this difficulty is eliminated by tuning the end farthest from the antenna. If the length is too long, a series condenser will decrease its electrical length. Usually two condensers as shown in Fig. 11C are employed to maintain the condition of a balanced line. If the line is too short, then added shunt capacity is required and connected as shown in Fig. 11D. A line or antenna may also be electrically lengthened by inserting a single layer wire coil. The length of the wire on this coil is the added length contributed. Where an antenna is to be switched from a fundamental to some harmonic frequency, as is often the case in transmitters, both series and shunt condensers as shown in Fig. 11E are used. Thus if the antenna is short or long for the harmonic frequency, adjustments will bring them to an electrically correct value. In all such cases, the line ammeters, marked x, must be at maximum reading; and their indications equal to have the line electrically balanced. If the tank circuit shown in these figures is a part of the plate circuit of a vacuum tube, C_T is adjusted to give minimum average plate current.

SO-CALLED SINGLE WIRE R. F. TRANSMISSION LINE

A single wire is often used to connect a half wave antenna to the output of a transmitter. Contrary to general opinion the wire always acts as a radiator, distorting the radiation pattern you expect from the half wave radiator. In one scheme the line is made λ/2 or some even number times this value in length. The wire is connected to the tank circuit of the transmitter at the end away from the terminal that is grounded.

Another scheme is to attempt to match source and load to the impedance of a single wire in space. If you were to measure the surge impedance of single wire in the air by using the ground as the other terminal, you would find that it is very nearly 500 ohms. Therefore if a single wire is connected to the tank circuit at a point P_2 (see Fig. 12a) which is 500 ohms above ground, and the other end at a point P_1 which is 500 ohms in respect to the center C (which is at R.F. ground potential, a voltage node), there would be

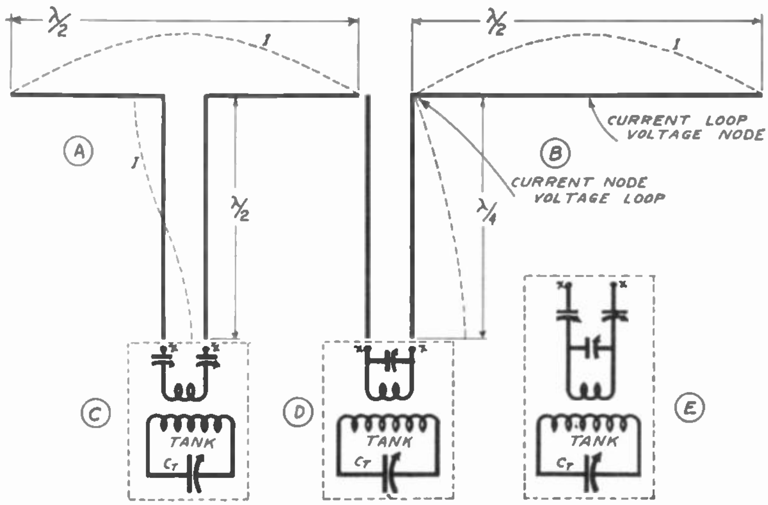


FIG. 11

no reflection losses at the source and the load. Current and voltage would decrease slightly in value from P_2 to P_1. The line may be of any desired length. The trick in making this sort of a connection is worth knowing. Here is how it may be done.

Suppose you wanted to radiate 1,000 watts into a 500 ohm line. Naturally the current should be $\sqrt{1{,}000 \div 500}$ or 1.41 amperes. Connect a 500 ohm dummy load (should be able to stand 1,000 watts of heat dissipation) to the tank circuit of the transmitter, as shown in Fig. 12a. Adjust P_2 so that I_{AC}, the thermal ammeter, reads 1.41 amperes. Adjust C_T, the tank condenser, so I_{DC}, the average D.C. plate current is a minimum. Connect the transmission line to the tap P_2, removing the dummy load. Adjust P_1 until the I_{DC} and I_{AC}

are at the original values. The job is easier if you know approximately where P_1 should be with respect to C. D, the distance, is roughly equal to .136 times the length of the half wave antenna. If antenna length is known in feet the computed D will be in feet.

This adjusting procedure is also used where a twin conductor line is employed to connect the transmitter and antenna, as for example, in Fig. 12b. The resistor you use to find P_2 equals the surge impedance of the line. Points P_1 and P_2 are determined in the same manner except they must be equally distant from their electrical center. They may be the two points on a shorted $\lambda/4$ coupling line, or the two points on an antenna coupling transformer. Where inductive coupling is used, the mutual inductance is varied instead of the taps.

TOTAL LENGTH OF ANTENNA AND R. F. LINE

Wherever half wave antennas are operated at resonance and are connected through a line to a transmitter, and the source and the load are not matched to the surge impedance of the line, it is worth remembering that the length of the antenna plus the total length of the feeder (twice each wire) must be some multiple of a half wave-length. You may consider the entire system as a number of half wave antennas in series. Of course, where two such antennas are close together, as in the transmission line, the radiation is cancelled. When a source or load is connected to the center of one of these doublets you have a current feed; when connected to an end of one of these doublets you have a voltage feed, and at any other point a connection which has an impedance greater than 75 ohms.

HIGH FIDELITY AUDIO LINES

Now let us return to A.F. lines. As the radio art progressed, it was quickly realized that good transmission demanded faithful transmission of all of the sound frequencies. At the present stage of radio, audio signal frequencies of 50 to 8,000 c.p.s. must be transmitted with a minimum of distortion. A high fidelity line must convey all frequency components in the transmission with a variation in attenuation less than 2 decibels. For ordinary 500 ohm lines this distortion becomes apparent for lines one or more miles long.

A long audio frequency line behaves in a well known manner. First its characteristic impedance is high at low frequencies and approaches the $\sqrt{L/C}$, the surge impedance value as the frequency considered becomes high; a variation of 3 to 1 is not unusual. In the second place, the signal components are unequally attenuated, the attenuation increasing with frequency. And finally the phase angle between the terminating voltage and current will vary with frequency, being higher for lower frequencies. The line acts as a capacity. Phase distortion is relatively unimportant for sound transmission. If television signals are conveyed over lines, this distortion factor will be quite important.

All three factors may be reduced to a negligible value by making the running line resistance as low as possible, for example, by using large conductors. This is hardly an economical procedure. The other and most used procedure is to increase the inductance of the line, and for long transmission lines effectively produced by inserting series inductors (loading coils).* The closer together along the line loading coils are placed, the better the equalization. Telephone companies always load their long lines (city to city telephone and leased broadcast wires). For chain broadcasting service, stations may lease lines with any degree of fidelity below or the high fidelity standard.

For local pickup, that is, where a station is to pick up a local

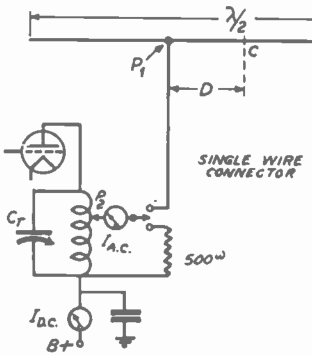


Fig. 12a

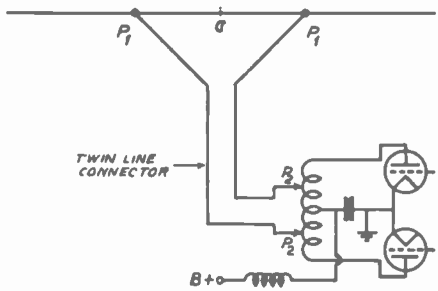


Fig. 12b

event, send it through local telephone lines to their station, it is possible to lease equalized or ordinary lines (lines without loading or some other form of frequency equalization). As it is cheaper to lease ordinary lines, it becomes the duty of the station operator to supply equalization before applying the sound signal to the audio amplifiers.

The standard telephone cable is made of twisted No. 19 A.W.G. wire having a loop resistance of 88 ohms per mile and behaving as if it had a loop capacity of .054 microfarads per mile and negligible inductance and leakage conductance. Its characteristic impedance at 1000 c.p.s. is about 570 ohms and is capacitive. When properly

* Theoretically, if the loading coil used changes the constants of the line so $RC = LG$; where these refer to the R, C, G and L of Fig. 2, a distortion-less line is produced. Actually the insertion of lumped inductance may result in resonance and the line will act as if it is a low pass filter, cutting off above a certain frequency.

terminated at both ends, its attenuation is expressed by the graph in Fig. 13. If a one mile line is used and we consider various frequency components we find that the attenuation is as follows: 500 c.p.s. —0.8 db; 1,000 c.p.s. —1.2 db; 2,000 c.p.s. —1.7 db; 3,000 c.p.s. —2.0 db; 5,000 c.p.s. —2.6 db; and, 8,000 c.p.s. —3.2 db. A line 2, 5, 20 miles long would have 2, 5, 20 times this attenuation. For ordinary lines intended to have 2 db. variation up to 4,000 c.p.s., the line must not be more than 7/8 of a mile long. In most cases some form of level equalization is needed.

We pointed out that the standard telephone cable behaved as a capacitance, thus attenuating the higher frequencies. If the line could be shunted by a device which would progressively compensate for line capacity as the frequency were increased, equalization could be realized. A parallel resonant circuit is capacitive above its resonant frequency and inductive below the resonant frequency. If such a circuit is shunted across a line and tuned to a frequency above the highest desired frequency component, progressive equalization is created. To control the degree of equalization a series resistance is included. This resistance should have a lower value for longer lines. A typical shunt type equalizer is shown in Fig. 14. All components are shown variable. In practice it is wise to choose suitable values of L and C and vary R, which is a 0 to 1,000 ohm decade type resistor. L and C are so chosen that they resonate slightly above the highest desired frequency. One station uses the following equalizers:

5,000 c.p.s. Max; $L = .005$ henries; $C = .171\ \mu f$, and LC resonates at 5,489 c.p.s.
8,000 c.p.s. Max; $L = .0022$ henries; $C = .171\ \mu f$, and LC resonates at 8,400 c.p.s.

Practical Facts About Leased Lines.—Where lines are very long it is best to break them up into shorter sections equalizing each section and raising the input from one to the other to a level of 2 db (above .006 watt). Single sections of 10 miles long are satisfactory without intermediate amplifiers or repeaters as telephone engineers call them.

You cannot feed a telephone line with a signal above 2 db considering .006 watt as zero reference level.

Telephone companies place many lines in a lead sheathing. If you lease a line, be sure to specify a quiet line for program purposes. You will probably get a center twisted pair where inductive interference is low. Lines can be ordered to have a noise level of —30 to —50 db below 6 milliwatts.

If a line has a pronounced resonant peak at some frequency in its response characteristic, a resistor, coil and condenser in series (series resonant circuit) shunted across the line and tuned to the peak will effectively reduce this objectionable characteristic. The resistor is varied to get the desired degree of attenuation. If the line has a decided drop at some frequency, a series resonant circuit connected in series with the line will reduce its response at all frequencies except at the resonant value, the amount of attenuation controlled by the series resistance.

The source and the sink are matched to the characteristic impedance of the line at some reference frequency—varies from 400 to 1,000 c.p.s.

Equalizing a Line.—An A.F. signal generator is connected to the line ahead of the amplifiers, pads, indicators and line matching transformer. The level indicator, calibrated in db, is used to indicate the line input level of this connection. Various frequencies are sent into the line at +2 db. The receiving end is terminated in a load equal to Z_o of the line and the level measured in db. A run of frequencies from 50 to 5,000 c.p.s. or 50 to 8,000 c.p.s. is made and the db variation between reference frequency (usually 1,000 c.p.s.) is compared with the db level at the highest frequency. If the equalizer employs fixed L and C, and R is calibrated in db, attenuation required at reference frequency, it is set to the db variation found. The equalizer is connected to the line and a check run made.

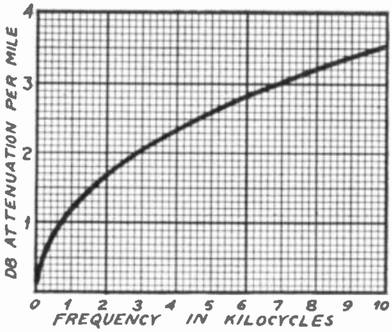


Fig. 13

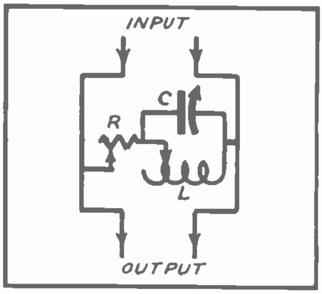


Fig. 14

Where L or C in the equalizer is variable, then shifting the resonance point of the equalizer may be advisable to get more or less progressive attenuation. If the line shows resonance peaks or valleys a series resonant equalizer may be used. Always take another run to be sure the line is properly adjusted.

If a frequency run is not made, the local telephone company will give you the db variation from reference to peak frequency of transmission and the equalizer may then be set to this value.

Power Level Indicator.—In order to properly monitor radio equipment, the operator needs a level indicator. For this purpose a high resistance A.C. voltmeter of the vacuum tube or copper oxide rectifier type is used. The power in watts is easily calculated from the formula:

$$Watts = Voltage \times Voltage \div Load\ Resistance$$

Of course, where line level is measured the surge impedance of the line is considered as the load resistance. The meter should be well

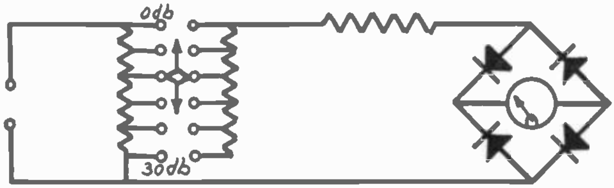


FIG. 15a

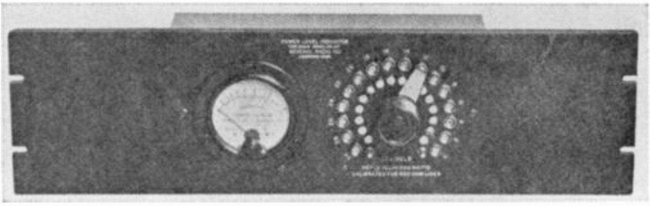


FIG. 15b

damped (dead beat) so rapid fluctuations in signal will not affect the meter needle reading.

Figure 15a shows the connection of a copper oxide rectifier type power level indicator, in which the voltmeter is connected to the line through an L type attenuator. The purpose of the latter is to increase the range of the indicator without disturbing its input resistance. The resistance of the meter should be at least 10 times the value of the load it measures. The meter shown in Fig. 15b is of this construction. It is directly calibrated from —10 to 6 db, and the attenuator increases the range by +30 db. When the attenuator is set at 0, the meter reads 0 db when placed across a 500 ohm line, and the power is .006 watt or the voltage is 1.73 volts. Reference or zero level may be varied from any value from 2 to 30 db above .006 watt by adjusting the L type pad.

The instrument reads correctly for a 500 ohm load. If some other line or load resistance is measured, a correction is necessary. A correction chart is supplied with this instrument. For lines below 500 ohms, zero db reading on this meter is low. For a 200 ohm line readings of the meter should be corrected by adding +4 db. The meter reads substantially correct up to 10,000 c.p.s.

Figure 16 shows the circuit diagram of a vacuum tube type volume indicator. The zero level is altered by varying the turn ratio of the transformer. The copper oxide rectifier type is now more universally used.

ELECTRIC AND WAVE FILTERS

If you had a large quantity of sand and wanted to sort the various particles as to size, you would resort to the use of a sieve or wire mesh. To separate large

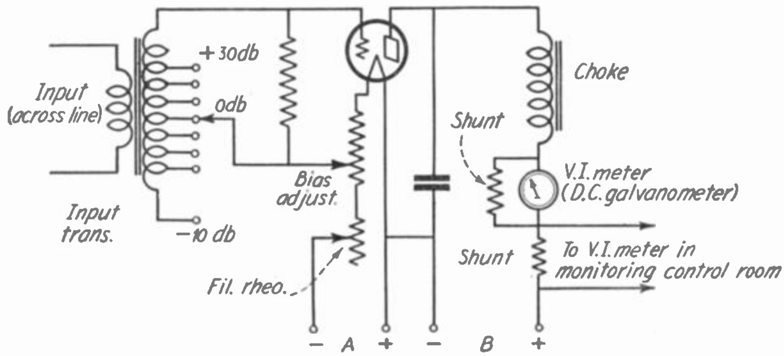


FIG. 16

sand particles you would use a large mesh, and retain what remained in the container. In a sense this is a large pebble filter. By using the particles that passed through the mesh, you would in reality have a small particle filter. If you were to use two meshes, one above the other and with this sift the sand, what remained between the two sieves would have a size not greater than the upper large mesh, and larger than the lower small mesh. If we retain the material between the two we have an intermediate, so to speak, band filter; if we retain the upper and the lower passed material, we have so to speak a band elimination filter.

When sound or visual currents or a carrier current modulated with sound and visual signals are conveyed from a source to a load, over a transmission line, filtering quite often assumes an important part of the process. Such signals consist of many frequency components. Thus in electrical circuits we have:

1. Low-pass Filters, which allow the low frequency components to pass through, and at the same time reduce or eliminate the high frequency components.

2. High-pass Filters, which allow the high frequency components to pass through, at the same time reducing or eliminating the lower components.

3. Band-pass Filters, which allow the frequency between two predetermined values to pass, eliminating or reducing all other components.

4. Band Elimination Filters, which cut out or reduce components between two desired frequencies, allowing all others to pass through.

Electrical filters are very widely used in electrical and radio circuits. Here are a few uses. They are used in the supply circuits to vacuum tubes to filter out the A.C. ripple of the power supply, or to prevent the currents from one stage reacting on the others. They are used in the A.C. to D.C. rectifier unit, or the output of supply generators. Filters are used in the output of oscillators or in the R.F. power amplifiers of transmitters to allow only the desired components to pass through. They are used in two way communication systems where sending and receiving is accomplished with one antenna. They are used in transmitters to remove the carrier, or the carrier and one side band. They are used in lines where several communications are required. In fact the so-called ether is a channel, where the transmitter and receiver are the filters which permit us to use the ether for a very large number of carriers. Filters find a very vital place in laboratories in the study of radio problems.

SIMPLE FILTERS

We all know that a coil has a large reactance at high frequencies, a low reactance at low frequencies. Furthermore, a condenser has high reactance at low frequencies and low reactance at high frequencies. That is why coils and condensers are extensively used to choke, block and by-pass currents. Let us review the most fundamental of the possible arrangements. Refer to Fig. 17.

A, shows a coil in series with the source and load. Low frequency currents are passed; while high frequency currents are progressively choked, that is the choking effect increases with frequency.

B, shows a condenser in shunt with the load. This condenser will allow the low frequency currents to pass through the load, and pass through itself the high frequency currents. The action is progressive being greatest at high frequencies.

C, is an improvement on *A* or *B*, in fact, is both combined. The coil chokes, while the condenser by-passes, both simultaneously. Filters *A*, *B*, and *C* are of the low-pass type, and *C* is the preferred connection. You will recognize filter *C*, as the brute filter. L_1 and C_2 should be as large as possible, yet their resonant frequency must never equal a frequency you wish to suppress. The filtering action starts at a frequency twice the resonant value of L_1 and C_2.

D, shows a coil in shunt with the load. At low frequencies its reactance is essentially equal to its D.C. resistance. If this is lower than the load resistance most of the current will pass through the coil. This by-pass action decreases progressively with higher frequency currents, provided the coil has reasonable inductance.

E, illustrates how a series condenser may be connected to effect high-pass action. At low frequencies the condenser C_1, has a high reactance and impedes the flow of current. For a D.C. current it acts as a blocking device. As the frequency of the current increases the reactance drops and more and more current passes through the load.

F, is a combination of *D* and *E* and improved action is obtained. The high-pass action becomes effective at a frequency half the resonant frequency of C_1 and L_2. The greatest pass action will take place at the resonant frequency of C_1 and L_2.

For band passing or elimination, resonant circuits are widely used. As you already know, a series resonant circuit has a very low impedance at resonance, approaching the D.C. resistance of the coil where low A.C. currents are involved, or equal to the high frequency resistance in the case of radio circuits. A parallel resonant circuit has a very large impedance at resonance, very nearly equal to the coil reactance at resonance divided by the coil resistance. Figures 17G to 17I show three typical circuits.

G, shows a parallel resonant circuit shunted across the load. At the resonant frequency of L_2 and C_2, the least shunting effect exists and the load is fed with maximum current. At all other frequencies either the condenser or the coil shunts most of the current away from the load. This is in effect a band-pass filter. On the other hand, when a parallel resonant circuit is connected in series with the load and source, the circuit current is greatly reduced at resonant frequency. This is then a simple band elimination filter.

H, shows how a series resonant circuit is connected to effect a band-pass filter. At resonance, filter C_1 and L_1 allows circuit current to flow as its impedance is at a minimum value. At all other frequencies, either the coil chokes or the condenser blocks the current flow. On the other hand, when a series resonant circuit is placed in shunt with the load, we obtain band elimination, the load at resonance being shunted by a circuit having a very low impedance.

I, is an improved band elimination filter much better than the filter shown at *H*. The parallel resonant circuit in series with load limits the line current, while the series resonant circuit across the load, by-passes the current away from

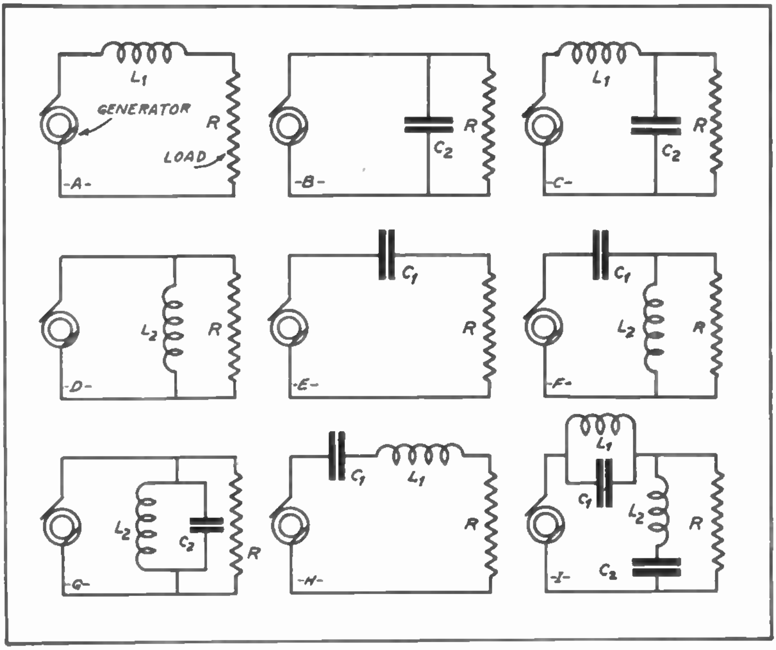


Fig. 17

the load. On the other hand, if a series resonant circuit is placed in series with the load and source, and a parallel resonant circuit is connected across the load, a very good band-pass filter is obtained.

WAVE FILTERS—T AND π TYPES

Figures 17C, 17F and 17I are referred to as simple L type filters. When connected to a line or load they alter the terminal impedance and thus introduce reflection or mismatch losses. If the filter is made symmetrical and is properly designed, it acts as a half wave line reflecting at the input, the impedance of the load. These are now known as wave filters. These wave filters are more desirable and their use is preferred. The elements may be arranged into a symmetrical T or π type wave filter, the design being exactly like that of an L. The filter is designed* to have a characteristic impedance equal to the load or to the surge impedance of the line, depending on where it is to be used.

The four basic L type filters are again shown in Fig. 18, under the L caption. They are marked L.P. (low-pass); H.P. (high-pass); B.E. (band elimination); and B.P. (band-pass). To the right of each L type filter, you should recognize the T and π modification. Notice that each filter has a T and π equivalent. There is a very definite order in representing filter elements, the coils and condensers. Observe that in all diagrams all horizontally represented elements have a *1* sub-index; thus you see L_1, C_1. They are referred to as the *series* element, and this part of the circuit as the *series arm*. All vertically represented elements are

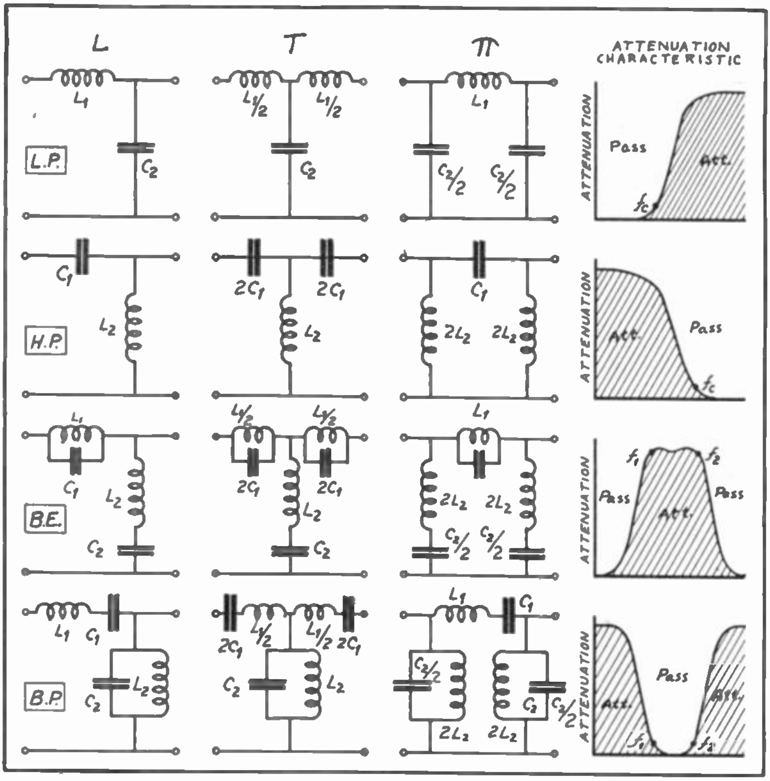


FIG. 18

sub-indexed with a *2*, as for example, L_2, and C_2. They are the *shunt* elements and that portion of the circuit referred to as the *shunt leg*.

In transforming an L filter to a T filter all series condensers are doubled; all series coils are halved. We are, of course, referring to their electrical values, microfarads and henries. On the other hand, when transforming an L filter to a π filter; all shunt coil values are doubled; and all shunt condenser values are halved. By doing this, the attenuation characteristic is not altered; the resonant frequencies of series and parallel resonant arms or legs are not changed; and we

* If you are interested in the design of filters, refer to special texts on the subject. Transmission Circuits for Telephone Communication by K. S. Johnson, published by D. Van Nostrand, Inc., N. Y. C., is an excellent book on the subject.

retain the desired feature of having an input resistance equal to the load resistance when the filter is designed so the square root of: the series impedance times the shunt impedance is made equal to the load resistance. The cut-off frequency occurs when the impedance of the series arm equals minus four times the impedance of the shunt leg.* In the case of L.P., f_c the cut-off frequency, is twice the resonant frequency of L_1, C_2; for H.P. filters one-half the resonant frequency of C_1 and L_2. For B.E. and B.P. filters the two cut-off frequencies are slightly above and below the mid frequency of circuit resonance. All computations are made for a simple L type filter.

IMPROVED FILTERING; DERIVED FILTERS

Notice that we considered all elements in the filter as if they had no associated loss, that is no resistance. This is a perfectly reasonable procedure. However, the loss does play an important part on the sharpness of cut-off and the maximum attenuation. Using reasonably good coils and condensers, the sharpness of cut-off depends primarily on the Q-factor of the coil, its $\omega L/R$ value. If we wish a sharper cut-off, we may either increase the Q-factor of the coils, or use 2 or more similar filters in cascade, one after the other. If the original attenuation for one filter at some frequency is 10 db, the use of 2 similar filters

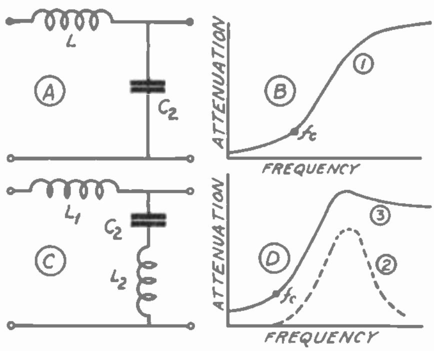


FIG. 19

will double the attenuation, that is make it 20 db. Three filters will triple the attenuation and in this case to 30 db.

In general, by designing the filter so its characteristic impedance has a value less than the actual load, sharper cut-off is obtained. The transmission increases slightly at cut-off frequency and then cuts off sharply.

There is a more desirable method of increasing the sharpness of cut-off. Otto J. Zobel, many years ago, showed how a resonant circuit introduced in either the series arm or the shunt leg tuned slightly off the cut-off frequency would cause infinite attenuation, resulting in better cut-off. This scheme is shown in Fig. 19, applied to a low-pass filter, and is called a *derived* low-pass filter. *A* is the normal L type filter; *B* is its attenuation characteristic. If an inductance L_2 is inserted in the shunt leg, so L_2 and C_2 form a series resonant circuit, resonating slightly above the f_c value, its characteristic will be given by curve *2* in Fig. 19D. The total attenuation characteristic of the *derived* filter, shown in

* The cut-off frequencies may be determined graphically by plotting the impedance of the series arm for various frequencies; then plotting the impedance of the shunt leg. A third curve is then drawn four times the shunt leg impedance and its value changed from + to — or — to +. The points where the first and third curves cross are the cut-off frequencies. Remember a capacitive reactance is minus, an inductive reactance is plus.

Fig. 19C, is the combination of curves *1* and *2*, and is given by curve *3*. Clearly, the introduction of L_2 has increased the attenuation at the cut-off frequency. Obviously this is much better than a simple filter and equal to many simple filters in cascade. Better because it is obtained at less cost. The same result could be realized by shunting L_1 in Fig. 19A, by a condenser C_1, so the series arm had infinite impedance at the frequency selected.

In the case of high-pass filters, a derived filter would use an additional condenser in the shunt leg, or a shunt coil in the series arm. A band elimination filter, see Fig. 18, would employ either a series resonant circuit in shunt with the existing shunt leg, or a parallel resonant circuit in series with the existing series arm.

The derived band-pass filter is obtained in a different manner. See B.P. of Fig. 18. The resonant series arm is replaced by two parallel resonant circuits in series. They determine the two side cut-off values. The shunt parallel resonant leg determines the mid band pass frequency. Thus this derived band pass circuit uses in its L type, 3 parallel resonant circuits. Or you may replace the parallel resonant shunt leg by two series resonant circuits in shunt with each other. Three series resonant circuits. The two shunt legs determine the side cut-off frequencies, while the series arm determines the mid pass frequency.

So far in considering derived type filters, we limited ourselves to the L formation. They may be transformed to the T and π types in the simple manner previously explained. Finally we have only considered the most important forms of electrical and wave filters, but the most important for radio technicians.

TEST QUESTIONS

Be sure to number your Answer Sheet with *the number* appearing on the front cover underneath the title of this text.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your Course, and the best possible lesson service.

1. What three factors must be compensated for when transmitting a wide range of audio frequencies over long lines?

2. What are the four distributed constants of a transmission line?

3. What are the sections of a transmission system?

4. In transmitting audio power over short lines, should the load and source impedance be low or high with respect to the line resistance for the least power loss?

5. On what two line constants does the surge impedance depend?

6. Does an open quarter wave line act as: *1*, a short circuit; *2*, an open circuit; *3*, a series resonant circuit; or *4*, a parallel resonant circuit?

7. In what two ways may a tuned R.F. line be electrically lengthened?

8. Does a standard telephone cable behave as a resistance, capacitance, or inductance?

9. Name the four basic electrical filters.

10. What is the purpose of coil L_2 in the derived filter shown in Fig. 19C?

Transmission Lines and Filters. No. 51 RH-1

1. Compensation for: loss of signal strength; unequal frequency attenuation; and line noise.

2. Distributed or running: 1, resistance; 2, inductance; 3, capacity; and 4, leakage conductance. R, L, C, and G.

3. (a) the source; (b) the load; (c) the transmission line.

4. High.

5. Distributed inductance and capacity.

6. Like a series resonant circuit.

7. By shunting it with a condenser; or inserting a coil.

8. As a capacitance.

9. 1, Low-pass; 2, high-pass; 3, band-pass and 4, band elimination.

10. To increase the attenuation at the cut-off frequency.

ACOUSTICS OF BUILDINGS

52RH

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

WHY ACOUSTICS?

Radio is a peculiar branch of science, highly important in itself yet closely interlocked with many other branches of science. In public address systems especially, where weak speech and music signals are greatly amplified in order to cover a given area with satisfactory sound, the association of Radio with an entirely different field of science, *acoustics*, becomes highly important.

Many Radio men never give a thought to this little-known science of acoustics, which deals with the transmission of *sound*, yet even with a perfect Radio system and a perfect loudspeaker, the final transmission path through air from the loudspeaker to the listener must be properly bridged before the system can be considered satisfactory. Many a costly high-fidelity receiver or well-designed public address system has been labeled poor because the acoustical characteristics of the surroundings were not considered.

Yes, acoustics is just as much a problem in the Radio field as it is to the architect designing a great auditorium or sound-proofing a noisy office—and that is *why* an entire book in this Course has been devoted to this subject.

J. E. Smith.

NATIONAL RADIO INSTITUTE

WASHINGTON, D.C.

1942 Edition

A LESSON TEXT OF THE N. R. I. COURSE
WHICH TRAINS YOU TO BECOME A
RADIOTRICIAN & TELETRICIAN
(REGISTERED U. S. PATENT OFFICE) (REGISTERED U. S. PATENT OFFICE)

NCP2M1141

Printed in U. S. A.

Acoustics of Buildings

THE PRINCIPLES OF ACOUSTICS

When a public speaker addresses a group of people, he naturally wants the entire audience to get his complete message. To work with, he has his clearness of speech, the power of his voice and his knowledge of the principles of elocution. The first two are factors with which sound engineers may aid him so that he can present his message with the maximum intelligibility.

In this lesson, we are going to study the effect of the shape of the room, the surroundings, the presence of an audience, the loudness of the speaker's voice, and the amount of interfering noise, on the intelligibility of his talk, all of which comes under the heading of Acoustics. We will learn to what extent artificial means can be used to increase the loudness, to over-ride the background noise and to reduce the effects of closed halls on speech. What we will say about speech also applies to music rendered by artists either directly or through P.A. systems, or by electrical transcription as in the case of sound pictures.

If all music were played and all speeches were made out in open fields, we would not have to bother about acoustics—all that would be necessary would be that the listeners stand within range of the music or speaker and these would be heard with perfect clarity and intelligibility. The major problem would be to have the source of sound loud enough to reach all the listeners.

But we have advanced far since the day when a gathering of any comparatively large size had to be held out in the open—and even today where we have large open air gatherings, they are not usually held in an open field. We must have our seats, in the summer time we must have shade, and we must have our refreshment stands. All these have an effect on the sound and just what their effect is we shall see. The important thing to realize at this point is that at the present time, wherever there is a sound program of any sort, we must consider the problem of acoustics.

The reason why an open field is acoustically perfect is because air absorbs sound completely. A brick wall or a mountain on the other hand will absorb only part of the sound and will reflect the rest, just as light is reflected by a mirror. All solids reflect sound—some more than others, others less than others.

Now suppose we had an auditorium out in the open just a trifle more complex than an absolutely open field—let us say that a roof was built over that portion of the field where the people assembled and that the talking was done from a raised platform at the end of the auditorium. The roof would reflect that part of the sound which would otherwise go straight up into the air so that the results of its use might be beneficial and the speaker would not have to exert himself as much to be heard by the same number of people as he would if the roof were not there. But if the roof were quite long, the people at the end away from the speaker might have difficulty in understanding what he was saying. They might hear the sounds coming in a straight line from the speaker and also the sounds reflected by the ceiling and if it took the reflected sound a trifle longer to reach the ear than the direct sound, the two would interfere with the result that the words would sound "muddled." Reception would become less intelligible.

It must be remembered that sound travels comparatively slowly, about 1,075 feet per second. As we are accustomed to thinking in terms of the speed of electricity, this is very slow.

Of course, if the reflected sounds and the direct sounds are in phase, that is, if identical sounds reach the ear at the same time, the one will reinforce the other and the total effect will be louder than either one alone. But if the sounds reach the ear out of phase, they will cancel each other, if both are of equal intensities.

Now what will happen if we put sides, a back and a floor on our auditorium? It is obvious that these, too, will reflect sound, in fact, now we will have a multiple reflection—from the ceiling and from each of the four walls. In this common type of auditorium, two sound waves might meet very easily. If they are out of phase, they will cancel each other; if in phase, they will reinforce each other.

It can easily be seen that where there is multiple reflection, it would result in the rebounding of the sound from one reflector to another in much the same way as a pool ball can be made to rebound from one side of the table to another, with the result that the ball would remain in motion for quite some time. In an auditorium, the same condition is encountered, the sound persists in the hall for quite some time after it has been produced, due to the multiple reflection from all walls. The persistence of sound in a room after the source of the sound has been stopped is called *reverberation.*

Reverberation may be measured, and its measurement is very important in the study of acoustics. The period of reverberation is the time it takes for the sound once created to reduce to one-millionth of its original value, that is, the time to reduce its intensity 60 db. This period may be measured by specially designed instruments, as will be later explained to you. It must be remembered that this period is not the same at all sound frequencies and in general it will be longer for higher audio fre-

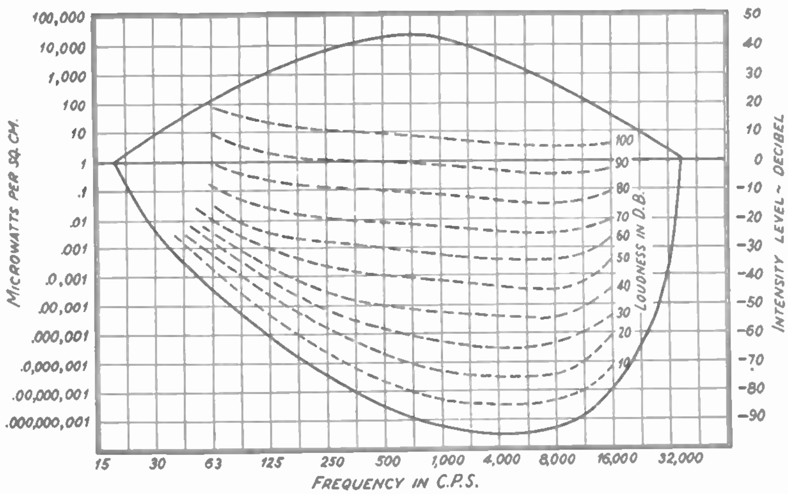


FIG. 1

quencies. As a standard, a frequency of 512 c.p.s. is used, and for enclosed space the period of reverberation may vary from 0.5 to 8 seconds.

It should be clear that if portions of speech will persist for 3 or 4 seconds, they will interfere with the new sounds, so that sounds will overlap and the speech or music will be confused. Reducing reverberation is a task acoustic experts are called upon to do when adapting theaters and auditoriums for sound reproducing devices.

It may seem like a long step from our simple four-sided auditorium in the field to a modern movie palace but the acoustic problems are essentially the same. If provisions were not made to correct for bad acoustics, our modern theaters would be extremely unsatisfactory and the sound output of the loudspeakers behind the screen would be unintelligible to all but a very small portion of the audience.

Going back to our enclosed auditorium, we may observe other factors which make it difficult to understand the speaker. If the room is a very large one, it will be extremely difficult for the audience in the rear to hear without some means of raising the original sound level. Usually the speaker or the orchestra, realizing that the enclosed space is large, will unconsciously talk or play louder. There is a proper loudness for maximum intelligibility in each enclosed room.

Suppose that a convention was in progress, or the hall was in a noisy district. If the interfering noise is loud in comparison to the desired speech or music it will be extremely difficult to understand what is being said or played. Of course, it would be natural to raise the level of the desired sound output.

The shape of the room has some effect on the sound, due to resonance and echoes. In general, however, we may neglect the effect.

Note that in discussing the subject of acoustics we mentioned the effect of certain factors on the intelligibility of the sound. This concept is very important as it is the purpose of an architect to design halls, rooms, theaters and auditoriums so that every person in the audience will understand what is said or played. It is the duty of every acoustical expert to furnish and alter the interior of the enclosed space to obtain this best effect. In fact, it might be said that the entire purpose of acoustical treatment is to increase the worth of the room for music or speech.

We have spoken so far in a qualitative manner regarding the effects of noise, reverberation, and sound intensity on the acoustical merit of a room. In attempting to rate rooms (on the basis of perfect acoustics) it is difficult to consider music, as even experts differ as to perfect rendition. Therefore it is the practice to rate the acoustical merit of a closed space for speech only, and make such corrections later for music as suits the convictions of the acoustical expert.

For years telephone engineers have been concerned with the degree of intelligibility with which they could transmit speech over wires and cables and repeater devices. They subject these devices to what they call an "articulation test"—a test which they have applied also to the study of the acoustical merit of theaters and auditoriums. These tests are valuable in the investigation of the effects of noise, sound level and reverberation on speech reception.

The test is very interesting as it differs considerably from any test that you have so far studied. No instruments are used.

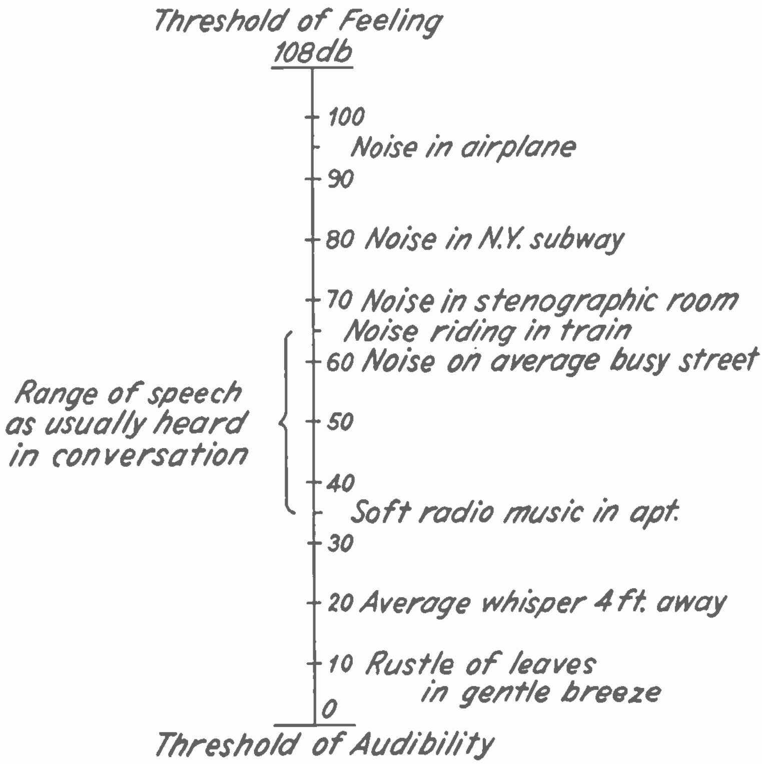


Fig. 2

A speaker standing at a point from which the sound is eventually to emanate, calls out certain characteristic monosyllabic speech sounds either directly, or where increased sound levels are desired, through a P.A. system. The sounds are presented in groups of three and so timed that each group will take two seconds. Listeners are stationed at representative points of the room and record what they hear. When the observed and the called syllables are compared, if, as an average, 35 out of 50 were observed correctly the room has a "percentage articulation" of 70 per cent. This method has worked out to be a very valuable way to rate the acoustical merit of a room. Repeated checks, using a different speaker and other observers give identical results even when measured after some lapse of time.

Percentage articulation is the quantitative rating of the acoustical condition of an enclosed room. The percentage will be affected by the size of the room (which determines the required power level), the amount of noise, the period of reverberation and the shape of the room. In a study of acoustics it is customary to vary the sound level, the amount of noise and the reverberation period and determine by the articulation tests, the percentage. Thus a complete insight as to how these factors affect intelligibility is possible.

Tests made in ideal rooms under varying conditions, free from noise, but with average speakers and listeners showed that the best articulation was only 96 per cent. This figure represents the highest acoustical rating for a room. This does not mean that in a well balanced acoustical hall that the audience can only hope to hear 96 per cent of what is said, for we must remember that in tests, only monosyllables are used which have no meaning, whereas in actual speaking, complete thoughts are presented which makes it possible for the alert person to fill in what his ears miss.

A percentage of 96 per cent is for practical purposes ideal, but a rating of 75 per cent is by no means to be regarded as not acceptable. In fact, fairly intelligible reception will be obtained with 75 per cent articulation.

For our purposes we can overlook the effect of the shape of the room on its acoustical merit. For small rooms and for theaters and auditoriums that are properly shaped so that echoes and resonance are not present or when corrections are made for these, the effect is negligible. Articulation percentage then depends on the loudness level factor (K_l), the distortion effect due to reverberation (K_r) and the signal-to-noise factor (K_n).

EFFECT OF LOUDNESS ON PERCENTAGE ARTICULATION

First we must have clearly in mind what we mean by loudness of speech or music. The matter is more involved than power level as used in radio work. You are familiar with the usual sound output rating made for audio systems. We say that 2, 4, 11.5, etc. watts are fed to a loudspeaker. But this does not imply that 2, 4, 11.5 watts of sound are reproduced. As a generator of sound, a loudspeaker is a very inefficient device. An efficiency of 3 per cent would be a good figure. Thus a loudspeaker fed with 2, 4 or 11.5 watts would reproduce .06, .12, .35 watt of sound energy. The question then arises, what effect do such intensity levels have on the human ear. It is the number of watts of sound power that reach our ear at our position in

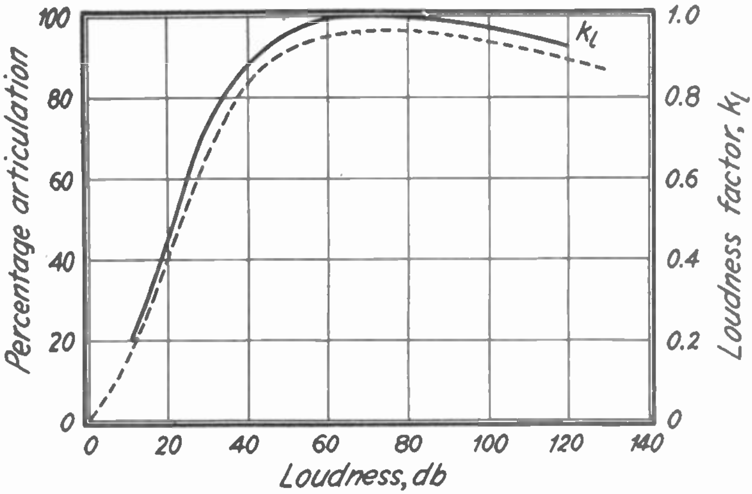


FIG. 3

the sound reception area that determines the loudness of the sound.

Extensive tests have been carried out to determine how different sound powers affect the ear. If a dynamic speaker, 25 centimeters in diameter (the metric system is always used by scientists) is producing 10 watts of power, it is clear that at the speaker, 10 divided by the area in square centimeters of the cone face is the intensity of sound at that position. In this case it is $10/(3.14 \times 12.5 \times 12.5) = .0202$ watt per square centimeter. Suppose this sound is transmitted (no absorption) down a hall whose height is 20 feet and width is 50 feet. That is, in terms of centimeters—613 centimeters high and 1530 centimeters wide.* If the sound distributes itself uniformly across the room

* To change feet to centimeters, multiply by 30.6.

the intensity will be 10 ÷ (613 × 1530) = .0000106 watt. This is an extremely small value so it is customary to speak in terms of microwatts. Multiplying this figure by one-million we get 10.6 microwatts.

Is the last sound level sufficient to be heard? Telephone engineers tell us that the reference level of sound is one microwatt per square centimeter which corresponds to the sound power reaching the ear when an average individual speaks at an average loudness, ½ inch away from the ear. Clearly 10.6 microwatts would be sufficiently loud.

It is by no means difficult to employ a condenser microphone followed by a distortionless audio amplifier with an earphone, and a special attenuation device, calibrated in sound levels, for the measurement of sound intensity. This device, which will be described later, may be used to measure the sound power at any point in a room.

Sound investigators have gone farther in their research. They know that if the intensity is increased too much it will become painful. If decreased too much, it will be inaudible. Between these two points, which vary with the frequency of sound, we have the working range of sound. They found that for every pure sound frequency there is a high intensity of sound that becomes painful and a low intensity at which the sound can no longer be heard. The upper and lower curves in Fig. 1 show these limits for various sound frequencies. On the left-hand vertical scale is given the required power in microwatts per square centimeter, while on the right-hand side is given the sound intensity level in db.

We must not overlook the fact that sound energy may also be expressed in db. above zero level (1 mw. per cm.). We learn from this curve that the threshold of feeling (level above which sound is felt) is 11,000 mw. for a sound signal of 1000 c.p.s. and the threshold of audibility (level at which sound is just heard) is .0000000008 mw. for the same frequency. Expressing the sound *intensity* in db., this corresponds to 44 db. and – 92 db.

What we mean by *loudness* may be understood from these curves. Loudness is expressed in db. above the threshold of audibility. The latter is considered as zero db. loudness. A series of dotted curves is shown which indicate the different loudness levels in db. above the threshold of audibility and from these curves, the loudness and intensity in db. for any sound intensity may be determined at any frequency. Music and speech as you know are made up of many sound frequencies. Hence an average db. level loudness scale is required. Figure 2 shows such a scale expressed in terms with which we are more or less familiar.

Now that we understand what is meant by loudness, we may proceed to see what effect it has on the intelligibility of speech reception. Experiments have been made in acoustically perfect rooms with the speaker talking at different loudness levels. Exactly how this was done does not matter, except that a standard articulation test was made at different received sound levels. The dotted curve in Fig. 3 shows the results of many tests.

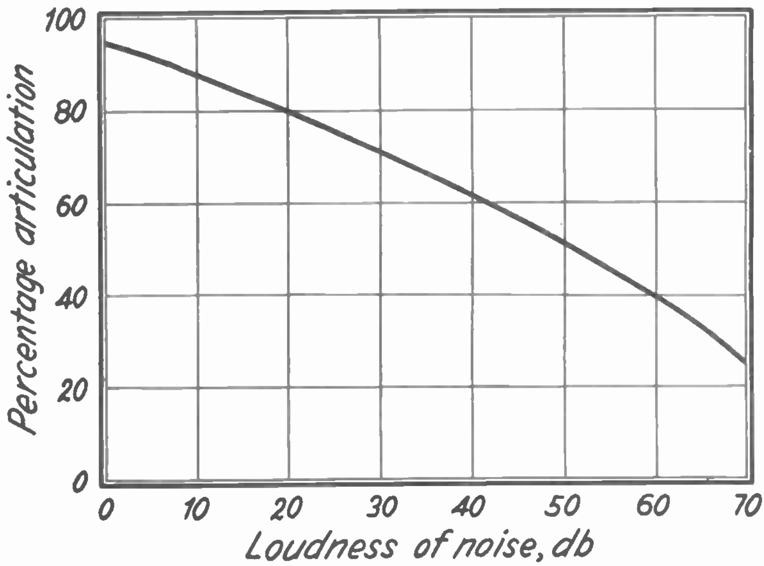


Fig. 4

From these tests we are informed that the loudness of speech reception, all other factors being perfect, must be at least 30 db. and preferably 60 to 80 db. Nothing is really gained as far as intelligibility is concerned if the level is increased above 70 db. On the other hand the effect of unnaturalness is obtained due to the abnormal loudness of the speech. When an amplifying system is used to reinforce the speaker's efforts or to present electrically transcribed entertainment, the loudness can be regulated by the gain control to suit the average listener. It is quite likely that the operator will err on the "loud" side of the adjustment which to most people is very offensive. A db. measurement with all apparatus installed will permit an optimum adjustment.

The solid line curve in Fig. 3 is a correction factor (K_1) necessary to determine the percentage of articulation when the level of loudness is above 80 db. and below 60 db. We pointed out before that the most ideal condition would result in an articulation percentage of 96. If, however, the received sound was 30 db., possibly in isolated spots of a large auditorium even with a P.A. system the percentage of articulation would be $96 \times K_1$ or 96×70 which is 67 per cent approximately. Means of raising the loudness level at these isolated points are essential and corrections are usually made by focusing additional speakers toward these poor spots. Of course, loudness level measurements are not always essential for a well trained ear will know when the level is too low for good articulation, or too high for complete naturalness.

EFFECT OF NOISE ON SPEECH RECEPTION

Everyone knows that it is not easy to hear and understand a speaker or enjoy music when the audience is talking or when there is any noise that tends to "drown out" the desired sounds. Ordinarily the speaker is conscious of the condition and raises his voice or the monitor of the P.A. system runs the sound level up. However, few realize to what extent noise, even of a low intensity, will affect the ability to understand what is said.

Again experiments have shown what effect noise will have on the percentage of articulation. With the speaker heard at a level of about 60 db., an ideal loudness level, noise was introduced and articulation tests made. The result is shown in Fig. 4. A noise level of 20 db. will reduce the percentage of articulation from 96 to 80 per cent. A noise level of 60 db. equal in intensity to the speech level will reduce the percentage to 40 per cent, or to the point of unintelligibility.

Suppose the voice is raised by a P.A. system. Can it be raised enough to overcome the noise? Some idea of what the effect is can be learned from Fig. 5. In this curve the ratio of noise level to desired sound level is plotted for various correction factors (K_n). For example, assume that the loudness of speech is 60 db. without noise, and the percentage of articulation is

96 per cent. If the loudness of noise is 40 db., which is not unusual for a convention hall, the ratio of noise to sound signal is 40/60 or .67. The factor K_n from Fig. 5 is .73. Therefore the actual percentage of articulation is 96 × .73 or about 70 per cent, a value not suitable for good hearing. Suppose a P.A. system

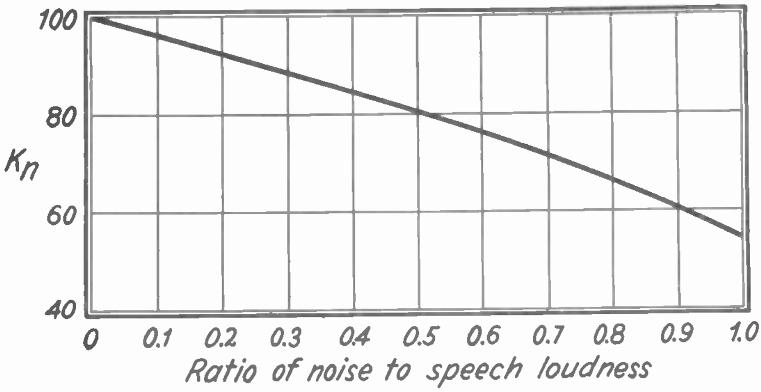


Fig. 5

boosts the signal to a loudness of 80 db. The noise signal ratio is .5, the factor K_n is .8 and the articulation percentage becomes 96 × .8 = 77 per cent—an acceptable value. The average loudness of noise for an auditorium is rarely below 5 db. and very often between 20 and 30 db.

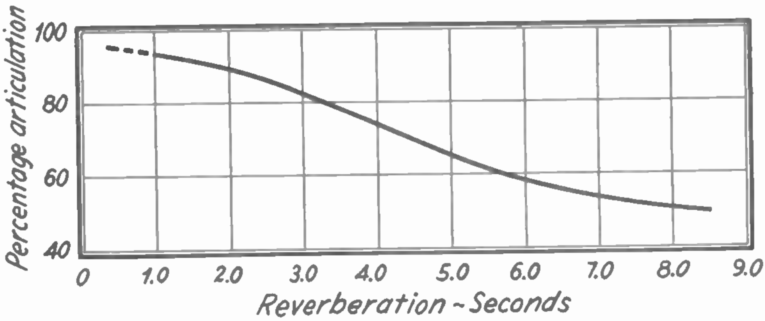


Fig. 6

The distribution of speech sound throughout a hall will vary and in long narrow halls, the absorption of sound is very likely to attenuate its level at remote points. In a rear section, the level of the sound from the stage horns may be 50 db. and for ordinary gatherings, such as an audience listening to a lecture or viewing talking pictures, the loudness may be sufficient. However, if a convention is in progress, a noise level of 20 db. may be present at every point in the hall. At the remote position, the ratio of noise to sound is 20/50 or .4. From Fig. 5 we find that K_n is .84 and the percentage articulation is 96 × .84 or 81 per cent, a satisfactory amount. However, a further correction must be made for loudness. From Fig. 3, we learn that a loudness of 50 db. introduces a correction factor K_l of .93. Therefore, the correct articulation percentage is 81 × .93 or 75 per cent, a low and just permissible percentage. In this case supplementary horns should be used at the remote points.

So far we have learned that the articulation percentage depends on loudness and the ratio of noise to loudness. Therefore, the resultant articulation is the product of the two factors or $\%A = 96 \times K_l \times K_n$.

EFFECT OF REVERBERATION ON SPEECH

Loudness and noise level are simple matters to deal with when sound amplifying systems are used. Even though the ear is not a perfect indicator, full scientific control has not yet replaced the experience of the monitors. In any case the latter have control of the condition and may vary the P.A. level to get immediate results. However, when confronted with the problem of reverberation, a control is not possible, so acoustic experts are compelled to correct for decrease in articulation percentage before the hall is accepted for definite uses. A special arrangement is being introduced into a new, large Russian Soviet auditorium so that the reverberation period may be altered within a few minutes and this will be considered when we have studied the effect of reverberation on the percentage of articulation.

Reverberation measuring devices are available and they have been used extensively by investigators to study reverberation effects. The device will be studied later. It is usual to measure the period of reverberation at an average speech frequency of 512 c.p.s. It has been found that as the period of reverberation increases, it becomes more difficult to understand what a speaker is saying. Figure 6 is the result of extensive experiment with the sound loudness set at ideal conditions of 70 db. and with the noise cut to a negligible degree. The ideal condition is obtained when the period of reverberation is such that the percentage articulation is between 95 and 91 per cent. A period of 4 seconds gives an acceptable amount—75 per cent.

In addition to loudness and noise-sound ratio, the correction factor for reverberation period (K_r) must be considered in estimating the over-all perfection of an auditorium for speech purposes. The curve in Fig. 7 shows the relation between percentage articulation and reverberation periods, other conditions being ideal. Suppose in our last example, in addition to a loudness of 50 db., and a noise-sound level of .4, a reverberation period of two seconds was characteristic of the hall. The over-all articulation would be 96 × .84 × .93 × .92* or 69 per cent. The factor .92 was obtained from Fig. 7. An over-all articulation percentage of 69 per cent would not be acceptable. Although the other factors can be easily arranged to correct for the condition,

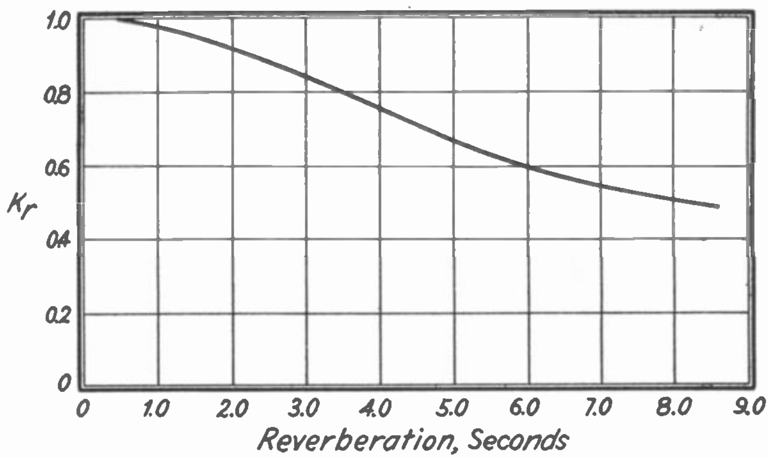


FIG. 7

it is also wise to correct the period of reverberation so that it is less than two seconds. The exact value chosen depends on other factors which will be considered later.

The period of reverberation should not be made as low as possible in the acoustic treatment of rooms. It has been found that although maximum articulation is desirable, naturalness of speech and music is an even more important factor.

Naturalness depends on the loudness of speech and the size of the room (its volume). Tests show that if the loudness of

* $\%A = 96 \times K_l \times K_r \times K_n$ (1)

speech is decreased from the ideal condition of 70 db. for a small hall, the optimum value of reverberation period is from .5 to 2 seconds. The highest level corresponds to amplified speech whereas the lowest value corresponds to a weak speaker without any electrical amplification aids. Experience seems to indicate that if the level is quite normal, the speech will be quite satisfactory if the period of reverberation is kept within 1 to 1.4 seconds.

Perhaps the most important factor that acoustic specialists and you will be confronted with is the correct period of reverberation for a given volume of space. It is well established that as the volume of the auditorium (cubic feet of space) increases, the optimum period of reverberation increases. Fig. 8 shows these optimum values for auditoriums of various sizes. These curves apply to halls in general. Three curves are given—the lower one for speech, the upper one for music. These curves were taken by experts who investigated so-called good acoustical halls, as judged by listeners whose opinion of clear natural speech and music was considered authoritative. In the opinion of these men, the period of reverberation for good music was considerably higher than for speech. The middle curve is average and applies to halls which are to be used for either speech or music.

The optimum reverberation will vary with the experience of many investigators. Experts of the Bell Laboratories have done considerable work in correcting theaters and convention halls for the adaptation of amplifying devices. The recommended reverberation periods are given in Fig. 9. The recommended values for talking pictures take into consideration the correction for reverberation made at the time pictures are recorded and for the fact that talking pictures are mostly speech. They claim that for normal conditions the percentage of articulation should never be below 70 per cent.

HOW THE REVERBERATION PERIOD MAY BE ADJUSTED

In the previous chapter it was mentioned that a certain amount of reverberation in an auditorium is desirable. An auditorium in which there was absolutely no reverberation would be acoustically "dead." On the other hand, a certain amount of reverberation makes the auditorium acoustically "alive."

In an auditorium that is acoustically alive, music will have a brilliance and richness of tone that is highly desirable. On the other hand, if an auditorium is acoustically dead, all sounds will appear muffled and flat.

The reverberation period of a given enclosed space may be calculated from the physical dimensions of the room and a knowledge of the absorption power of the material used in the room. The late Professor Sabine of Harvard University, a pioneer in acoustic treatment of auditoriums, developed an em-

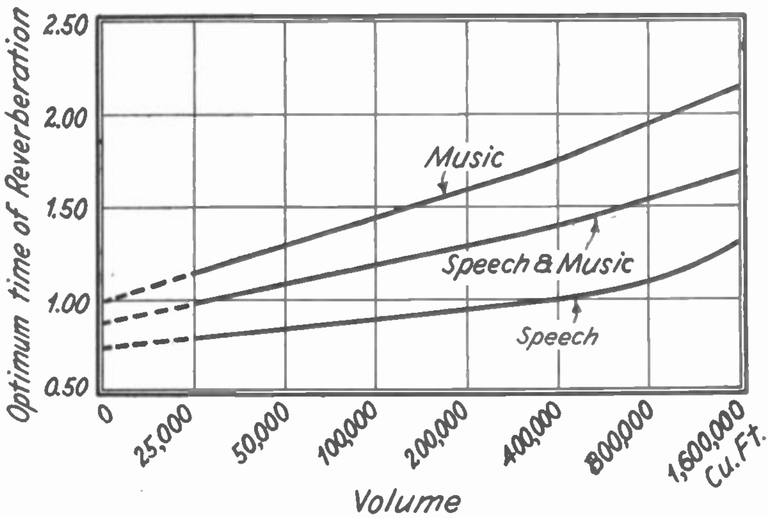


Fig. 8

pirical formula to be used in calculating the actual reverberation period of the room. It is:

$$t = \frac{.05V}{a} \qquad (2)$$

Where V = volume of room in cubic feet.
a = absorption power of the material used in the auditorium.

We will shortly learn how a, the total absorption, can be calculated. Knowing a and calculating V, it is a matter of simple arithmetic to calculate the probable period of reverberation.

When sound strikes a surface, some will be absorbed and some will be reflected. It is obvious that the amount of reflected energy will determine the time it will take the sound intensity to drop to one-millionth of the original intensity. In considering the absorption of various materials, the absorption of an opening one square foot in area is taken as reference. If sound strikes such an opening it passes out of the room—none is reflected. Under these conditions we have maximum absorption. The absorption of an opening one square foot in area is considered as unity.

All other materials are compared to an open space for determining their absorption qualities. Investigators have considered many materials and have assigned absorption coefficients per square foot of the various materials used in theater and auditorium construction. Items such as seats or individuals must be considered individually.

TABLE 1

Material	*Coefficient per sq. ft.*
Open space—as window, etc.	1.00
Openings under theatre balconies	.25 to 1.00
Stage openings	.25 to .40
Plaster	.025 to .034
Concrete	.015
Brick set in Portland cement	.025
Marble	.01
Glass, single thickness	.027
Wood sheathing	.061
Wood, varnished	.03
Cork tile	.03
Linoleum	.03
Carpets	.20 to .29
Cretonne cloth	.15
Curtains in heavy folds	.50 to 1.00
1 in. hairfelt	.45
Celotex, painted or unpainted 1¼ in. thick	.70
Celotex, painted or unpainted 13/16 in. thick	.47
Individual Objects	
Audience, per person	4.7 units
Church pews, per seat	.2 unit
Wood seats in auditorium, per seat	.1 unit
Upholstered seats, per seat	1.6 to 3.5 units

Knowing the absorption coefficients that various materials have per sq. ft. and the area of various materials used, the number of people in the audience, the number of empty seats, it becomes a straight-forward problem to calculate a in formula (2) and so to estimate the reverberation period of a hall. If the value differs too much from that recommended in Figs. 8 and 9, less or more absorbing material may be employed.

Although Table 1 was made for sounds at a pitch of 512 c.p.s., we must realize that coefficients vary for different pitches. In exact acoustical correction it is practical to calculate "t" for

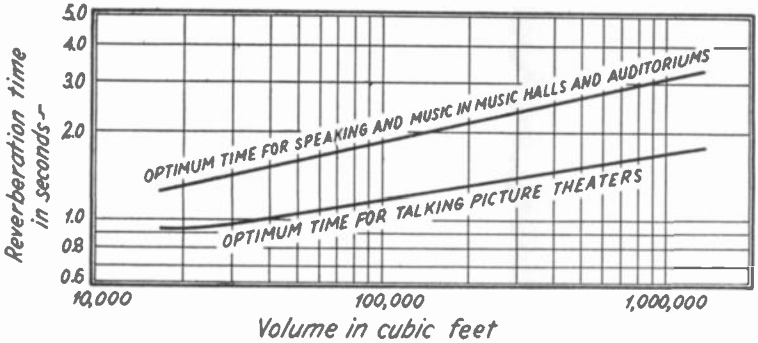


Fig. 9

128, 512 and 2048 c.p.s. and from these facts and a knowledge of the variation of the coefficients with frequency, it is possible to make the reverberation period constant for the entire fundamental pitch range of speech and music. However, calculation made at 512 c.p.s. is sufficient for all ordinary corrections.

From this table it can be seen that if the period of rever-

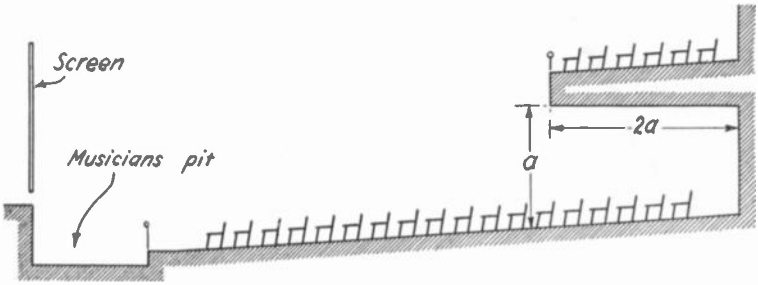


Fig. 10

beration for a certain auditorium is too high, it can be reduced by the use of curtains over the bare walls, for a square foot of a heavy curtain will have twenty times the absorbing power of a square foot of plaster. If the floor is uncarpeted, the period of reverberation can be reduced by the laying of carpet, which has a comparatively high absorption coefficient—.20 to .29. Celotex has a very high absorption coefficient—.70 for celotex 1¼ in. thick. It is for this reason that celotex is frequently used in the construction of broadcasting studios where an almost dead effect is desirable. It is also used to cover a bare plaster wall in auditoriums that have a too high period of reverberation.

Now let us take a practical problem of acoustics and work it out—in this way we shall learn how to solve many of the problems of acoustics that we may meet in our work. Let us consider a theater having the following dimensions and constructional characteristics: The main floor and the balcony have an area of 9,000 square feet—concrete; the stage opening—1,000 sq. ft.; ceilings and walls—24,000 sq. ft.—plaster on brick; carpets (lined)—1,800 sq. ft.; stage curtains—400 sq. ft.; 1,500 ordinary wood seats, 300 under the balcony; opening under balcony—1,200 sq. ft.; the volume of the theater is 300,000 cu. ft.

With this much data we can calculate the total number of absorption units both with a capacity house and with no audience. For convenience, these calculations are tabulated below—for no audience:

Concrete floor	9,000 sq. ft.	at .015	=	135
Stage opening	1,000 " "	at .25	=	250
Plaster (ceiling and walls)	24,000 " "	at .025	=	600
Carpet	1,800 " "	at .25	=	450
Stage curtains (permanent)	400 " "	at .4	=	160
Opening under balcony	1,200 " "	at .25	=	300
Wood seats (1200) (seats under balcony not included)	1,200 " "	at .15	=	180
				2,075

And now that we have calculated the total number of absorption units, our next step is to calculate the period of reverberation for this building. We use Sabine's formula*:

$t = \frac{.05V}{a}$ —substituting in this formula, we get:

$$t = \frac{.05 \times 300{,}000}{2075} = 7.2 \text{ sec.}$$

* The Bell Laboratories quote as follows: "Sabine worked in rooms which did not have a large amount of sound-absorbing material present. Later work in the Bell Laboratories has shown that Sabine's formula is only true for certain conditions, a formula applied more generally being:

$$t = \frac{0.05V}{S \log_e\left(1 - \frac{a}{S}\right)}$$

In the formula, S represents the total exposed area in the theatre, all other factors are the same as in formula (2)."

Let us see what effect this high period of reverberation will have on the acoustical properties of the building. From Fig. 6 we notice that the articulation percentage is reduced to 52 per cent which is absolutely unsatisfactory, even if the noise-to-sound ratio and the loudness level are ideal.

What should be the optimum value for maximum intelligibility and naturalness knowing that the volume of the theater is 300,000 cu. ft.? Referring to Fig. 9, we observe for ordinary speech and music either radiated directly from the stage or through a P.A. system, the reverberation period of the theater should be 2.4 seconds, and in the case of talking pictures it should be 1.4 seconds.

But we must not overlook the fact that a period of 7.2

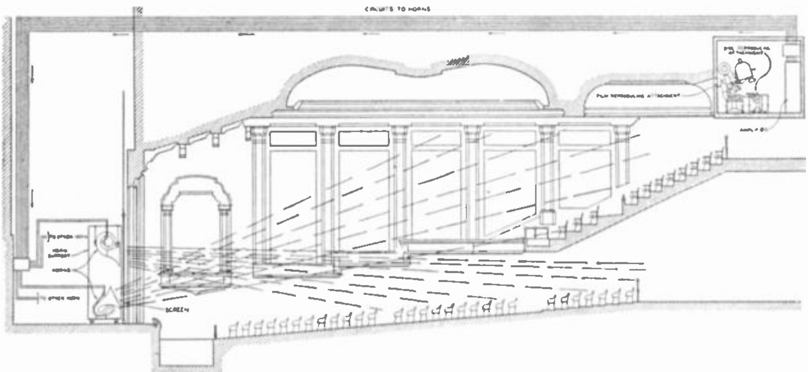


FIG. 11

seconds is for an empty auditorium. Let us see to what extent a full audience will reduce the period of reverberation. To begin with, count out the 300 people under the balcony, leaving 1,200 persons to consider at this time in the theater. The absorption coefficient of each person will be 4.7 units. So for full audience the net absorption will be 4.7 × 1200 or 5640. How about the effect of an audience under the balcony? In the case of the empty hall, with no audience under the balcony, we assigned an absorption coefficient of .25 for every square foot of opening under the balcony. When the seats under the balcony are filled, then the coefficient should be 1.0 instead of .25 as almost ideal absorption will result. Thus the absorption under the balcony is 1200 × 1.0 or 1200 units.

The total number is: 135 (concrete) + 250 (stage opening)

+ 600 (walls, ceilings) + 450 (carpets) + 160 (stage curtains) + 1200 (opening under balcony) + 5640 (audience) a total of 8435 units. Roughly,

$$t = \frac{.05 \times 300,000}{8435} = 1.8 \text{ seconds.}$$

This value is too high for talking picture theaters and too low for general speaking and music presentation. The required absorption for either case is given in formula (2), transposed:

$a = \frac{.05V}{t}$ The required absorption will be:

For talking pictures $a = \frac{.05 \times 300,000}{1.4} = 10,700$ units

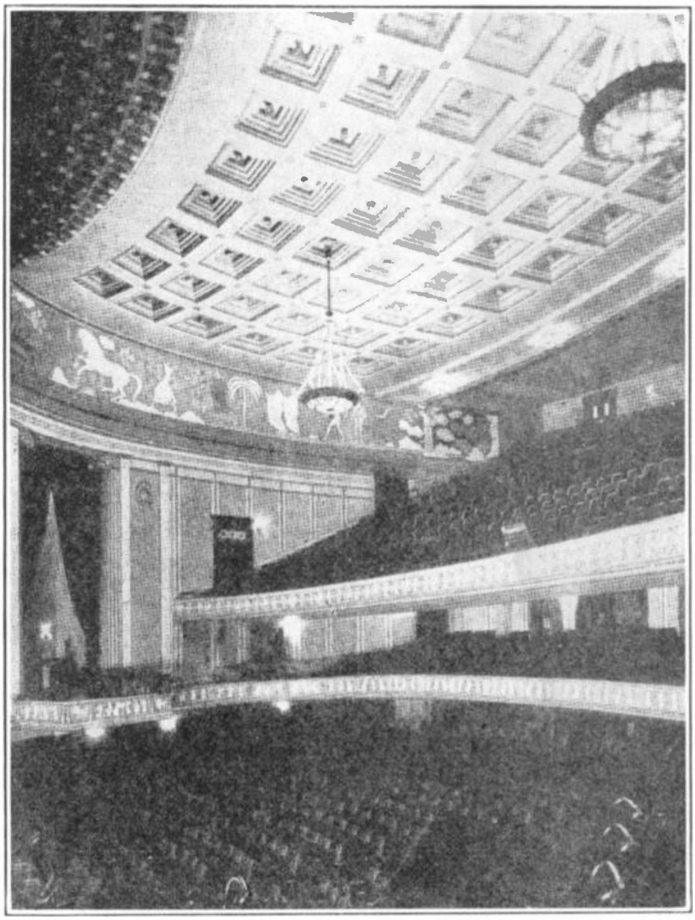
For sound and speech $a = \frac{.05 \times 300,000}{2.4} = 6,250$ units

Very little can be done to raise the period of reverberation once the building is erected. In our case, the curtains on the stage could be removed (160 units); the carpet on the floor eliminated (450) —and a total of 610 units removed. Of course, this is insufficient but as a value of 2.4 seconds seems to be a variable factor depending on the opinion of various acoustic experts, it would be expected that this approach to an ideal condition would be satisfactory.

The usual way to obtain added absorption units is to hang draperies made of velour, a heavy, sound absorbing material, along the side or rear walls. This particular material has a coefficient of .5 unit per square foot. However, it must not be forgotten that the velour used will be hung over plaster. Therefore in calculating the amount of velour needed, we shall have to subtract from the coefficient of velour, the coefficient of plaster which gives us, dividing .475 into 2265 (the extra units required), 4800 square feet—the amount of velour needed.

Where we are not sure of having a full house all the time, it might be well to design our auditorium so that acoustics will be most nearly correct for a three-quarter audience. To find the additional absorption units needed in this case, we repeat our calculations. The fixed absorption units for the theater are

135 + 250 + 600 + 450 + 160, a total of 1595. If the audience is ¾ capacity, there will be .75 × 1200 or 900 units absorbed under the balcony and (900 × 4.7) + (300 × .15) respectively for the audience and empty seats. Total units equal 1595 + 900 + 4230 + 45 or 6770 units. This is approximately 3930 units



Typical theater interior showing paneled walls and coffered ceiling.

below the number required for ideal conditions. A total of 3930 ÷ .475 or 8300 square feet of velour will be necessary.

If upholstered seats were used instead of plain wood seats, our problem would be greatly simplified, for a well upholstered seat will absorb almost as much sound as a person (the ratio is 3.5 to 4.7—about 74 per cent). The use of upholstered seats also reduces the effect of an audience on acoustics to a large degree. With seats having a coefficient of 3.5, our theater would have a reverberation constant of 2.5 seconds without a person in the theater, which would be quite acceptable.

There are several factors other than those mentioned, which might have to be taken into consideration in regard to the acoustics of individual auditoriums. For example, the stage may be bare of furnishings and there may be a bare brick wall at the rear which would introduce considerable reflection so that the stage will have a period of reverberation all its own. Possibly the best solution to the problem in this case would be the installation of materials at the boundaries of the stage opening which would have sufficient absorbing power to eliminate the effects of this reflection.

In the case of talking picture theaters, the screens on which the pictures are projected are made to have no absorption so that sound will pass through them. In other words, when considering the acoustics of a moving picture theater we can disregard the screen and consider the area it covers as the stage opening.

Then, too, regarding the space under the balcony, we do not always consider it as an opening with an absorption coefficient of a certain number of units per square foot. In fact, the rule is that this should be done only when the distance from the front of the balcony to the rear wall of the theater is twice the height of the front of the balcony. This is illustrated in Fig. 10. In auditoriums having smaller balconies, the seats under the balcony are considered and the area of the opening under the balcony is disregarded.

In the special auditorium designed by American acoustic architects for the Soviet Government, a special condition was demanded. The hall is to be used for symphonies, band music, conventions, community singing, opera, cinema sound projection and public speaking. Each requires a different period of reverberation for most natural acoustic effect. It is impossible to change curtains or in any way affect the permanent absorption material. The engineers therefore decided to change the volume of the room, for as you will see from formula (2), if

V is increased the period of reverberation will increase. The depth of the stage and a large opening in the ceiling was made variable and easily adjusted in a few minutes for correction purposes.

HOW THE SHAPE OF THE HALL AFFECTS SPEECH

In spite of the fact that the period of reverberation in an auditorium is correct, the acoustics may be poor in certain portions of it, due to reflection from the ceiling or a wall. It was mentioned before that if a reflected sound reached the ear, out of phase with the direct sound, distortion would surely result if

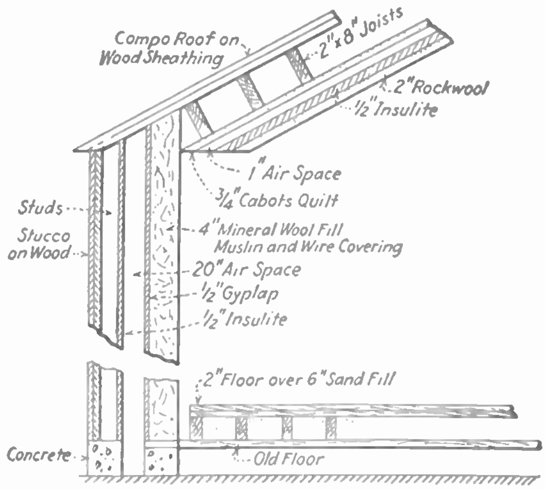


Fig. 12

not a complete balancing out of the sound resulting in so-called "dead spots."

Distortion of this kind can be detected only by observation. If there is any troublesome reflection at all in an auditorium, it will be more pronounced at the higher sound frequencies. Where the walls are flat and fairly porous, reflection distortion is not often experienced. But when the walls are curved or the ceiling is in the form of a dome, reflection is very likely to prove troublesome as the reflected sound is focused to a point in the auditorium.

Auditoriums having domed ceilings can be made fairly free from reflection by proper design. Instead of having a ceiling or dome of flat construction, it may be coffered, that is, broken up into a number of recessed squares with an irregular design in each square. The effect of coffering is to break up the sounds as they strike the surfaces and so to prevent undesirable reflection. The treatment of walls is less difficult, as they can be paneled and covered with fabric of some kind with fairly high absorbing qualities.

After an auditorium has been constructed, if troublesome sound reflection appears, various corrections are possible, such as the covering of bare walls with fabric and the installation of baffles. A baffle used for acoustic purposes is a sheet of sound absorbing material. Used to correct for reflection, baffles may be hung up near the ceiling to cover the portions where reflection occurs.

In cases where directional speakers are used in talking picture theaters, most of the effects of reflection can be eliminated by proper placement of the speakers. Fig. 11 shows the proper placement of theater horns for minimum reflection from the ceiling. Sometimes "dead spots" are eliminated by the use of small supplementary speakers focused on these spots.

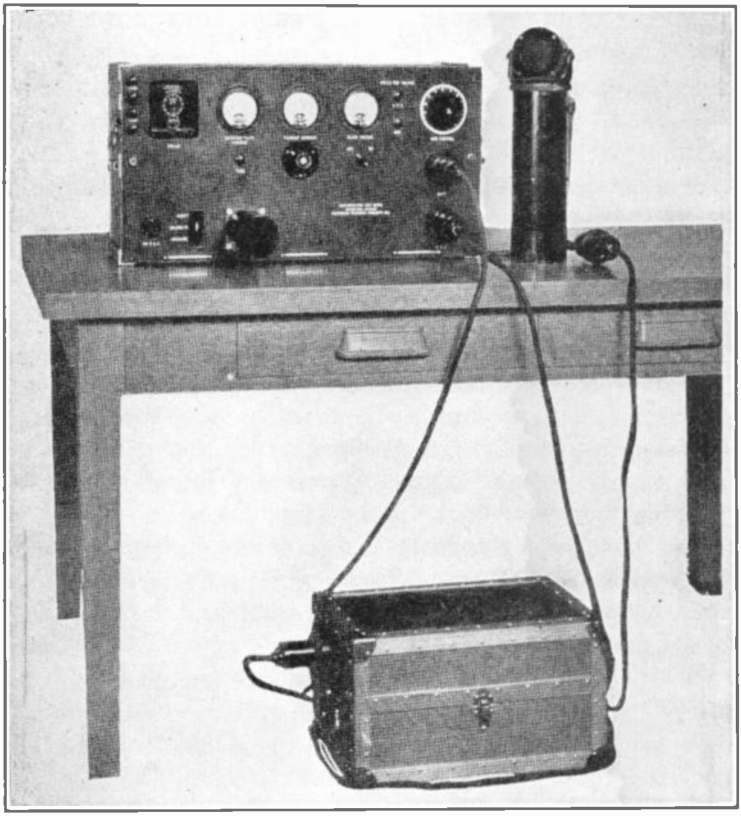
In the initial design of auditoriums and theaters, uniform distribution of sound is a very important factor and calls for expert architectural design. Experimental work is very valuable. Generally a model cross-section will be made, the sides of which are painted grey and black and rays of light from the intended spot of sound emanation substituted for sound. The distribution of light gives a good indication of the eventual sound distribution. Cancelled and reinforced reflections, echoes, resonance spots are thus easily spotted and corrected for in the building design.

But in halls that are completed, the alteration of the angle of reflectors, the use of sound absorbing material and the use of directional speakers are the general methods of correction.

SOUND PROOFING IN BUILDINGS

Too much attention cannot be paid to the problem of sound proofing. In the broadcasting studio and the motion picture sound stage outside sound absorption is essential for proper operation. The camera must be absolutely sound proof when studio recording is in progress. The projection booth in the theater must be sound proof so that the unpleasant noise of the motion picture projection machines when in operation will not be heard by the audience. The field of sound proofing is not limited to the theaters, as we shall see by a partial list of its applications. We find sound proofing essential for quiet rooms in hospitals, hotels, office buildings and music studios.

We will limit ourselves in this chapter to the sound proof-



Western Electric reverberation time measuring apparatus.

ing of the projection booth in the theater and the sound stage for sound recording. After all, these two are exactly similar. In one case we are recording sound and in the other, we are reproducing the same sound or sounds. In one case we wish to keep all outside noise from reaching the stage and in the second we prevent any of the sound in the projection booth from reaching the audience.

Sound may be transmitted into a building in three different ways: (1) by direct air vibration, (2) by direct transmission through the material of which the building is made, and (3) by what is termed panel action, i. e., the setting into vibration of a portion of the wall structure which in turn will set up air waves inside the structure.

In order to obtain perfect sound insulation, the following constructional features must be observed:

1. There must be no leakage of air from the inside to the outside of the structure, that is, no connecting air passages, ventilator pipes or openings. Adjacent rooms must be sound free from what goes on in the other, they must be air tight.

2. The construction of walls, floors, ceilings of the room must be such that sound will not be easily transmitted through them.

3. The actual structure of the walls, floors and ceilings must be so rigid that no panel action occurs under any operating condition. Even loud sounds outside must not be heard inside and loud sounds inside must not be heard outside.

The degree of insulation required is determined by the fact that a sound attenuation of 60 db. must be obtained.

Doors must be of massive construction and carefully sealed to insure no air leakage from the inside to the outside.

To obtain an insulation value of 60 db., heavy concrete or stone may be used, or thin layers of sound insulating material may be used, separated by air spaces. It must be borne in mind that in sound stages or broadcast studios, the use of sound absorbing material will reduce the period of reverberation. The design is such that for a sound stage, the period will be about one second.

Sound absorbing material is generally used in sound proofing, such as sheet rock, Masonite, Celotex, Insulite, Cabots quilt, rock wood and a host of similar sound absorbing materials. The accepted practice is to use thin layers of this material alternating with an air space. The entire structure is made extremely rigid to prevent panel effect.

In sound studios, each studio is built on its own concrete foundation, with an air space between adjacent rooms. Fire proofing material is generally used to separate the sound stages or studios. Fig. 12 shows a typical wall construction.

Ventilation is a serious problem in sound proof rooms and calls for elaborate air-conditioning plants. Washed, cooled and dehumidified air is conducted into the rooms through baffled ducts and the air exhausted through grills in the walls, but in no way is a direct air passage between sound-proof rooms permitted.

ACOUSTIMETER

This sound measuring device consists of an electrical sound pickup, a four stage transformer coupled audio amplifier, a gain control, a vacuum thermocouple and a very sensitive millivoltmeter. The schematic diagram is shown in Fig. 13.

The sound pickup is a magnetophone of the Baldwin type, the sound moving the diaphragm causing a flux change in the

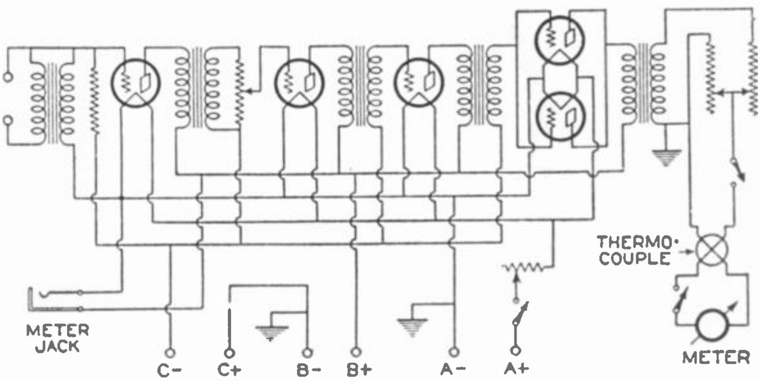


FIG. 13

magnetic circuit. The change in flux linkage induces a voltage. The small voltage set up in the microphone due to the sound waves impinging on its diaphragm is amplified and a current is fed to the thermocouple, which supplies a direct current to the millivoltmeter. This current is proportional to the square of the current from the amplifier. The intensity of sound is proportional to the square of the amplitude of the sound waves (which determines the microphone voltage) and since the final current is proportional to the square of the voltage which is generated by the pickup, the meter reading will be proportional to true sound intensity units.

The calibration of the instrument is simple. A source of sound is placed one foot from the pickup and it must be of such intensity as to give a readable deflection on the millivoltmeter. The observers now walk away from the source of sound to a point where the sound is just inaudible. This is the point of zero db. or unit intensity. Knowing the distance d in feet and the fact that it is zero db., the intensity reading of the meter may be calculated for: $I_{1ft} = d^2$ units. The meter may then be calibrated in terms of db. loudness or directly in intensity.

REVERBERATION TIME METER

From the definition of reverberation period, the time it takes the sound to decrease to one-millionth of its initial value (60 db.), we have some indication as to how it may be measured. A simple electrical instrument has been developed by the Electrical Research Products, Inc., to measure this period.

A microphone converts the picked up sound energy into an electrical current; which is amplified by a cascade tube amplifier. This amplified current operates an electrical timing device. When the sound source is cut off, the timing device begins to operate and continues to register time, until the sound intensity has decreased below some predetermined threshold time. This time is read off the timing device and is proportional to the period of reverberation. It would be exactly equal to the period of reverberation if the timing device was cut off at a point 60 db. below the maximum.

TEST QUESTIONS

Be sure to number your Answer Sheet with *the number* appearing on the front cover underneath the title of this text.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another set ready to send in. Send each lesson in by itself before you start on the next lesson.

In that way, we shall be able to work together much more closely, you'll get more out of your Course, and the best possible lesson service.

1. Tell what is meant by the "period of reverberation" of an auditorium.
2. What is considered as the perfect "percentage articulation" rating?
3. (a) From the curve in Fig. 4 what would be the percentage articulation if the noise level were 40 db?
   (b) Would intelligibility be satisfactory under these circumstances?
4. At what sound frequency is the period of reverberation usually calculated?
5. Why is a certain amount of reverberation needed in an auditorium?
6. If the period of reverberation in an auditorium is too high, what can be done to lower it?
7. What would be the reverberation time in seconds for a theater with a volume of 420,000 cubic feet, if the floor, carpet, stage curtains, seats and other sound absorbing materials utilized in the construction of the building amounted to 3000 absorption units?
8. In what three ways may troublesome sound reflection be corrected in an auditorium?
9. Name three different ways in which sound may be transmitted into a building.
10. What is the db. level of loudness at the threshold of audibility?

Acoustics of Buildings. No. 52RH

1. The period of reverberation is the time it takes for a given sound to reduce to one-millionth of its original intensity.

2. 96%

3. (a) About 62%
   (b) It would not be satisfactory.

4. 512 cycles per second.

5. To make the speech or music sound natural, and to make music sound brilliant.

6. Various sound absorbing materials may be placed over walls or floors.

7. $t = \frac{.05V}{a} = \frac{.05 \times 420{,}000}{3{,}000} = 7$ seconds.

8. By altering the angle of the reflectors; by the installation of sound absorbing materials; and by the use of directional loudspeakers.

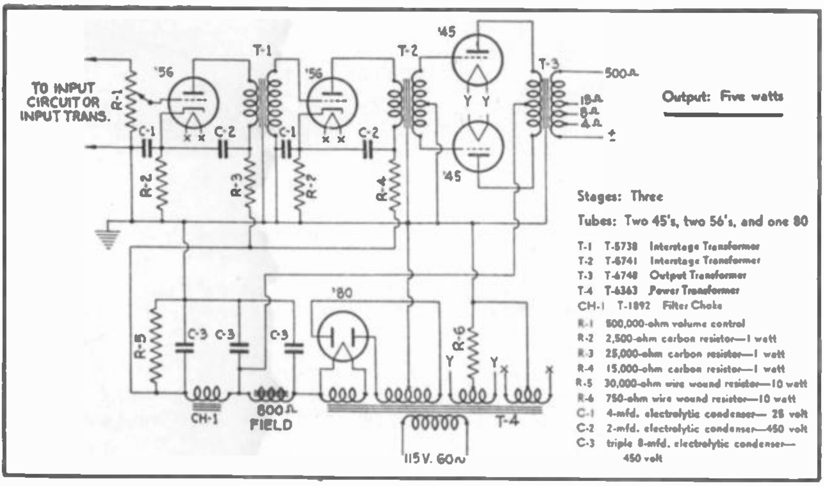
9. (1) By direct air vibration; (2) by direct transmission through the material of which the building is made; (3) by setting into vibration a portion of the wall structure which in turn will set up air waves inside the structure.

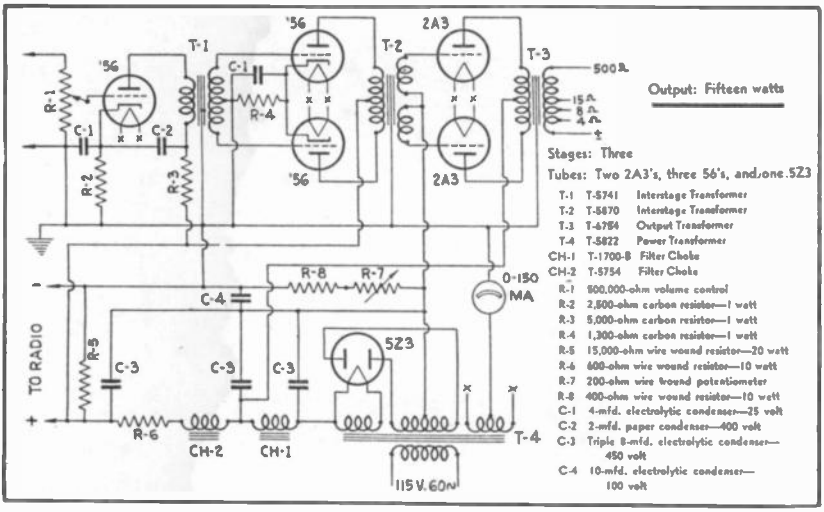
10. Zero db.

ESSENTIALS OF INDOOR AND OUTDOOR PUBLIC ADDRESS SYSTEMS

PART 1 53RH-1

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.





Typical P. A. amplifiers. Class A output. Approximate gain sufficient to work out of a high quality double button carbon microphone. Input through a microphone-grid impedance matching transformers or equivalent. Designed and tested by the Thordarson Electric Mfg. Company, Chicago, Ill. Thordarson transformers and iron core chokes specified, but equivalent of other makes may be used. Note: The field in the upper diagram may be replaced by a 30 henry choke having a resistance of 800 ohms; if its resistance is less, insert in series a 10 watt resistor so total equals 800 ohms.

NATIONAL RADIO INSTITUTE

WASHINGTON, D.C.

A LESSON TEXT OF THE N. R. I. COURSE
WHICH TRAINS YOU TO BECOME A
RADIOTRICIAN & TELETRICIAN
(REGISTERED U. S. PATENT OFFICE) (REGISTERED U. S. PATENT OFFICE)

NCP2M841

Printed in U. S. A.

Essentials of Indoor and Outdoor Public Address Systems

INTRODUCTION

It is generally agreed that the job of installing, monitoring and servicing public address (P. A.) systems is closely associated with the radio receiver servicing field. Many expert servicemen are in this branch of radio on a part or full time basis. Like many other "off-shoots" of radio servicing, the main obstacle in getting started is the fear that perhaps you do not know enough. If you have diligently studied the principles of radio so far presented in the Course and the essentials of public address systems now to be presented, you will gradually acquire more confidence and ability. Start with small P. A. systems and when you gain experience in dealing with the public you will quickly find that no P. A. job will be too big to tackle.

A public address system is a sound reinforcing system, designed to broadcast or project to a limited audience some local event, so this gathering may hear all that is being conveyed to them with the least personal effort. They should not feel that they are listening to amplified sound, otherwise the naturalness of the presentation is destroyed. Many sound technicians make this mistake. Of course, for every rule there are exceptions and a P. A. system used for "ballyhoo" or attention getting is an exception. In general, a permanent installation should not make the public aware of the artificial means of raising the sound level. By this we mean that the equipment should be out of sight, the loudspeakers hidden or made to match the surroundings, and the sound level just enough to be clearly understood above objectionable noise.

Broadly speaking a P. A. system is an assembly of sound pickups, feeding through controls and amplifiers and transmission lines to one or more loudspeakers. But a well organized system is more than a haphazard connection of these components. These parts must be impedance matched so the greatest undistorted power can be derived from the entire assembly. Controls must be simple to operate and positive in their action; the public must not hear a definite abrupt switch or change in a program. Nor should the amplifiers have too much or too little gain. If the amplification is low, the desired reinforcing effect will be lost; if the gain is too great, the system in the hands of an inexperienced operator will blast out the sound, ruining the naturalness of the reproduction. Strive for natural reproduction!

Every public address installation presents a group of problems that can be met in a general way with a portable or temporary system, or can be completely fulfilled by means of a special assembled system. Public address systems broadly divide themselves into: *a*, indoor; and *b*, outdoor systems. The problems encountered will depend on: *1*, the space or area to be covered; *2*, the quality of reproduction, that is, fair, good, or high fidelity reproduction; *3*, kinds of service to be rendered, that is, are speakers * or performers to be picked up, phonograph records to be transcribed, or a local radio broadcast to be tuned in, and then amplified and projected to the gathering of people? Many associated questions must be answered before a plan can be started. What kind of power: battery, A. C. or D. C. mains, or no source at all is available; is the installation to be permanent; will there be additional future demands, and does the customer want to have the system laid out so future additions will be inexpensive; who is to operate the system, will he have technical ability; will there be a rapid change from one type of program to another; where will the amplifier, controls, pickups and loudspeaker be placed; and finally, what is the acoustical nature of the space that is to be showered with reinforced sound?

The well informed sound technician carefully considers all these factors, in fact, makes a careful record of them so they will be constantly before him while laying out his plans for a suitable system. Furthermore, he would make a detailed sketch of the place where the system is to be installed. Only after a careful survey of the job can specifications for the system be made. And before the work is started, the plans and price should be approved by the customer—in writing.

Assuming that your technical plans are complete, further problems must be answered; who is to install the system, and where will you get the various components? In many localities, permanent wiring must be made by a licensed electrician. If you are faced with this problem get a licensed electrician to do your wiring under your supervision.

Now for the components, such as the microphones, loudspeakers, amplifiers, cables, etc. Be wise, and buy only manufactured components of a reliable maker. Leading radio supply houses and some manufacturers will sell directly to you, and they will gladly render valuable technical assistance. In the long run, it is far cheaper to buy the products of good makers. Mistakes which might be costly are avoided, you know exactly what you are getting and what it will do, in fact, performance as specified is guaranteed. And if you think that there is little to do if this burden is removed, hold your decision until you learn more about P. A. problems. Remember, too, that a lot of time is consumed in soliciting customers for permanent and rental systems. Let us stress this: a modern sound technician buys the required components, assembles them on racks or a control table, completes the necessary wiring, and trains the operator designated by the customer.

---

* In this text the word *speaker* will refer to the person in front of the microphone, the word *loudspeaker* will mean the audio signal to sound converter. This distinction is made because many technicians use speaker and loudspeaker interchangeably.

ESSENTIAL PARTS OF A P. A. SYSTEM

Now let us briefly enumerate the components of a P. A. system which we will later discuss in greater detail. We will not consider the theory or principle of their operation as this has been taken up before, many times.

Pickups.—Every system must have a source of sound, which you know is too weak to reach the audience as it originally exists. Or there is some other source of entertainment that must be translated into an audio current. The *microphone* is of primary importance in a P. A. system. They are of the *1*, double button carbon; *2*, condenser; *3*, inductor, dynamic or moving coil; *4*, ribbon or velocity; and *5*, the crystal types. Each type has its own peculiar properties and special features which render them useful for a given purpose. We will come to this shortly.

The phonograph record, the phono-pickup and the turn table group is second in importance in a P. A. system. In fact, this pickup is practically indispensable. Music is often used to get and hold a gathering. Recorded music ties programs together and often places the audience in the proper state of mind for a subsequent presentation. Showmanship plays an important part in this case, but you are merely interested in supplying this feature in a technical way.

Local radio broadcasts are usually third in importance as a source of entertainment. Yet in the case of a centralized radio system as usually installed in apartments, hotels, clubs and hospitals they may be of prime importance. In general, a radio tuner is used to pick up important sport events, special concerts, an address from a notable person, or an educational talk; all subjects that would normally interest a special group of individuals. This radio tuner invariably contains the R. F. system and the detector. Programs from a local station are only picked up, as they alone have fidelity and freedom from noise.

A microphone, a phono-pickup, or a radio tuner may be the only pickup. They may be used in combination or several of each may be required depending, of course, on the purpose of the installation.

Pickup Amplifiers, Pads, Matching Transformers and Lines.—Each pickup has its own peculiar electrical properties. Its output level and its output impedance may be quite different than the other pickups it may be used with. If the output level is too low, it must be raised to a higher value before the signal can be conveyed over a long transmission line to the main controls. Microphone or head amplifiers, close to the pickup, are often essential equipment. Should the output level of some device, the radio tuner, for example, be too high, then it may be necessary to cut the level down by means of an attenuating pad. This balancing of levels tends to make the following controls behave more uniformly and allow inexperienced operators to handle the equipment.

Not only is a condition of equal level considered good practice, but equal output impedance is often a desirable feature. For example, a velocity mike has a very low impendance, about .01 ohm. A great deal of the signal would be lost even if a short line were used. So an impedance step-up transformer is used to raise .01 ohm to 200 or 500 ohms, which are considered standard pickup output impedance values.* A radio tuner or a crystal mike normally have output impedances above 10,000 ohms. If connected to a line, noise currents will interfere with the desired signal. An impedance step-down transformer is required, and in the case of the crystal mike a microphone amplifier may be needed.

To approach the ideal of naturalness, we said that the control and amplifier equipment should be out of sight. Microphones are, in most cases, an exception. Microphones are connected to the control equipment by means of low frequency lines. They must be: durable, flexible, contain large gauge conductors, have little capacity and in the majority of cases covered with metal loom or shielding. Shielding is required to prevent noise and hum signal pickup. In spite of the shielding, pickup (low level) cables must be laid as far away as you can possibly put them from high level signal lines and A. C. supply lines.

Mixers and Faders.—Where only one type of pickup is to be used, or even where two or more may be used but never at the same time or quickly following each other, it is possible to feed the signal directly from the pickup to the amplifiers provided their impedances are matched. In fact, it is often the practice to terminate each pickup in a phone jack; make the input to the amplifier through a similar phone jack; and connect the pickup and the amplifier with a so-called "patch cord." The latter is nothing more than a flexible cable with a phone plug at each end.

However, the above procedure is not good practice if the pickup is to be quickly changed while the program is on. For if the patch cord carries D. C. or signal current, a loud "plop" will be heard by the audience. You will later learn, that the output level of the main amplifier may be reduced to zero before a switch in pickup is made, thus removing the objectionable plop. An operator must be trained in this procedure. But if these facts are not objectionable you may resort to patch cords or toggle switch change-over schemes.

The logical procedure is to feed each of the pickups, which we said were of equal output impedance and about equal power level, to a constant impedance variable attenuator (a variable pad) of the same impedance; connect the variable pads in series or in parallel; and the combination matched by means of a transformer to a master attenuator or to the input of the amplifier. If the master level control is used it should be impedance matched to the device it feeds into, usually a voltage amplifier. Thus the output level of each pickup may be controlled; any pickup may be gradually taken out of the circuit and another pickup introduced; or 2 or more pickups may be used simultaneously and to any desired

* Velocity microphones are now available with a high impedance output, for a direct grid connection.

level. Flexibility in the choice and use of a pickup is the desired objective.

Voltage and Power Amplifiers.—When you stop to think that the average level of a sensitive microphone or a high fidelity microphone and its amplifier is about —50 db, it should be clear that considerable amplification is required to raise the signal to the usual power levels of 30 to 40 db (6 to 60 watts) above 6 milliwatts. As you no doubt know, this is accomplished first by the use of several stages of voltage amplifiers feeding into a final power audio stage. In some cases a high gain low power output amplifier feeds a high power class B amplifier.

Shall the amplifier be one complete assembly; or should the amplifier system be divided into a main voltage amplifier, followed by a unit having a single voltage amplifier feeding the power stage? For permanent installations a single unit is best; but where there is any possibility of expanding the system, a divided unit is best in the long run. There is no "hard and fast" rule.

The power amplifier terminates in a line matching transformer which feeds one or more loudspeakers. Usually there are several output impedances to choose from, so any combination of loudspeakers may be used.

Audio Power Lines.—The lines connecting the power amplifier and the loudspeakers are audio power lines, conveying from 6 to 60 watts. Power is valuable and must not be lost on the line. You should know that for normal fidelity (up to 5,000 c.p.s.) very little frequency attenuation is obtained in lines up to 4,000 feet; however, even when the conductors are made large and the terminating impedance is made high (about 500 ohms) appreciable power loss is experienced in lines of 4,000 feet. Compensating for frequency attenuation is not important unless longer connections are required.

Loudspeakers.—From an electro-acoustic viewpoint, the loudspeaker is the terminal point of a P.A. system. The volume of space in the case of indoor systems; the area to be covered in the case of outdoor systems, determines the sound energy required from the loudspeakers. The efficiency of the loudspeakers used determines the total required power input; while their input power rating determines the number required. Knowing the required audio power and the output of the pickups you plan to use, a basic start in planning a system is obtained.

Magnetic and permanent dynamic loudspeakers are used for small halls and centralized radio systems; phones are generally used in hospitals; moving coil units with horns, and dynamic cone loudspeakers with flared baffles are always used in outdoor P.A. systems, and generally in indoor systems. Flat baffle dynamic cone loudspeakers are used indoors when the space has been acoustically treated. Tweeter loudspeakers, a crystal or moving coil unit with a small horn, working in the audio range of 3,000 to 10,000 c.p.s., are very often used in conjunction with the regular sound projectors to reinforce the high audio sound signals. This addition provides higher fidelity.

Horn or flared baffle loudspeakers are preferred whenever their appearance is not objectionable or when they can be concealed from sight, because sound from them may be directed to the audience. Their efficiency as a sound converter is generally four times that of a flat baffle loudspeaker.

A Block Layout.—Let us sum up this discussion with a block diagram, as shown in Fig. 1. Power supply is omitted at this point of our study. There are three kinds of pickups: *R.T.*, a radio tuner; *V.M.*, a velocity mike; and two phonograph pickups, *P.P.* The radio tuner and the phono-pickup are close to the controls and the amplifiers. *R.T.* has a detector plate indicator to indicate resonance and relative power output, a station selector and *V.C.*, its volume control. Two phonograph pickups are used so reproduction can be switched quickly from one record to the other, using *F* the fader. They, too, are close to the control and amplifier equipment. The velocity mike, *V.M.*, is placed with its associated microphone amplifier at the source of pickup and fed to the mixer, *Mx*, through a shielded line. All three pickups are terminated at equal impedances and at approximately the same level.

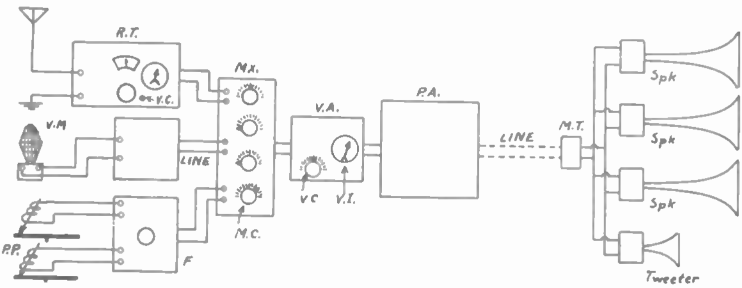


Fig. 1

Three of the controls on the mixer adjust the level of the pickups, and *M.C.*, the master control allows a change in the general output level. Following the mixer is *V.A.*, the voltage amplifier and *P.A.*, the power amplifier. Two units are shown although one unit may be used. The loudspeakers, *Spk.*, are connected in parallel and through a matching transformer, *M.T.*, presenting a fair impedance to the power line. The line connects to the output of the power amplifier. All connecting units are impedance matched, and the *V.A.* and *P.A.* supply the needed level raising.

Now that we have an overall picture of public address systems, let us study each section, unit and control in greater detail. The purpose shall be to get the practical importance of each section as used in P.A. systems.

POWER LEVEL AND POWER OUTPUT

Before we consider the technical side of the various P.A. sections, two thoughts should be made clear. First, let us clearly understand what is meant by the input and output impedance of a device. Of course, a pickup has only an output impedance, a loudspeaker only an input impedance. Technically for a load it is the ratio of an A.C. voltage applied divided by the A.C. current developed in the loading device; for a generator or a signal source it is roughly the open circuit voltage divided by the short circuited current.

If a generator with a variable impedance is connected to an input or a variable load is connected to a supply source, maximum power will be transferred when the impedance of both are equal. In some cases, especially with a tube output circuit, an exact match is not desired for a higher or lower load impedance may be desired to obtain a large voltage amplification, or the maximum undistorted power output. All this should be familiar to you by now. Fortunately, the recommended input and output impedance is given by the manufacturer of the unit you plan to use so you need not worry

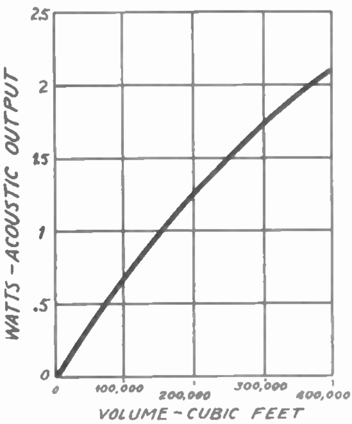


Fig. 2

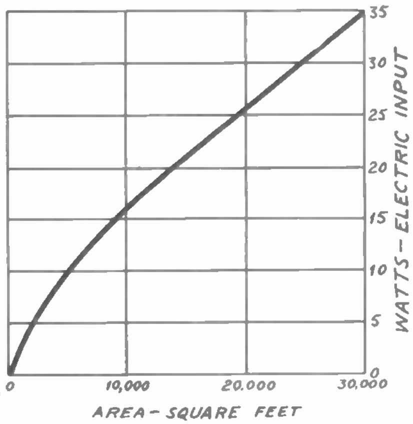


Fig. 3

why that particular value is needed. Furthermore, the gain or power output level is given for the recommended impedances.

Thus, and this is important, the output level of a pickup is given for a load equal to the impedance of the device. The gain of an amplifier, or the loss in a pad or a control is given for the condition of matched input and output impedance and the controls set to full value. If frequency is involved, this information is given for a reference frequency, usually 1,000 c.p.s.

Required Power Output.—Although the loudspeakers are at the end of a public address system, they are for design purposes the starting point. "How much power should I feed the loudspeakers to adequately cover the audience?" is a question constantly asked by beginners. It is easier to ask the question than to answer it. Sound engineers can tell you how much power must reach an individual's ears to give reasonable intelligible reproduction; but how much sound power to shower on an audience is only answered by experience.

Power Required Indoors.—Experienced sound theater engineers have very carefully studied the indoor problem and their results are worth following when an indoor job is considered. Figure 2 is a chart of experience for an indoor job. Note that the acoustic power is delivered by the loudspeakers; the volume of the space is its *length* × *width* × *height*. Of course, only average conditions are considered. If the hall is long and narrow more power is required; if short and high less is required. Thus a hall having 200,000 cubic feet of space requires 1.2 watts of acoustic power. To determine the input, we must know the conversion efficiency of the loudspeaker we plan to use. Although this varies with frequency, we can roughly assume from experience that the efficiency of a:

Flat baffle dynamic loudspeaker is 5%

Exponential horn or flared baffle dynamic loudspeaker is 20%

TABLE NO. 1

WATTS	DB	WATTS	DB	WATTS	DB	WATTS	DB	WATTS	DB
.00048	−11	.006	0	.076	11	.95	22	11.9	33
.00060	−10	.008	1	.095	12	1.2	23	15.2	34
.00076	−9	.010	2	.12	13	1.5	24	19.0	35
.00095	−8	.012	3	.15	14	1.9	25	23.7	36
.0012	−7	.015	4	.19	15	2.4	26	30.4	37
.0015	−6	.019	5	.24	16	3.0	27	38.0	38
.0020	−5	.024	6	.30	17	3.8	28	47.4	39
.0024	−4	.030	7	.38	18	4.7	29	60.0	40
.0030	−3	.038	8	.47	19	6.0	30	75.9	41
.0039	−2	.047	9	.60	20	7.6	31	94.9	42
.0048	−1	.060	10	.76	21	9.5	32	119	43

To find the input power in watts for a flat baffle loudspeaker multiply by 20; for a good horn type dynamic loudspeaker multiply by 5. Thus in the case just cited where 1.2 sound watts are required, you would need an input of 1.2 × 20 or 24 watts when flat baffle speakers are used; and 1.2 × 5 or 6 watts if horn loudspeakers are used.

A few final facts about indoor power requirements. The value of input power obtained in the aforementioned manner, is for an auditorium with normal background noise, with little breaking up of the space, and a near capacity gathering. The power determined is for reproduction of music. Speech power required is about 6 db lower. However, if the power is figured for music, speech levels will be more than adequately covered. Improved reproduction is obtained if the auditorium is acoustically treated.

Power Required Outdoors.—A guide for outdoor coverage is not so easily laid down, but again the experience of sound technicians can be relied on. In this case the governing factor is the square feet area to be showered with sound power. Figure 3 is a chart of experience for average conditions and in this case the power input to horn type dynamic loudspeakers or flared baffle dynamic cone loudspeakers. The horns are directed to the area to be covered. If the area is broken, as it would be in the case of a stadium, each area is considered by itself and loudspeakers for that area installed. In general, greater power is required outdoors than indoors, as there is no reflection of sound energy to reinforce the direct sound waves, the noise outdoor is quite high and you may have to project sound against a wind.

Converting Watts to Decibels.—For purposes of selecting loudspeakers and determining the power output of the driving amplifier, watts required is the important information. But when the gain of the amplifier is to be figured, power level in *db*, is the accepted method of expressing output. The reference zero level is 6 milliwatts (.006 watt); that is, .006 watt is zero db. Power above this value can be computed, although Table No. 1 may be more convenient. Remember that if you increase the level by 3 db you roughly increase the power by two.

SOUND REPRODUCERS

The type of reproducer that you would select for use in a sound reinforcing or distributing system will vary with the purpose of the system. Furthermore, the number of reproducers and their size would depend on the character and size of the space involved. Reproducers may be classed as low and high level reproducers, the dividing line being about one watt. Phones (earphone) and moving armature magnetic loudspeakers would be considered as low level reproducers; moving coil dynamic reproducers of the permanent magnet or electromagnetic type of excitation would fall in the high level class.

Phones are only used when the reproduction is to be confined to a single listener; as for example, in hospitals, centralized court reporting systems or where a special channel is installed in a P.A. system for those hard of hearing. Of course, several phones may be used in parallel supplied from a common audio supply. A phone and head band is required for each listener and this combination is called a head or ear set. Although phones can be obtained in all degrees of sensitivity and impedance, it is best to use a high impedance high frequency (music) reproducing unit. The average phone when fed with 10 milliwatts (about 2 db) will give fairly loud reproduction. The A.C. impedance should be about 10,000 ohms and the unit should have a resonate peak at about 4 to 5,000 c.p.s. Remember that the resistance of a phone, the usual rating, is not its A.C. impedance; figure about 5 times the D.C. resistance, if the impedance at 1,000 c.p.s. is not given.

Several phones may be connected in parallel and the required input power figured as the: *number of phones* $\times$ *10 milliwatts;* the total impedance figured as: *impedance of one phone* $\div$ *numbers of* *phones.* This does not provide for any volume adjustment which, of course, is a very desirable feature in any centralized sound system. For level control, the input to each phone should be through an approximate constant input impedance variable attenuator, 10,000 ohms for the average case. This addition does not appreciably alter the impedance of the unit, but additional power may be required. Figure 4 shows: *a*, phone unit and head band; *b*, an inexpensive dual variable resistor, one unit preferably with a sharp taper; and *c*, the proper connections. If both resistor units R_1 and R_2 are of the uniform resistance type and equal to the phone impedance, the input impedance will vary from *Z* to *Z/2* (in our example a variation from 5,000 to 10,000 ohms); required power input will be *twice* that needed by the phone. If R_2 is a tapered resistor, increasing in resistance from points *2* to *1*, the input impedance will be substantially equal to *Z* and the power consumed at full volume nearly 10 milliwatts, if this is our base value.

Magnetic Loudspeakers—The magnetic or moving armature loudspeakers needs only little further discussion. A typical con-

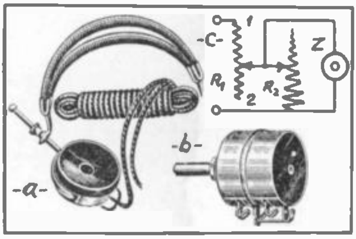


Fig. 4

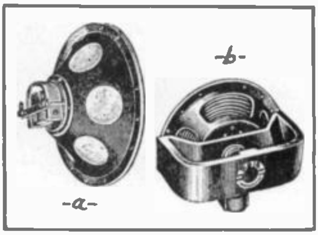


Fig. 5

struction is shown in Fig. 5a. As it employs a permanent horseshoe magnetic to produce the magnetic field, no power supply is required. These reproducers are generally used in a sound distribution system, such as you find in hotels, apartment houses and school rooms. Of course, the entire unit is housed in an attractive box with a grill, or is built into the wall and covered with a loudspeaker plaque or grilled board. The compartment in back of the loudspeaker should be lined with sound absorbent wool, or other acoustic absorbing material. Naturally a volume control, as shown in Fig. 4c should be used, so the sound level in the room can be controlled or the loudspeaker can be shut off completely.

The average magnetic loudspeaker has an input impedance of about 4,000 ohms at 1,000 c.p.s.; the D.C. resistance is about 1,000 ohms. Loudspeakers should be purchased without input transformers or choke-condenser systems, for in a normal installation only A.F. currents will be fed to it. Loudspeakers are connected in parallel to a common line and the input of the line matched to the amplifier. A magnetic loudspeaker should not be fed with more than one watt (22 db) of power, although it usually is sufficient to supply about .5 watt (19 db). When connected into a system the input to each loudspeaker should be kept substantially constant, so the load on the power amplifier will not vary. An variable L pad with one tapered unit will accomplish this without appreciable loss of power. Figure 0.5 watt per loudspeaker for the average small room and one watt for large rooms only if this kind of control is used.

Permanent Magnet Dynamic Loudspeakers—There are cases where a room requires more sound than available from a single magnetic loudspeaker; or there are cases where only a small sound output is needed in a complete P.A. installation; or cases where sound reinforcement is desired in out of the way corners of a large installation. Here are conditions where it would not be wise to use the regular dynamic loudspeaker with its costly field supply system; and naturally a permanent magnetic dynamic loudspeaker is recommended. These loudspeakers will handle 3 to 6 watts (27 to 30 db) and give reproduction comparable to any average dynamic. A typical loudspeaker is shown in Fig. 5b, which must, of course, be attractively housed and the rear acoustically treated if built into a wall.

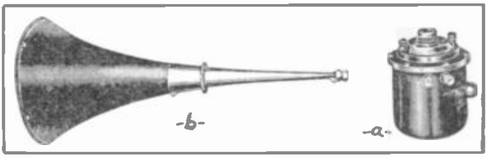


FIG. 6

These loudspeakers have a normal voice coil impedance of about 6 ohms. If these loudspeakers are placed close to the power amplifier, a direct line can be used. We shall shortly learn that a power amplifier has an adjustable output impedance. Thus 2 or more such loudspeakers may be fed directly over a short line. *As a rule, no control of level is provided at high level reproducers,* the control existing in the amplifier.

Separately Excited Dynamic Loudspeakers—Where 5 or more watts are to be fed to a single reproducer, a moving coil loudspeaker excited by an electromagnet is generally used. The basic unit is made in two forms: *a*, the moving diaphragm, a unit for a horn or trumpet; and *b*, the moving cone unit which couples to the air by means of a flat or flared baffle. Both types are to be obtained in sizes of 5 to 25 watts input continuous handling power. Their voice coil impedances vary, but are usually in the range of 6 to 15 ohms.

Figure 6a is a typical dynamic moving diaphragm unit, while Fig. 6b is a trumpet or morning glory type of horn. The unit is selected for the power you wish to feed to it; while the horn is selected according to size (length, flare and mouth oppening). In general, the longer the horn and the wider the mouth opening of the horn, the lower the frequency response. The throat or smaller opening must equal the diameter of the unit opening for perfect acoustic match. If you buy both horn and unit from the same maker, these details may be assumed as being correct. Collapsible trumpets may be purchased for use in portable or easily knock-down systems. Horns for outdoor use should be of the weather proof type.

Of course, you are familiar with the dynamic cone shown in Fig. 7a. These units come in sizes of 6 to 14 inches cone rim diameter and, generally speaking, the power handling ability and the fidelity of reproduction increases with the diameter. The average cone dynamic is made in 5, 10, 15, 20 and 30 watt sizes. To reinforce the base response, a baffle is required. Flared or horn type baffles as shown in Fig 7b are best suited for P.A. needs; although the flat or box type baffles are often used in auditoriums that have a low reverberation (sound persistence) period. Always use the flared baffle if its appearance is no objection, or where it can be concealed behind a grill. Be sure to order baffles with a hole to match the rim size of the unit. Note that the unit is placed in a box attached to the flared baffle. The box should be sound absorbent, to prevent box resonance and to prevent rear sound radiation, an ideal condition. Quite often in theatres where a sound reinforcing system is installed for stage entertainers or speakers, two cabinet baffles as shown in Fig. 7c placed at the front facing the audience and at the extreme sides of the stage are used.

Horns and flared baffle dynamic loudspeakers are superior to the usual flat baffle type, first because they increase the electric to sound conversion efficiency and secondly because they have directive effects. Wherever a localized group on the ground is to be covered, a flared baffle with the upper surface of the flare parallel to the ground will be found to be best. Outdoors, the sound produced may be showered on the audience by pointing the loudspeaker to them; indoors, the direction of the horn is varied so best coverage without echoes or sound cancellation is obtained. The position of horns in an indoor installation is only considered correct after various directions have been tried. It is always best to use 2 or more low power loudspeakers rather than one large power loudspeaker, because various directions may be selected to better cover the audience.

The input power to the loudspeakers required to cover the gathering divided by the power input rating of the loudspeakers you choose to use equals the number of loudspeakers required.

Excitation of Dynamic Units—As a rule units such as shown in Fig. 6a have a low field resistance and when connected to a 6 to 8 volt source, the field will draw 1 to 1.5 amperes. For mobile needs, as, for example, an installation on a truck or an automobile, the car storage battery reinforced by a good car generator may be used, directly connected. For permanent installations and where 110 volts A.C. 60 c.p.s. is available, a copper oxide rectifier low output voltage power pack should be used. Where 110 volts D.C.

is available the fields of the loudspeakers (all the same) should be connected in series and connected to the source with a series current limiting resistor. Dynamic field exciters to feed 1, 2 or 4 low voltage fields may be obtained, housed in a box of perforated sheet steel, which operate from a 110 volt-60 c.p.s. source.*

Cone type units invariably have a high resistance field; 1,000 and 2500 ohms are standard. They are normally fed from a D.C. 110 volt source and draw from 50 to 100 milliamperes. In the case of D.C. mains, the loudspeaker fields are directly connected; with a 110 volt A.C. source, a field supply power pack is required, if one is not built into the frame supporting the loudspeaker. These supply units employ a tube rectifier system.

It is always wise to have the power switch to the loudspeakers near the control panel, hence a separate power line is run to the loudspeakers from the control position. In some cases a relay control line is used, the relay at the far end throwing power on at the will of the operator.

Phasing of Reproducers—When two or more loudspeakers are

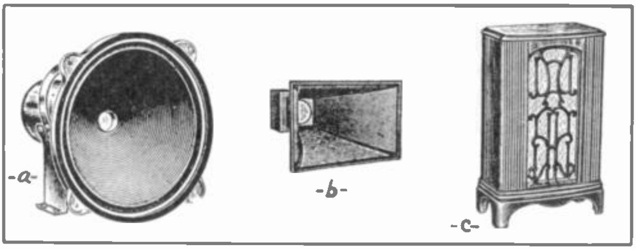


FIG. 7

used side by side, the sound output must be in phase, that is, the cones or diaphragms must move in and out together. This may be determined by trial. Place the loudspeakers a few feet apart facing you, excite them with audio (preferably a single tone); reverse the voice coil connection to one loudspeaker; choose the connection which gives the loudest response.† If several loudspeakers are to be phased, repeat for the others, one at a time, always using one loudspeaker as reference. After the correct connection for each loudspeaker is determined, they may be permanently connected.

Where loudspeakers are used facing each other, as they may be in long auditoriums, (one group at each end) the loudspeaker groups should be out of phase, that is connected during the previously explained test so the sound heard is the least. With such

* 110 volts 60 c.p.s. is standard. Any P.A. unit may be obtained to operate at any other voltage and frequency at a slight increase in cost.

† If the two loudspeakers are momentarily connected to a D.C. supply, they should either move out or in together for proper in phase action. A visual check is sufficient. This test is best for cone type loudspeakers.

a connection the sound in the center of the hall will be the sum of both groups.

High Frequency Booster Reproducers—As a rule, the power output response of a dynamic loudspeaker is poor in the high frequency range. If the space in front of a baffle or horn loudspeaker is analyzed, it will be found that the space directly in front of the cone will have all frequency components generated by the system. To be sure, the high frequencies of 3,000 to 10,000 c.p.s. will be less intense than the lower frequency values. The space away from the center line will have less intense high frequency sounds. Furthermore any high frequency sound striking the room or ground will be absorbed more completely than low frequency sounds. In general the frequency response will be like that of *curve 1*, Fig. 8a. Sound power output will start to drop at 3,000 c.p.s. and be negligible at 5,000 c.p.s., even though the amplifier is feeding all frequencies up to 10,000 c.p.s. at the same level.

For high frequency reinforcement the "tweeter" reproducer is used, supplementing the regular loudspeakers. Figure 8b shows

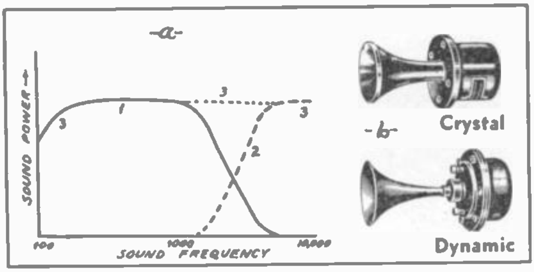


Fig. 8

the appearance of the crystal and dynamic types. Both require a high pass filter so they only respond to high sound frequencies, as portrayed by *curve 2* in Fig. 8a. The response starts at 3,000 c.p.s. and approaches a uniform value at 7 to 8 kilocycles. The overall response of a regular and tweeter reproducer in parallel is given by *curve 3*, practically uniform up to 10,000 c.p.s. The crystal tweeter has a built-in filter, requires no power supply and is so designed that it may be connected in parallel with the voice coil of any dynamic loudspeaker with negligible change of the load; in fact, the power factor is improved as the usual dynamic is inductive while the crystal loudspeaker is capacitive.

The dynamic tweeter loudspeaker requires a special filter-impedance matching device and you may purchase them for a 500 or 4,000 ohm input value. Its loading must be figured in. They require a source of D.C. supply. Either 6 or 110 volt fields are available.

Only experience can indicate how much high frequency reinforcement is needed. Probably one with each group of regular loudspeakers and in phase. If two are needed to a group the tweeter should be pointed towards the audience and away from each other. If less than the whole power available from a tweeter is needed, a constant impedance T type variable attenuator should be used at its input.

Multiple Loudspeaker Connections—It was pointed out that the impedance of the average voice coil at 1,000 c.p.s. was a value from 6 to 15 ohms. Furthermore the average power amplifier has several output terminals so one of several output impedances may be selected for use. Remember, you can only connect to two of the many terminals at one time. Therefore the loudspeakers, *of the same power rating*, must be arranged so their net input impedance corresponds to a value obtainable at the power amplifier.

To begin with, low impedance voice coils may be connected directly to the amplifier if the connecting line is not over 150 feet. The resistance of the connecting line must not be more than one-tenth the net impedance of the loudspeakers for a .5 db. loss. You must add this loss to the power required by the loudspeakers to get

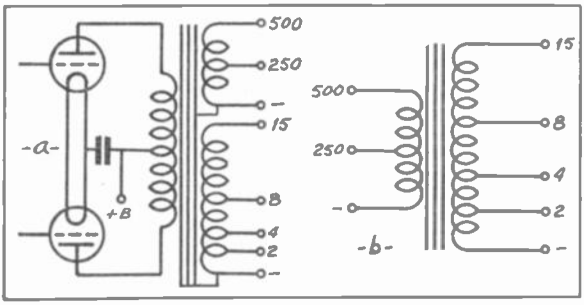
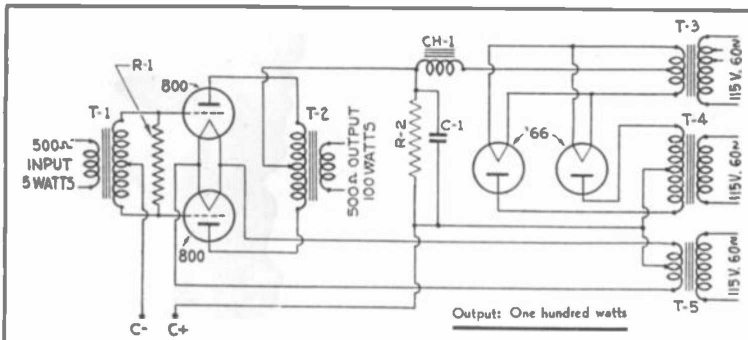


FIG. 9

the power needed from the amplifier. There will be a slight mismatch but nothing to be concerned over. A 4 ohm loudspeaker would be connected to the minus and No. 4 terminals of the system shown in Fig. 9a; a 15 ohm loudspeaker to the minus and No. 15 terminals; a 6 ohm load to the minus and No. 4 terminals (slight mismatch). If four 8 ohm loudspeakers are used, the loudspeakers should be connected thus: two in parallel and the two parallel groups in series; the net impedance is still 8 ohms. Obviously, the trick is to connect the loudspeakers in such arrangement so less than a net 15 ohms impedance is realized. An exact match is required in case of class B power amplifiers; even if a series or parallel resistor is required; an approximate match will suffice for class A or class A' amplifiers.

For long extension lines, it is important that power be conserved and as you know the terminating impedances of the line should about 500 ohms. Note in Fig. 9a there is a 250 and a 500 ohm impedance output. When these terminals are used, it is customary to raise the voice coil impedance to 250 or 500 ohms, using a matching transformer. Either impedance value may be used for a single reproducer. For two loudspeakers either value may be employed and the loudspeakers connected in parallel or series as the case may be. For four loudspeakers choose a 500 ohm line to voice coil matching transformer and connect the loudspeaker transformers in series-parallel. Every case requires its own solution, but remember where several loudspeakers are used, each loudspeaker should be of equal power rating and have equal terminating impedances; or made so by a suitable transformer. Figure 9b shows the connection of a universal voice coil matching transformer to give 250 or 500 ohms to the line. This transformer is quite flexible. For example, if an 8 ohm loudspeaker is connected



T-1	T-6265	Line to Grid Transformer	R-1	50,000-ohm wire wound resistor—10 watt
T-2	T-6755	Output Transformer	R-2	25,000-ohm wire wound resistor—75 watt
T-3	T-6433	Filament Transformer	C-1	4-mfd. high voltage condenser—2000 volt
T-4	T-5489	Plate Transformer	C— and C+	55 volt C battery
T-5	T-6435	Filament Transformer		
CH-1	T-6315	Filter Choke		Tubes: Two 800's and two 866's

A class B high level power amplifier. Designed by the Thordarson Electric Manufacturing Company. This amplifier must be driven by a 5 watt class A amplifier having a 500 ohm output. Similar amplifiers may be built in output powers of 20 to 100 watts driven by a 5 watt class A amplifier at lower levels.

to the 4 ohm tap, the transformer input impedance will be 500 and 1,000 ohms; if connected to the 15 ohm tap the input impedance will roughly be 125 and 250 ohms.

Suppose phones or magnetic loudspeakers are involved. The proper procedure to take is to connect these high impedance outputs in parallel and group them into sections or bays. Wherever possible, connect enough in each bay to reduce the bay to a 500 or 250 ohm load. Thus eight 4,000 ohm loudspeakers in a bay would net 500 ohms; twenty 10,000 ohm phones would give a 500 ohm bay. The various bays would then be treated as a group of 500 or 250 impedances and arranged to match the power amplifier.

One more hint. Suppose low and high level reproducers are connected in shunt in the same feeder line. How can you make each draw its correct amount of power? The unit with the lowest impedance will draw the most power. A 500 ohm dynamic loudspeaker will draw ten times as much power as a 5,000 ohm magnetic loudspeaker; a 250 ohm dynamic will draw twice as much power as a 500 ohm dynamic; a 250 ohm dynamic unit will draw twenty times as much power as a 5,000 ohm magnetic loudspeaker. The ratio will be inversely equal to the ratio of loudspeaker impedance. No distortion is produced in these units if they are not alike. Distortion will occur in the output stage of the power amplifier if the net impedance of all the loudspeakers in parallel is not matched to the recommended load for the amplifier. Figure the net loudspeaker impedance and use a suitable matching transformer. The power output of the amplifier should equal the sum of the individual

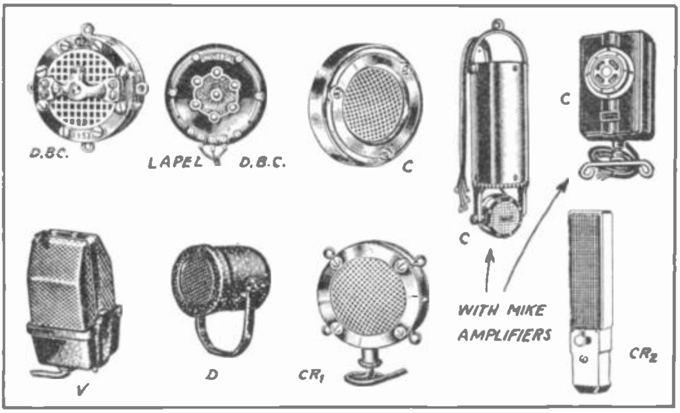


FIG. 10

powers of the loudspeakers. If you use heavy gauge feeder wires you may neglect the line resistance. For example: two 20 watt, 250 ohm; one 10 watt, 500 ohm; and ten 1 watt, 5,000 ohm loudspeakers are connected in parallel. The total power drawn will be 60 watts; the relative impedances are correct so each draws its correct power; the net parallel impedance is about 83 ohms. If the amplifier has a 250 ohm output terminal, a 250 to 83 ohm (1.73 turn ratio) matching transformer, 60 watts rating will be required.

PICKUPS

Choosing suitable pickup devices is, as we said before, a matter of fulfilling the services desired. Once the various kinds have been determined, the problem arises of choosing the correct type of each kind. We must therefore understand the characteristics of each type.

Microphones—The double button carbon, condenser, inductor or dynamic, velocity or ribbon, and the crystal mikes are usually compared as to their: *1*, fidelity; *2*, sensitivity; *3*, directional properties; *4*, output impedance; *5*, ruggedness; *6*, background or inherent noise; and *7*, excitation requirements.

Physical Characteristics—Figure 10 illustrates the types of microphones generally used in public address work. Those shown are designed to give good characteristics at a reasonable cost. Most of those shown may be purchased from a radio mail order house, as can all other P. A. equipment. Those marked *D. B. C.* are double button carbon microphones. One of them is a lapel unit; that is, it is small, has a small clip on the rear which permits the speaker to clip it on to the lapel of his coat. With the latter unit, the speaker may wander at will over the stage, talk directly or away from the audience without a change in sound pickup. D. B. C. mikes must be handled carefully and must be supported on springs or fastened to some soft material, as the lapel of a coat.

The instruments marked *C* are condenser microphones. One illustration shows the appearance of the unit alone, one with a "bullet" shaped closely associated microphone amplifier, the third one with a box shaped amplifier. Only the diaphragm is fragile and if protected by a mesh, the instrument is quite rugged.

V is a velocity or ribbon mike and the element is surrounded by a perforated steel case. The bottom houses the mike to line matching transformer. The type shown is very rugged and will take considerable physical abuse.

D illustrates a dynamic, inductor or moving coil unit and is very rugged.

The circular microphone marked CR_1 is a crystal mike. It is referred to as the "astatic" crystal mike. This unit contains a diaphragm which is mechanically coupled to the crystal. The long crystal mike, marked CR_2, has a pile of crystals (one on top of the other) and the sound impinges directly on the crystals. Both units are fairly rugged. It is important that crystal mikes be kept out of a damp or moist atmosphere. When they accumulate moisture they should be baked out in a drying oven.

Fidelity—A curve between constant level sounds of varying frequency and electrical power output (assuming a matched load) is the usual way of presenting the response characteristic of any microphone. To be sure, the fidelity may vary with some units with the direction of the sound, but the usual response characteristic assumes that sound is impinged directly and perpendicularly to the sound receiving surface or element.

The comparative frequency response for the microphones mentioned are given in Fig. 11. Observe that the fidelity of *V*, the velocity mike is better than *C*, the condenser mike; *C* is better than *D*, the dynamic or inductor mike; *D* is better than CR_1, the circular type crystal microphone; and CR_1 is superior to D. B. C., the double button microphone. The crystal pile microphone is comparable with the velocity microphone. Clearly the double button carbon and the astatic crystal mikes are suitable for ordinary voice and music reproduction. The others are used where high fidelity is desired. Of course, there is no objection in using a high fidelity mike under any circumstances. But note that the greater the fidelity the lower the output. Consequently it is wise to use sensitive low fidelity microphones where they will suit the condition; and by doing this the gain of the subsequent amplifier can be kept low, reducing expense and amplifier difficulties.

You will find high grade carbon, condenser, and dynamic microphones with fidelity characteristics that are far superior than the ones shown. In fact, a reasonably flat response to 10,000 c.p.s. is readily obtained in most types of mikes. These microphones are costly and for P. A. work it is wiser to purchase a less expensive mike with the desired fidelity.

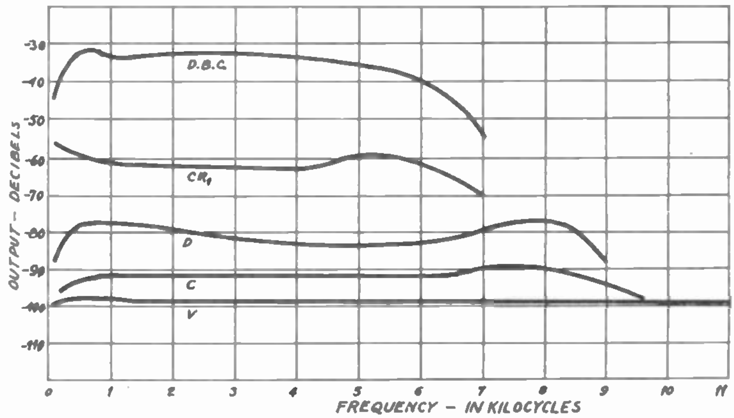


Fig. 11

Power Output and Directivity—Curves shown in Fig. 11 also tell us how much power to expect from the various types of microphones. Again the values given are only approximate and vary with the construction and fidelity of the mike you plan to use. As a rule, for any type of mike the output decreases with increased fidelity, due essentially to the stretching of the diaphragm to improve the response. The powers shown are for a matched load and the sound directed to the front of the moving element, about 6 inches away, which is the usual position for an announcer. Observe that the average outputs are about: —30 db for *D.B.C.;* —60 db for CR_1; —80 db for *D;* —90 db for *C;* and —100 db for *V.*

The question arises, what will be the output if the announcer or a speaker talks from greater than ½ foot; or to one side of the direct line. As the microphone is placed farther away from the speaker you will find that power output decreases as the square of the distance. For example, if the output at 6 inches is taken as standard, at 12 inches the power will be one-fourth; at 24 inches it will be one-sixteenth, etc. Figure 12 indicates what additional loss to expect when the announcing distance is increased 2, 3, 4, 5, 6, 7, etc., times the reference distance, usually ½ foot. This additional loss is numerically subtracted from the rated power output to get the actual power output. For example, let us say that the output of a crystal microphone is —60 db when the speaker talks ½ foot away. If the microphone is placed 5 feet away, the distance with respect to standard has been increased 10 times; the power loss according to Fig. 12 is 20 db; and the output is 60 plus 20 or a net value of —80 db.

Observe that we were only considering microphone output for voice announcing. What are we to expect if a piano, flute or a 15 piece orchestra is being picked up? There is no question that the sound level will be greater, but how much? No direct answer can be given, but relative and useful information is available. Broad-

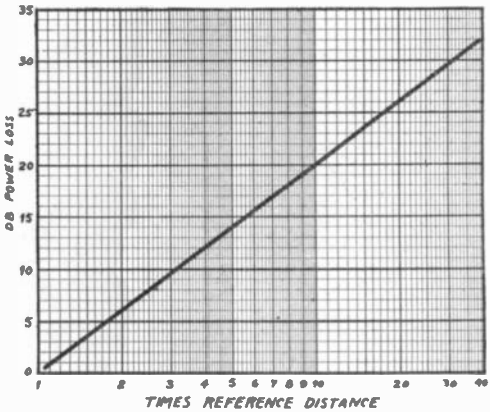


Fig. 12

cast engineers have computed the peak power of various instruments, which is presented in Table No. 2. The average power of the voice is about 10 to 20 micro-watts, but the peak power is about .005 watt. With the latter figure as our reference we may tabulate the db level above voice for the various instruments, as given. The information is helpful in microphone placement. If an amplifier is designed for normal voice pickup, ½ foot away; then the mike may be placed 4.5 feet away for a piano and the same output from the system will be obtained. This is how we determine this fact. The level of a piano is roughly 19 db above the voice. Referring to Fig. 12, a distance of 9 times reference (4.5 feet) would just equal normal voice input. Or you could reason that by placing the mike on the piano, the gain of the amplifier could be reduced 19 db. It should be clear that if you figure for long shot voice announcement, that the amplification of the system will be adequate for instruments.

To know what power output to expect when the performer talks or plays off the center line, we must resort to a sound pickup field pattern for the microphone and for exact results the one for the microphone you plan to use. Figure 13 shows approximate field patterns for the types mentioned in this text. Each curve represents the field pattern for the mike for a definite sound frequency. The

TABLE NO. 2—PEAK POWER OUTPUTS

INSTRUMENT	WATTS PEAK SOUND POWER	D. B. ABOVE VOICE	INSTRUMENT	WATTS PEAK SOUND POWER	D. B. ABOVE VOICE
75 piece Orchestra.	70	41	Bass Sax........	.3	18
Large Bass Drum.	25	37	Bass Tuba.......	.2	16
Pipe Organ.......	13	34	Bass Violin......	.16	15
Snare Drum....	12	34	Piccolo..........	.08	12
Cymbals.........	10	33	Flute...........	.06	11
15 piece Orchestra.	9	32	Clarinet.........	.05	10
Trombone........	6	31	French Horn.....	.05	10
Piano...........	.4	19	Triangle.........	.05	10
Trumpet.........	.3	18	Average Voice...	.005	0

distance from the center *O*, to the curve represents the amount of sound power with reference to *Oy*, direct talking; and the direction of the line represents the direction of performance with respect to front of the mike. Thus in Fig. 13A, the pattern for a D. B. C. mike, *Oy*, represents the peak output, and obtained by talking directly in front of the mike. By talking in the direction *2 O*, the

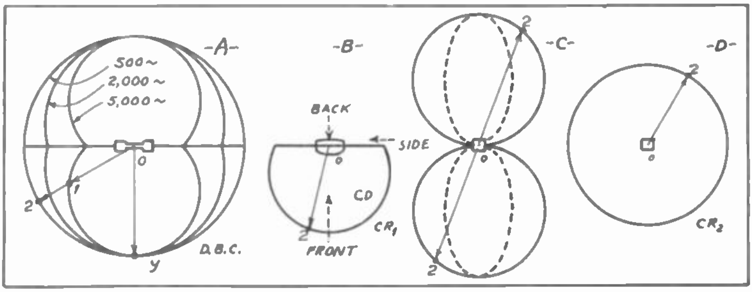


FIG. 13

sound output is not materially reduced for 500 c.p.s., yet greatly reduced for 5,000 c.p.s. High frequency sound pickup is poorest when the sound is directed to the microphone from the side. Note that pickup is obtained from all directions.

Compare pattern *A* with pattern *B*, the latter for condenser, dynamic and astatic crystal type microphones. As the back of these mikes are closed, only pickup is experienced from the front.* Except for this feature these mikes behave similarly to D. B. C. types. Velocity mikes, see pattern *C*, have a figure-of-eight field pattern. Minimum pickup is obtained if sound originates from the side. This property is extremely valuable in reducing loudspeaker to microphone sound feedback. The velocity microphone may be obtained with a very sharp pickup characteristic, as shown by the dotted pattern of Fig. 13C. This feature is quite useful if a particular person or instrument or remote performer is to be picked out of a group. It is said that the velocity microphone responds almost as well for high as for low frequencies in any direction.

Pattern *D* is for a crystal pile microphone. Observe that it responds equally in all directions and equally as well for all frequencies.† Clearly these mikes cannot be used anywhere where there is some possibility of acoustic coupling with the loudspeaker.

Microphone Technique—In considering the position of the microphone or several microphones if necessary, you must consider: *1*, the range of frequencies and sound levels of the performers; *2*, the relative position of the various instruments or performers and the microphones; *3*, the relative position of the microphones and the loudspeakers; and *4*, the acoustics of the space where the performance takes place.

To begin with, the technique for P. A. work is quite different than that used in commercial radio broadcasting, in fact not anywhere near as exacting. If a speaker or a soloist (voice or instrumental) is to be reinforced the microphone is placed in front of the performer as shown in Fig. 14A and as close as is convenient without obstructing him too much from the eyes of the audience. The microphone position is selected so there is no feedback from the loudspeaker. The microphone is placed close to the performer so that maximum power may be derived and the background noises reduced to a minimum. If the performer actually talks very close to the mike, less than 6 inches, he should talk from the side as in Fig. 14B, in order not to muffle the sound.

For *close talk* any mike may be used provided it covers the frequency range desired, is not acoustically coupled to the loudspeaker and the subsequent equipment supplies sufficient amplification. For distant pickup of normal sounds, 5 or more feet, it is best to use a microphone that has no power supply such as the velocity, dynamic and crystal mike. The carbon mike must not be used as the gain required will be so great, that so-called carbon roar will be emitted from the loudspeakers.

Now let us turn our attention to the prevention of sound feed-

---

* In high grade D.B.C. mikes, the back is closed and its characteristic pickup response is like Fig. 13B.

† A crystal pile microphone is now available which has a circular field pattern, as shown in Fig. 13D, or a uni-directional field pattern, as shown in Fig. 13B, merely by changing the internal connections of the crystal units; a switch is used. A velocity microphone may be changed from pattern C to D by tilting the unit from a vertical to a horizontal position, but the unit must be far above or below the level of the sound source.

back. Imagine we have two loudspeakers with closed backs, as shown in Fig. 14C, facing the audience; imagine a string running from the mouth of one loudspeaker to the other. This line represents the danger line and the microphone should always be in back of this line and below it. The ideal situation is one where the loudspeakers are of the directional type, the sound from the rear of each loudspeaker absorbed; the microphone used should pick up at one face, the one facing the performer. It is best to have the microphone well to the rear of the loudspeakers, further back than

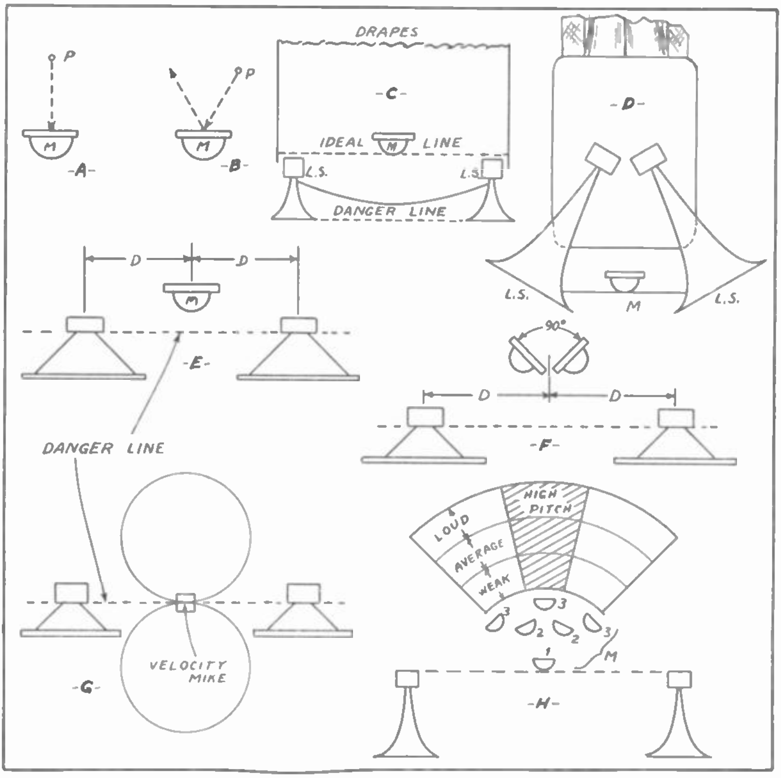


FIG. 14

the ideal line of Fig. 14C. This cannot always be done, as exemplified by the outdoor truck used for speeches. Note in Fig. 14D that two long horn loudspeakers are used. The mouth of the horn is well in front of the mike, but the moving coil unit is in back of the microphone.

What should be done if the loudspeaker has an open back? In the first place, it is important that you use two loudspeakers, one on each side of the mike. The mike should have a closed back and be well in the rear of the danger line. The distances *D*, as shown in Fig. 14E, should be equal and the output of each loudspeaker equal. Sound waves reaching the mike will be equal and opposite in phase and thus cancel. Because it is difficult to control the sound output of each loudspeaker, it is usual, as shown in Fig. 14F, to use two mikes, at 90 degrees to each other. Each mike is independently controlled at a mixer panel, for cancellation may be easily realized by changing the output of each mike.

The velocity microphone is extensively used because it is easy to eliminate feedback. The mike is placed mid-way between the loudspeakers and essentially on the danger line. By placing the velocity mike so the greatest pickup is towards the audience and the performance, the zero pickup line is in the direction of the loudspeakers. The microphone unit should in practice be slightly turned one way or the other for the least feedback. If the mike is used as a close talking device it is rather rare that feedback will take place. Figure 14G shows the relative positions.

An important fact. It is always wise to have the back of the stage heavily draped, as shown in Fig. 14C. Thus sound cannot be reflected from the back to the front of the microphone. Of course, outdoors there is no back reflector but should there be, this precaution is quite important. A trial will quickly prove whether precautions are required. A lot of grief may be avoided by using directional loudspeakers with the rear acoustically closed. Technicians have found that the flatter the overall response of the system the less the tendency for a predominate feedback.

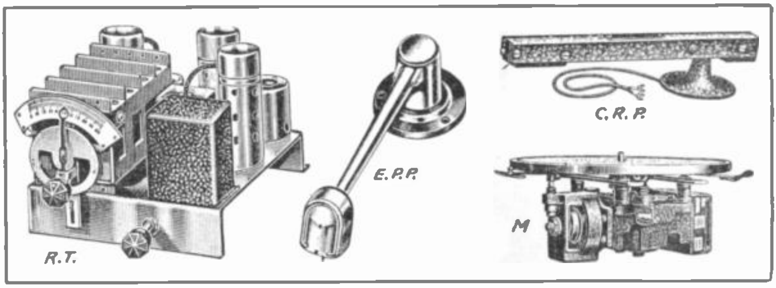
Now let us turn to group performers. To be sure, the P. A. operator can only recommend to the leader the best positions for the individual performers. One, two or three mikes may be used, although one good mike should suffice. The entire arrangement should have a wedge shaped appearance, as shown in Fig. 14H. Loud (usually bass) performers or instruments, unless they are to be accentuated, should be in the rear; the weak or low level instruments in front. The high frequency instruments or soprano singers should be in the middle of the wedge. Any voice or instrument that is to stand out should be in front facing the mike. The mikes should be at the apex of the wedge.

When an individual is to play a solo, he should come out in front before the mike, the gain of the system reduced. A special mike may be placed in front of the performer while in the group. In the latter case the level of the group mike is reduced or removed entirely while the soloist's mike is properly regulated.

The lapel microphone, and they now can be obtained in the double button carbon, dynamic and velocity types, is finding a good deal of favor for speakers and soloists who will not "stay put" on the stage or platform. Quite often it is used by the soloist in a group and controlled at the mixer.

RADIO TUNERS—In choosing a radio tuner for a P. A. or centralized radio system, particular attention must be given to the peculiar needs of the service. Good fidelity, freedom from interfering noise or stations stand out as paramount requirements. At once this limits reception to only local stations, or in a "pinch" nearby stations. The receiver used with other pickups, invariably has an R. F. system and an audio demodulator; no audio amplification is required as this is furnished by the amplifiers in the P. A. equipment.* Selectivity is far more important than sensitivity, although reasonable sensitivity will be needed if semi-distant stations are the only program sources. Never rely on stations more than 50 miles away unless they are the super-power ones.

For normal needs, a 3 to 4 stage tuned R. F. receiver feeding into the power type detector will answer the requirements. The controls needed are the station selector and the manual volume control. A 0-1 milliampere meter could be advantageously used if connected into the plate of the detector. This will permit the operator to set the station selector to exact resonance (maximum deflection); and to adjust the receiver to the same level (amount of deflection). The meter should be by-passed by a .002 mfd. condenser. When the detector is to feed into a switching or mixing system, the detector should terminate in a step-down transformer,



R.T. a T.R.F. tuner designed for P.A. systems, with filament transformer, P.A. amplifier furnishes B power. *E.P.P.*, electromagnetic phono-pickup. *C.R.P.* crystal phono-pickup. *M*, electric phonograph motor 33⅓ and 78 R.P.M.

and to give an output impedance of 200 or 500 ohms; when the receiver is to feed directly into the grid circuit of an amplifier, no changes in the tuner are necessary as it terminates in a high impedance.

Any of the modern superheterodyne receivers may be used, if you select one carefully. The I. F. stages should have band-pass couplers; the first detector should be preceded with at least one stage of R. F. amplification, to keep the frequency converter noise low with respect to the desired signal. A diode detector output feeding into one stage of audio amplification is desirable if good quality is wanted; the output impedance governed by the proposed connection. If you plan to use a regular receiver, you may remove all the audio tubes provided you load the power pack with a resistor to compensate for the load removed (resistance equals power tube supply voltage divided by total plate current of all tubes taken

* In a centralized radio system, a regular receiver may be used, followed by a class B power amplifier.

out); and provided you replace the loudspeaker with a choke of equal inductance and resistance. If a detector or first audio step-down transformer is to be installed, refer to a tube table to find the correct load impedance for the tube and from the formula, *square root of: load impedance divided by 200 or 500,* determine its turn ratio.

Should the receiver you use have an A. V. C., connect a T or L type constant impedance variable attenuator to the output of the transformer.* This will be the level control. The correct position may be determined after the P. A. system is installed and regulated. The position of the manual control in the case of the T. R. F. set may be determined in the same manner.

Always connect the receiver to a noise-reducing antenna, being especially careful in selecting the position of the straight-away. If noise still prevails, trace down the sources and install noise filters. Never allow a customer to influence you to install an all-wave receiver until you are convinced that short wave transmission has reached a stage of perfection where noise is negligible; or the customer assures you in writing that the noise will not be objected to.

PHONOGRAPH PICKUPS AND FADERS—Commercially, only the electromagnetic and the astatic crystal type phonograph pickups are used. Both are designed to give flat response with the modern electrically transcribed records, which are of the round flat type having a side-to-side cut. Naturally a motor is required to revolve the record and wherever 110 volt 60 cycle current is available, an induction type motor should be used. Be sure the one you get has the 33⅓ and 78 R. P. M. speeds. The motor should be equipped with an automatic stop. For mobile or portable use, purchase a 6 volt motor with automatic speed governor; or a spring driven phonograph motor.

The average output for an electromagnetic pickup is —15 db; for the astatic crystal the output level is about —10 db. As a phonograph unit is invariably located at the control racks, no amplification is generally required for safe transmission.

Electromagnetic pickups are made in the low impedance (50 to 200 ohms) and the high impedance (1,000 to 10,000 ohms) types. The impedance of the unit you use should be specified by the maker. The crystal pickup has a very high impedance and the recommended load is not critical. A load value of .1 to 5 megohms may be used. Neither one requires any form of supply, the unit producing an audio current by virtue of the movement imparted to their elements.

In actual practice, it is not wise to let a recording come by itself to a dead stop. A most disagreeable sound will be heard. A similar undesirable noise will be obtained if the record is started with the output at maximum level. To prevent this, a volume control close to the pickup is imperative. It is for these facts that

* Will not be needed if a variable input control is provided in a duo diode triode or pentode output.

automatic record changers are not as a rule recommended for high quality reproduction to a large group. If they are used, a trained operator should be ready at the start and finish of each recording to reduce or raise the gain of the amplifier which follows. Where records are to be played one after the other, two turn tables, each with its fader will be a more satisfactory set-up.

Typical fader connections are shown in Fig. 15. *A* is the normal connection for a 200 ohm low impedance unit; *B* is the proper connection for a high impedance unit, the T type variable attenuator coupled to the unit by means of a matching transformer. In both cases the variable attenuator should have an impedance common with the other kinds of pickups. *C* shows the electrical connections for two low impedance units to be used alternately. The controls are connected in series and matched to the subsequent equipment by a transformer. For two high impedance pick-

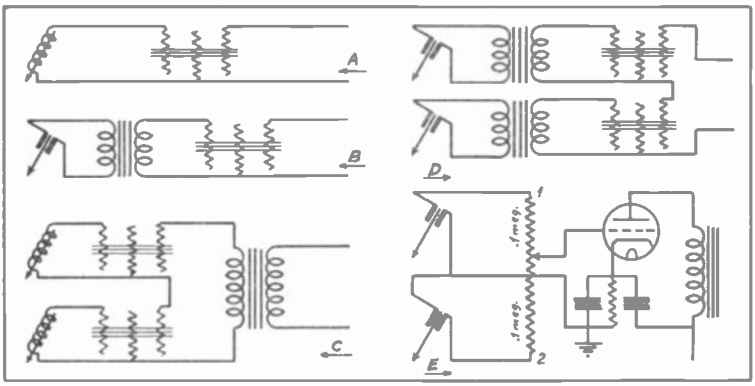


FIG. 15

ups a matching transformer precedes each T type attenuator and the latter are connected in series. A third matching transformer may be used if the impedance of the two attenuators in series do not equal the impedance of the device it couples to. Figure 15E shows a direct unit to amplifier connection used quite often with crystal pickups. Each unit is terminated in a .1 megohm potentiometer and the latter connected directly to the grid circuit of the voltage amplifier. It is wise to use a twin composite (single unit) potentiometer, so the variation of slider *P* from point *1* to point *2* gradually takes out one and puts the other unit into action. Wherever two units are to be faded, one *out,* the other *in,* twin unit faders with a single knob control should be used. Type T faders are readily obtained.

Matching transformers can be ordered with a definite turn ratio, or to match a source of given impedance and a load of a definite impedance. When ordering a matching transformer for a crystal phono-pickup secure one to match 150,000 to 200 or 500 ohms.

For average needs an electromagnetic unit is satisfactory, but when records are revolved at 33⅓ R. P. M. the unit should be accurately counter balanced so the needle will not rest too heavily on the record. The astatic crystal pickup has a wide frequency response and is especially good for high fidelity reproduction. Do not misunderstand, the other types can be had for high fidelity recording, if additional expense is no objection. The crystal pickup is very light and therefore is the ideal unit for slow revolving records.

Needle scratch may, in some cases, be objectionable. For an amplifier system designed exclusively for disc reproduction, the highs (scratch frequencies are above 5,000 c.p.s.) may be suppressed by designing the amplifier with a sharp 5,000 c.p.s. cut-off. Where a phono-pickup is to be used in a P. A. system, where for other purposes a greater frequency range is desired, the logical procedure is to introduce at the terminals of the pickup a low pass wave filter, with a 4,500 c.p.s. cut-off value. A simpler procedure is to shunt the pickup terminals with a coil (L), condenser (C), and variable resistor (R) which are in series. This circuit should resonate about 4,500 c.p.s. For a 200 ohm phono-pickup use the following values: $C = .2$ mfd.; $L = 7$ millihenries; $R = 1{,}000$ ohms; for a 2,000 ohm pickup use $C = .02$ mfd.; $L = 70$ millihenries; $R = 5{,}000$ ohms. Incidently these filters may be used with microphones to suppress noise. In these filters, the reactance of the condenser at resonance should approximately equal the impedance of the pickup, and the variable resistor should be about five times the impedance of the device.

TEST QUESTIONS

Be sure to number your Answer Sheet with *the number* appearing on the front cover underneath the title of this text.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your Course, and the best possible lesson service.

1. Why are the parts of a P.A. system impedance matched?

2. What are the three important pickup devices in P.A. systems?

3. What are the two standard values of output impedances for pickups?

4. What two types of loudspeakers are used in small halls?

5. What microphone, when placed along the danger line, gives the least loudspeaker feedback?

6. If a 5,000, a 500 and a 250 ohm loudspeaker were connected in parallel to the same feeder, which would draw the greatest amount of power?

7. For what input and output impedance condition is the db gain rating of an amplifier given?

8. What type of baffle would you recommend for a dynamic cone loudspeaker for the greatest electric to sound energy conversion?

9. In what range of impedance values are low impedance electromagnetic phono-pickups made?

10. How many watts should you feed to trumpet loudspeakers to cover an outdoor area of 30,000 square feet?

1. To derive the maximum undistorted power.

2. The microphone, the phono-pickup and the radio tuner.

3. 200 and 500 ohms.

4. Magnetic and permanent dynamic loudspeakers.

5. The velocity microphone.

6. The 250 ohm loudspeaker, because it has the lowest impedance.

7. For a condition of matched input and output impedance.

8. A flared baffle.

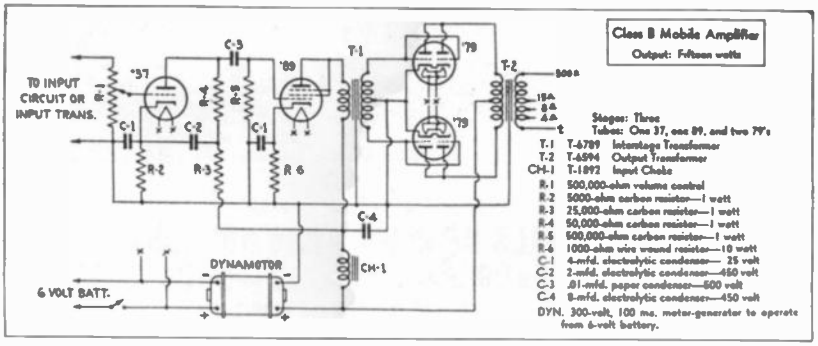
9. 50 to 200 ohms.

10. 35 watts, determined from Fig. 3.

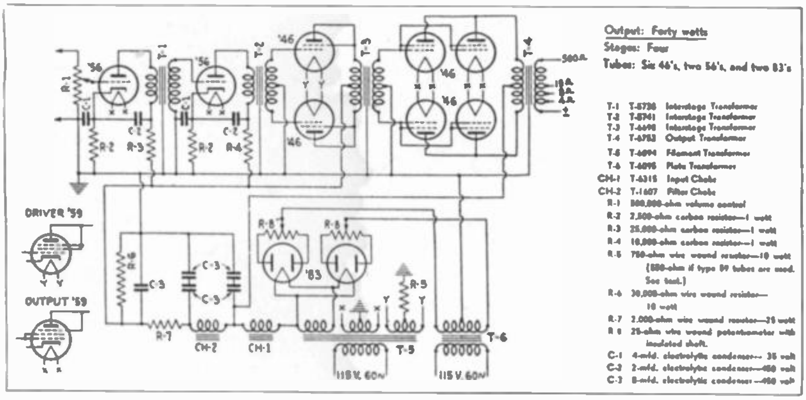
ESSENTIALS OF INDOOR AND OUTDOOR PUBLIC ADDRESS SYSTEMS—PART 2
TYPICAL P.A. SYSTEMS

54RH-1

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.



A mobile Class B amplifier, used wherever a 6 volt storage battery is available, as in trucks, automobiles, or aircraft. Thordarson Electric Mfg. Co., chokes and transformers indicated.



A forty watt Class B parallel push-push amplifier. If the 59 heater type tubes are to be used, connect as shown in the lower left corner. In this case, *R* is removed, the center tap of secondary *yy* connected to ground; the two cathodes of the 59 driver tubes are connected together and grounded through a 550 ohm, 10 watt resistor. Thordarson Electric Mfg. Co., chokes and transformers indicated.

NATIONAL RADIO INSTITUTE

WASHINGTON, D.C.

A LESSON TEXT OF THE N. R. I. COURSE
WHICH TRAINS YOU TO BECOME A
RADIOTRICIAN & TELETRICIAN
(REGISTERED U. S. PATENT OFFICE) (REGISTERED U. S. PATENT OFFICE)

NCP2M1141 Printed in U. S. A

Essentials of Indoor and Outdoor Public Address Systems—Part 2; Typical P.A. Systems

MICROPHONE AMPLIFIERS

The output level of a pickup may be any value from —100 db to 0 db depending, of course, on the kind (microphone, tuner, etc.) you choose to use. If the pickup can be located close to the main amplifier, the latter is often selected to have enough gain to raise the power delivered to loudspeaker levels. Even when several kinds of pickups are used, jack inputs may be provided in several of the first stages of the amplifier, so the pickup can be plugged into the stage that will give the correct overall gain. But, in a well planned P.A. system, it is wise to follow radio broadcasting technique, by terminating each pickup in the same impedance and power level values and then switch, control or fade their inputs as needed.

Before we discuss pre-amplifiers, head amplifiers and microphone amplifiers—names for the same thing—it is important to bring out that hum interference and noise due to tube and circuit effects are limiting factors to the minimum level you may operate pickup units. Hum is kept out of the pre-amplifiers by brute filtering its power supply, and by employing interstage hum bucking filters. The pre-amplifier is built and located so no hum is magnetically induced into any of the stages. Turning now to the noise problem we are told that it is now possible to keep circuit and tube noises down to a level of —135 db. Assuming hum can be kept to this value, we should not operate a microphone below —100 db. so as to assure at least a db signal to noise difference of 35. For high quality this difference should exceed 45. Clearly if a long sound "shot" (voice a long distance away from the microphone) is considered, astatic crystal and dynamic mikes are best, because their normal close talk output level is sufficiently high to permit additional loss and what is equally important, they have little inherent noise.

It is safe to assume that the average high fidelity microphone will deliver —100 db, safely above noise; and the double carbon microphone will deliver about —50 db, when used for close talk. As most modern complete P.A. amplifier units are made to work from a double button carbon mike, to bring the high fidelity mike to the level of a D.B.C. mike, a pre-amplifier with about 50 to 60 db gain is required. If more amplification is required it may be introduced in the mixer or in the circuit directly following it.

An important problem arises: where should the microphone amplifier be located? If the distance between the pickup and the main amplifier is less than 50 feet, a low capacity shielded cable may be used with any mike except the very low level types provided the impedance is made 200 or 500 ohms. When the mike output is below —70 db the amplifier should be close to the pickup.

In general the condenser, the velocity and the crystal pile microphones require a closely associated pre-amplifier. In the latter case, the pre-amplifier should be not over 6 feet away and the connection made through a low capacity shielded cable. The output from a dynamic or astatic crystal mike may be run over a shielded line for 50 to 100 feet long provided its impedance facing the extension line is made equal to 200 or 500 ohms. Double button carbon microphones may be run 500 feet in a shielded three wire cable, one lead for a common D.C. current return. If a long voice shot is made with an astatic crystal or dynamic mike, a closely associated microphone amplifier is required. The principles involved are quite simple. Amplification is required to keep the level of the signal well above the noise and hum signal which may be picked up even in a shielded line; a low impedance source and load (about 200 ohms) is essential so the capacitive reactance of the line will be high in reference to terminating impedance; that is why low capacity cables are best.

Microphone Connections.—Now let us turn to the microphone connections through the line, matching transformer and the pre-amplifier. First let us consider the double button carbon mike. Figure 1A is the recommended battery connection for a double button carbon microphone. The mike is placed in its support and connected to a shielded three wire cable. A black, a white and a red rubber insulated wire are usually found within a flexible metal loom shield. Rubber covers the shield. A cable of suitable length should be selected and the shield at both ends connected to a common wire. At the microphone end, the lead connected to the shield is attached to the mike frame terminal, and the other two leads are fastened to the button terminals. At the terminating end, the three wires terminate in a special three prong microphone plug. The remaining apparatus is placed in a control box, the input connection made through a triple slot receptacle or jack, which is a part of the microphone plug and jack. Note that the terminal leading to the wire connected to the shield is grounded and connects to the center terminal of the mike transformer through a 2 mfd. condenser. The other two leads connect to the outer terminals of the transformer. A 4.5 volt dry cell battery (3 type #6 or a 4.5 volt C) is connected in series with an *off-on* toggle switch, a 1,000 ohm rheostat and a 30 henry low resistance choke. The supply circuit connects across the condenser. The condenser and choke is a surge filter, preventing excessive current from flowing through the buttons upon connecting or cutting off of the mike. Furthermore the serious plop, which might be heard if the surge choking circuit were omitted, is removed.

Where several D.B.C. mikes are used, each mike has a similar circuit, but the points *x x* are connected to a common voltage supply. A closed circuit jack may be placed at *y y*, so individual microphone button currents may be measured by the insertion of a 0 to 25 ma. D.C. meter connected to a cord with a plug. The transformer *T* is made to match the impedance of the mike, usually 200 ohms per button, and the load. For a mixer connection the secondary termi-

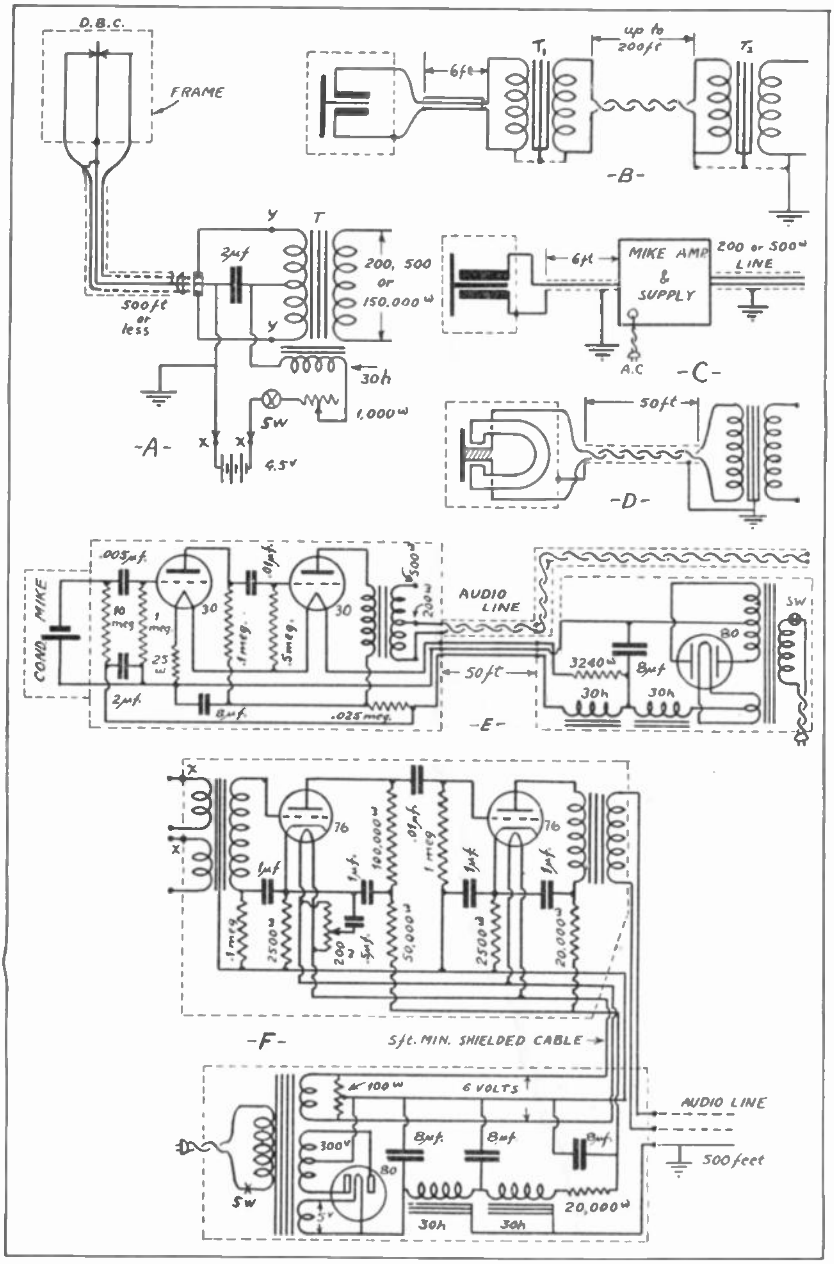

D.B.C.
FRAME
500 ft or less
2μf
Y
T
200, 500 or 150,000 ω
30h
1,000 ω
SW
4.5 v
-A-
6 ft
T1
up to 200 ft
T2
-B-
6 ft
MIKE AMP & SUPPLY
200 or 500 ω LINE
A.C.
-C-
50 ft
-D-
.005μf
COND. MIKE
10 meg
1 meg
25 ω
2μf
30
.01μf
1 meg
.5 meg
8μf
.025 meg
500 ω
200 ω
AUDIO LINE
50 ft
3240 ω
8μf
30h
80
SW
-E-
76
1μf
2500 ω
200 ω
.5μf
100,000 ω
.01μf
1 meg
50,000 ω
20,000 ω
-F-
5 ft. MIN. SHIELDED CABLE
100 ω
6 VOLTS
300 v
5 v
8μf
20,000 ω
AUDIO LINE
500 feet

FIG. 1

nates as a 200 or 500 ohm impedance; for a direct connection to a tube grid it should be about 150,000 ohms and a resistor of 500,000 ohms (preferably a potentiometer) shunted across the secondary. Any of these transformers are easily obtained from a radio supply house.

Experience has shown that the connection in Fig. 1A is the best. However, the choke and condenser may be omitted in low priced P.A. jobs. Very often the voltage supply for the mike is provided for in the main amplifier. You may build the circuit suggested in Fig. 1A or buy a complete D.B.C. control box from a supply house, making any addition you may wish.

Crystal mikes are extensively used, especially the sensitive astatic type. In an ordinary P.A. system, no attempt would be made to use a pre-amplifier with it, unless a long voice shot were considered. The crystal mike (see Fig. 1B) would be connected to a single center conductor shielded cable, the shield connected to the mike frame terminal, the center conductor to the crystal terminal. The cable should not be over 6 feet long. At the far end, a 150,000 to 200 or 500 ohm matching transformer (T_1) would be connected, and the low impedance winding connected to a twisted (preferably shielded) extension lead. This lead may be 200 feet long for normal purposes and should be terminated in a transformer T_2, raising the 200 or 500 ohm source to the input impedance of the device it feeds, if the load happens to be of a different value. Note that in the diagram one lead in the line is grounded; jumpers are used at transformers T_1 and T_2.

For high fidelity insensitive crystal mikes, a pre-amplifier should be used, not more than 6 feet from the mike, as shown in Fig. 1C. The amplifier should have its own power supply. Its output impedance should be either 200 or 500 ohms. The amplifier normally raises the level to —30 to —50 db, and then if the extension line is well shielded, 500 foot extensions are permissible.

Dynamic microphones are easily adapted to P.A. work. One type made for P.A. systems has a 200 ohm impedance voice coil. Therefore, you may use it with a 50 foot (200 feet in a "pinch") two wire shielded cable, the shield grounded and connected to the microphone case, as shown in Fig. 1D. The transformer is only needed at the terminating end when the line connects to a load of a different impedance, as the input to an amplifier. If the line terminates in a 200 ohm variable T pad, no matching transformer is required. When you encounter low impedance voice coils, for example, 25 ohm voice coils, keep the extension leads short or start off with a 25 to 200 or 500 ohm matching transformer.

A condenser microphone requires an amplifier as close to itself as is possible. The box the pickup is mounted on, or the cylindrical container from which the mike hangs houses the amplifier unit. A typical internal connection for this mike amplifier is shown in Fig. 1E. A five wire shielded cable connects the microphone amplifier and the power supply. To be sure this five wire cable may be as much as 500 feet long, but as this cable is expensive it is wise to use a short length, enough to place the power unit out of sight, and then extend the audio line from the power unit with a twin conductor shielded cable. In a power unit that is extensively used by sound technicians, the output is made through three binding posts; two for the audio line, one for the ground. Naturally the power unit should be placed near a 110 volt 60 c.p.s. power outlet and a water pipe. Either 200 or 500 ohms impedance output may be used, the desired impedance selected in the microphone amplifier output.

The velocity microphone is widely used in high fidelity sound systems, because of its excellent field characteristic. As you know the mike itself is connected to a line impedance matching transformer which may be obtained with a 200 or 500 ohm output value. Because the output level is low it is not wise to run the line, a two wire shielded cable, more than 25 feet.* It should be fed directly into a closely associated microphone amplifier as indicated in Fig. 1F. A typical all A.C. power unit is shown. Automobile type tubes are employed because they work on a relatively high A.C. filament voltage which reduces induction hum. The power supply should be at least 5 feet away from the amplifier, and where they are close together perfect shielding and part placement for least hum induction is imperative. Many technicians like to accentuate the high frequencies. To do this a condenser *x* is inserted in series with the mike line, shunted with a S.P.S.T. toggle switch so it may be shorted. A value of .1 mfd. is recommended for a 500 ohm input; a .25 mfd. condenser for a 200 ohm input. Some technicians prefer to insert this clarifier, as it is called, in the grid circuit of the first tube.

PICKUP SELECTORS AND MIXERS

We have constantly indicated that the output of a pickup should be terminated as a 200 or 500 ohm impedance. Which should you use? Fundamentally all pickups should terminate in the same impedance, to permit ready interchange of units, without mismatch losses. A value of 500 ohms is standard for broadcast and telephone work, as the lines used have a surge impedance of this value. If you plan to use the telephone line as an extension, choose this value. Even if you do not build the equipment for these lines a matching transformer will do the trick when a telephone line connection is made. If very long microphone connections are contemplated a 500 ohm terminating impedance will give less mismatch loss than a 200 ohm impedance. Experienced sound technicians claim that *less hum and noise pickup is obtained with a 200 ohm line,* and choose this value realizing that the loss will be negligible.

On the other hand, if the units you happen to choose, like the dynamic microphone or a low impedance phonograph pickup have a 200 ohm output impedance, then you should terminate the other pickups in this value. A monetary saving will be obtained. Other-

* A high level 2,000 ohm velocity microphone is available. This pickup may be connected through a 200 foot line to the grid circuit of a high gain amplifier—matching transformer and pre-amplifier may be omitted.

wise, either of the two impedance values may be chosen; there is little practical difference. Pickup manufacturers usually allow a choice so the apparatus you buy may be readily adapted to existing equipment.

Now, how should the various kinds of pickups be connected for smooth changeover, level control or mixing? The correct procedure is to terminate each unit in a constant input and output variable attenuator of the T or L type. The variable pads are connected in series (or parallel) and fed through a matching transformer to the input of the voltage or main amplifier. In some cases the matching transformer is fed to a T type attenuator (a master level control), and then through a matching transformer to the input of the amplifier. As it is customary to build amplifiers, ex-

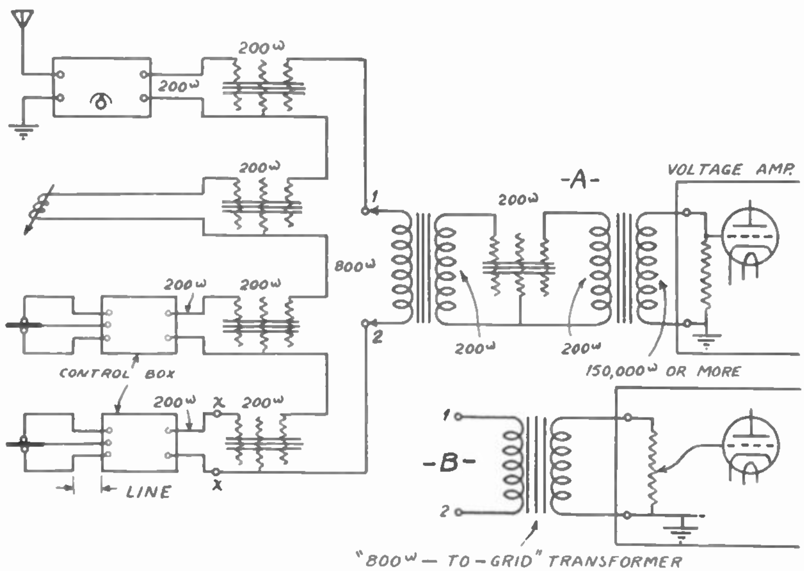


FIG. 2

cept class B power amplifiers, with a high impedance input, about 500,000 ohms,* the last transformer should be a *line to grid* transformer. The latter should be placed extremely close to the amplifier input, so positioned or placed in a separate steel box so 60 c.p.s. induction from the supply of the amplifier will not introduce hum.

A typical connection is shown in Fig. 2A. A radio tuner, a 200 ohm electromagnetic pickup, two 200 ohm per button D.B.C. microphones are connected to their respective T attenuators, the latter connected in series and to a 800 to 200 ohm matching transformer. The latter connects to a 200 ohm to grid transformer

* It is usual to shunt a line to grid transformer with a 500,000 ohm (.5 meg resistor) to load the grid circuit. The transformer does not have to match this high resistance. A line to 150,000 ohms, matching transformer is quite satisfactory.

through a master 200 ohm T type variable attenuator. Figure 2B shows the alternate method, where the master T type control is omitted. The second connection may be used only if the voltage amplifier has a master volume control, like the one shown in Fig. 2B.

There are other methods of controls, in fact, you will find that various technicians have their own "pet" systems. Figure 3 shows a mixer control for three D.B.C. mikes. This control is especially valuable where a remote pickup is being considered, the operator watching the performance, fading in or out the desired mikes, or even blending or mixing 2 or 3 of them. The mixer has its own single stage voltage amplifier and microphone button current indicator, while it terminates in a 200 or 500 ohm impedance, so a long line may be used to connect to the main control at the am-

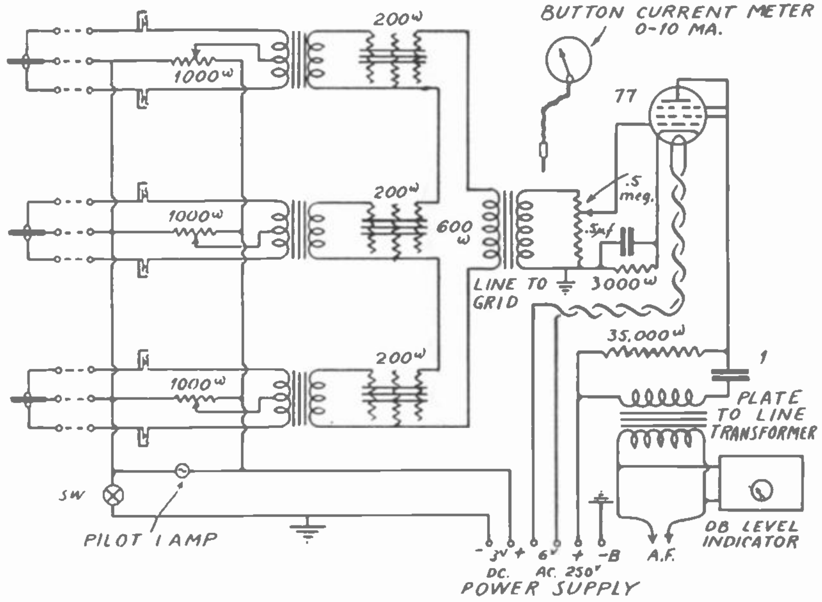


Fig. 3

plifier racks. For example the output of a system as shown in Fig. 3 may be connected to points x x in Fig. 2A through a long line, while the other mike in the control room may be used for control room announcing of phonograph or radio entertainment. What you should bear in mind is that any combination or arrangement may be used, provided all parts are impedance matched, that line signal level is high with respect to noise and all units terminate in the same impedance value.

A large number of P.A. systems do not incorporate as complete a control of pickups as shown by Figs. 2 and 3. To keep costs low, switching arrangements are considered sufficient. The annoying "plop" may be avoided by turning down the volume control on the voltage amplifier before a pickup change is made.

Figure 4A shows: *R.T.*, a radio tuner; *V.M.*, a velocity microphone; and *C.P.P.*, two high impedance crystal pickups, each terminating in an open circuit jack. The voltage amplifier input is through an open circuit jack. The connection between a pickup and the voltage amplifier is made with a patch cord. Another method is shown in Fig. 4B, where each pickup terminates in a double pole, single throw toggle switch, the latter connected in parallel and to the voltage amplifier. Only one unit may be on at a time. Figure 4C shows another switching system, and employs a double pole, multi position switch. The latter may be readily duplicated by employing a double deck, multi point switch, such as used in all-wave receivers.

There is a decided tendency to make amplifiers with enough gain to be connected directly to the pickups and the loudspeakers. This is generally true for portable P.A. units. In order to make

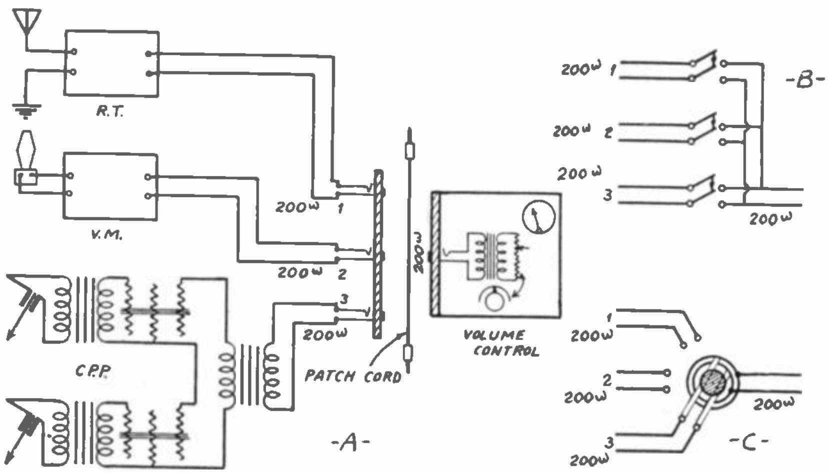


FIG. 4

these units flexible, several input circuits are provided. A typical example is given in Fig. 5. A radio tuner, a dynamic microphone, a low or high impedance electromagnetic phono-pickup may be directly connected to the amplifier. An astatic crystal mike or phono-pickup is easily adapted by employing a matching transformer. A double button carbon microphone is equally simple to adapt; only a current control and supply box is required. Each section should have a toggle switch, marked *x*. If they are not included, it would be wise to put them into the circuit. With these toggles, control *P* is set to zero and the pickup change made.

AMPLIFIERS

The audio amplifier is the heart of the public address system for it supplies the necessary signal level *elevation* to drive the loudspeakers. It takes the signal from the mixer control, or in some cases directly from the pickup and raises the signal level by the desired amount. It must do this with a minimum amount of distortion and interference. We say minimum amount of distortion and interference, because there is no need of having an amplifier better than what the needs of the service demand. As a rule, an amplifier cannot supply what the pickup or prior controls destroy, although it may favor or partially restore what the previous apparatus discriminates against. Thus the amplifier is a link in the P.A. system, and a very important one.

How Amplifiers Are Rated.—Of prime importance in amplifier rating is its power output, considered in watts output, or expressed in decibels above the .006 watt reference level. Output rating is important because it tells us how much undistorted power we have available to feed the loudspeakers or to drive a larger power amplifier, as in the case of a class B tube circuit. It is also important to know how much peak power the amplifier will deliver, although

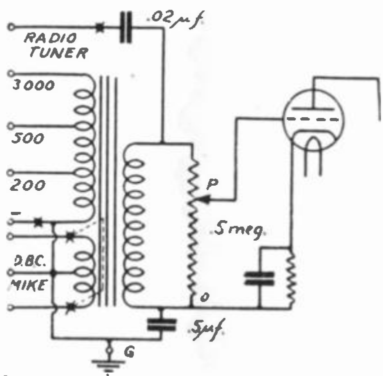


Fig. 5

no amplifier should be continuously operated at this value. Only temporary peak loads are permissible.

The overall db gain is another important amplifier characteristic, as it tells us whether sufficient amplification is available to raise what we deliver to it. Gain in an amplifier is always expressed as so many decibels. If the overall amplifier gain equals the numerical * level of the signal you feed to the amplifier, plus the numerical value of the power output level, you are assured of rated power output. Power output and overall gain are the two important amplifier characteristics, as all others may be adjusted.

The *input* and *output* impedance should be given. This provides the necessary information to make matched impedance connections. In the case of output impedance, you may have several values to choose from.

The electrical quality of an amplifier is first given by its *output vs. frequency* characteristic curve at rated power output. In the

* Without regard to — or + signs.

second place, the percentage of distortion at some reference frequency (usually 1,000 c.p.s.) and at rated output is important information. It should not exceed 10 per cent at full load. The output-frequency characteristic response should not show more than 2 db variation from maximum to minimum values of frequency. Although a composite P.A. system may be designed where one section compensates for the deficiency of another, it is wiser to have the response of each section as flat as possible, taking the overall response as is. Thus a poor section may in the future be replaced with improved equipment and with it obtain a better overall response. Where compensation is desired it should be supplied by a separate unit.

Output hum level is another important factor and should be 60 db below the full output of the amplifier. This is another way of saying that it will not be heard through low level reproduction. Circuit and tube noise level is not usually given, although you may assume that it will be sufficiently low if the level of the picked up signal is greater than —100 db.

For practical reasons you should know the overall size and weight of the amplifier and for that matter any of the other devices. A picture of the amplifier is of practical value. You should be given a list of the tubes used, for it is unwise to select an amplifier which uses tubes that are not readily replaced from a local source of supply. Then, too, the cost of tube replacement may have an important influence on the amplifier you choose.

You should know what controls are provided. A master gain control is quite important. If one is not included, your mixer to amplifier connection must be through a constant impedance T type variable pad. Some amplifiers have a tone control, which will only be needed if a P.A. system is used in a space where the wall reinforces the high frequency notes or in an installation where loudspeaker to microphone feedback becomes objectionable. A tone control is really valuable in portable equipment where no attention is paid to acoustically treating the space.

An output level indicator is important to the installation and service technician. It should be calibrated in db and placed across the 500 ohm output terminals. If connected at some intermediate point, calibration is not required although the installation man should indicate the peak swing. For high quality P.A. systems a level indicator should be a part of the amplifier and the operator trained in its use. When installing a new system, a portable output indicator may be used. In the latter case the previous adjustments are set so peak power is never exceeded under normal use. The intermediate connected level indicator may be calibrated against the portable output standard.

Power supply is another practical consideration and we will consider it shortly and in some detail.

Although power output and percentage of distortion are usually sufficient information, it is worth knowing whether the output amplifier tubes are connected in class A, class B or class A prime (also referred to as A′, A″, AB, etc.). This is a rough guide to quality and power efficiency. Class A amplifiers give the best quality but require a relatively large power supply to operate. Class B amplifiers normally give the least quality but are very efficient. They are widely used in mobile installations such as portable and automobile jobs. They are the best for battery operated amplifiers. Class A prime outputs are the most universally used. High quality is provided at low level and fair quality on peaks. Its efficiency is less than a class B amplifier but well in line with normal demands.

The method of heating the tube filaments is important in only one case, that is, when the amplifier is to be used intermittently as in a call system. As the usual heater type tube takes 10 to 60 seconds to get ready, only filament type tubes like the 30, 31, 33,

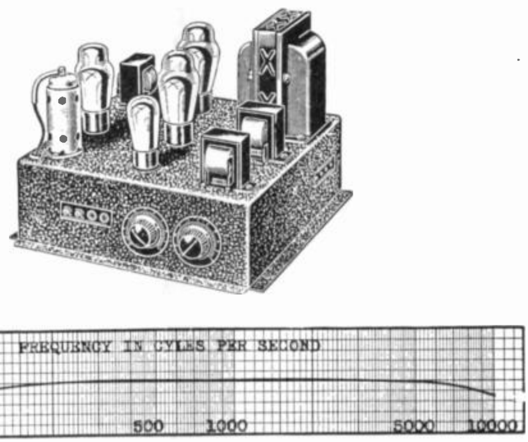


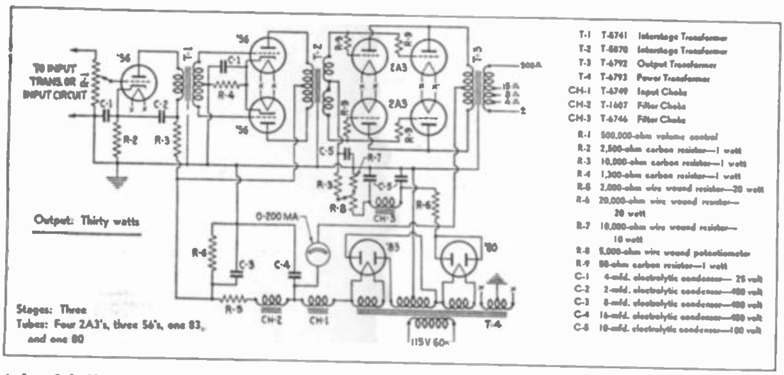
Fig. 6. Amplifier Specifications as Given by the Manufacturer

Power Output: 10 watts, 32.3 db.
Peak Power: 14 watts, 33.6 db.
Gain: 100.2 decibels
Output Impedance: 2, 8, and 500 ohms
Input Impedance: 500,000 ohms
Tubes: 57, 56, and two 2A5, the latter in class A push-pull, 83 rectifier
Hum Level: 64.7 db down.
Dimensions: 12" wide, 12" long, 9½" high
Shipping Weight: 30 pounds
Power Supply: 110 volts, 60 c.p.s., power pack built in.

45 or 50 may be used when this service is required. Or you may excite the tube filaments of a regular amplifier through a separate filament transformer, which is permanently connected to the supply during the period that a call may be sent out.

Figure 6 shows the specifications of a typical amplifier, as given by the manufacturer. The information may not be given in exactly this form, as usually the characteristics are clothed with "sales talk." Remember one thing, consider the maker. Is he reliable, is his reputation good? You "stake" your reputation on his. It is not sufficient to know that the maker or distributor will quickly replace defective material; you must be reasonably sure that the equipment will stay in operation. Constant break-downs are not good for any technician.

Single or Multi Section Amplifiers.—Although a single amplifier may be obtained to give the necessary gain and output, it is often wiser to use two or more sections. For example, you may need 60 watts (40 db) to cover a stadium. Such high level amplifiers are rarely needed, so a complete amplifier may be costly or must be made to order. To solve this situation many amplifier makers supply a high power amplifier with relatively little gain (a typical case is 15 db gain, 60 watt output) which is fed by another amplifier. As these amplifiers are usually of the class B push-push type, it is important that the driving amplifier have the correct output impedance and power. Here is a possible case. A class B amplifier will deliver 60 watts if it is supplied with 3 watts of power; its input impedance is 500 ohms. The same amplifier will deliver on peaks only, 80 watts if fed with 8 watts of power. To utilize this amplifier all you need is a small amplifier delivering 3

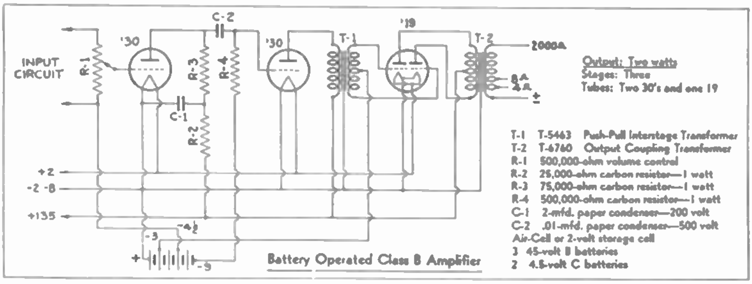


A high fidelity Class A parallel push-pull amplifier for normal 115 volt A.C. operation. Like all other amplifiers described in this text will work out of a normal double button carbon microphone, close talk. R_8 should be adjusted so plate current meter reads 160 milliamperes. A temporary meter connection or close circuit jack connection may be used, thus eliminating a permanent meter installation. Thordarson Elec. Mfg. Co., chokes and transformers indicated.

watts, one that has sufficient gain to be actuated by the pickups and has an output impedance of 500 ohms or made so with a matching transformer. If this amplifier will deliver 8 watts, then 80 watts may be realized but only on peaks.

Suppose you are considering a centralized radio system, a radio receiver feeding many magnetic loudspeakers. Assume that you need 60 watts and it is convenient to separate the loudspeakers in three bays. Each bay will need 20 watts. There are many ways of feeding this bay. A single 60 watt amplifier may be used (as previously indicated), the three bays connected in parallel and impedance matched to the output of this large amplifier. Or you may use three 20 watt amplifiers, the output of each connected to a separate bay, the input connected in parallel and impedance matched to the output of the radio tuner. Or you may connect the radio tuner to a 3 watt output amplifier. The latter may be impedance matched to three 20 watt power amplifiers each feeding a bay. Suppose the 3 watt amplifier has an output impedance of 7,000 ohms, the 20 watt power amplifiers an input impedance of 500,000 ohms. If you connect the three amplifiers in parallel their net input impedance will be 500,000 ÷ 3 or 167,000 ohms. Hence, a 7,000 to 167,000 impedance matching transformer will be needed—about 5 to 1 turn ratio.* The 20 watt amplifier should have a volume control in the input to its first stage so the following stages will not be overloaded. The overall gain is roughly the sum of the gains of both amplifiers, which will usually be more than required.

Figuring Required Amplifier Gain.—How much gain shall the amplifier have? Theoretically just enough to excite the output tubes to full load. Actually it is wise to have an overall gain of about 10 more decibels. Here is how you would estimate the size of your amplifier. From the space or audience you planned to cover you would determine the input power to the loudspeakers.



A two watt Class B battery amplifier. Designed to give long battery life. Transformers are critical. Thordarson Elec. Mfg. Co., transformers indicated. If dry cells are used, connect four in series—parallel and insert a series 4 ohm, 2 watt resistor.

To this power in watts or decibels you would add the expected audio power line loss. The amplifier you choose should at least deliver this total power, and this characteristic is independent of the gain of the amplifier. If you would like to "play safe" you may add about 20 per cent more power. For example, if the amplifier needed is 20 watts, you may well consider a 25 watt unit. But be sure the amplifier you choose is not rated below the needed value; when the value needed is smaller than any unit you can buy, choose one with the next highest rating.

Next you consider the pickup devices, estimating the db level of the least sensitive unit. If you plan to use a microphone on a long voice shot, be sure to figure in the added loss in power. For every externally inserted volume control add an additional loss of 2 db. The latter does not mean that because a mixer may have 4 controls that you should add 8 db loss. You must consider only those attenuators in the path from pickup to the input of the last audio stage, and the mixer figures as only one control. To this

* A 5 to 1 plate to grid interstage transformer will suffice.

total add a loss of 10 db. This apparent pickup output level added to the amplifier output level is the amount of db gain your amplifier should have. For example: the amplifier must supply about 24 watts of power, a level of +36 db; you plan to use an astatic crystal mike which delivers —60 db; the mike may be used at a voice distance three times the normal value of 6 inches, which contributes an additional loss of 10 db; there is a mixer and master control, so you add 2×2 or 4 db; an additional loss of 10 db is added for failure to include certain unknown factors and to permit reasonable control of peak power. The apparent output of the pickup is $60 + 10 + 4 + 10$ which is equal to —84 db. Add this numerical value to 36 db and an overall gain of 120 db is required. The microphone output is —70 db well above the minimum of —100 db at which noise becomes apparent. The amplifier is satisfactory if other factors, hum, fidelity, etc., are what you want.

EXTENSION LINES

In any complete P.A. system, extensions will be required; from the pickups to the amplifier, assuming the mixer and master controls are closely associated with the amplifier; from one section of the control or amplifier unit to the next; and from the output of the amplifier to the loudspeakers. A few words of caution will be helpful.

High impedance lines should be short, not over 6 feet, and should be shielded. The impedance of a line is considered as the impedance of the matched source and load that it connects. For example, a high impedance crystal mike, or phonograph pickup may feed directly into the grid of an amplifier, provided the line is a two wire shielded cable and is less than 6 feet long. The output of one amplifier may feed the next amplifier without an impedance reducing transformer provided the line is short and shielded. Low impedance lines may be run several hundred feet provided the line resistance is low with respect to the load or source impedance and the signal level is well above —30 db. Of course, the higher the signal level the longer may this line be, up to 4,000 feet. If the line resistance is one-tenth the terminating impedance a loss of 0.5 db will be experienced. Even low impedance high level lines should be shielded to prevent electromagntic influence on low level lines. Amplifier to loudspeaker extensions in a permanent installation should be run in conduit, BX cable or lead pipe (lead covered wire).

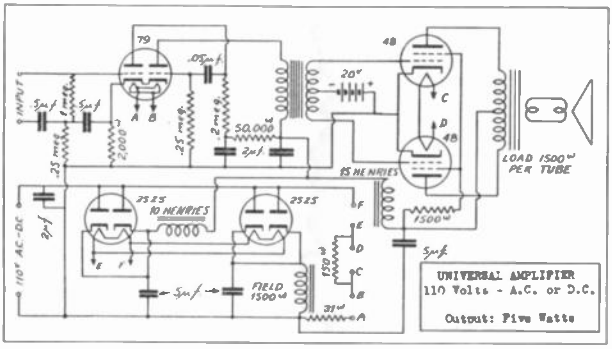
Pickup extensions should be kept far away from audio power or A.C. lines. This will prevent noise and hum induction pickup. One side of any line should be grounded. If this wire is at ground potential make a direct metallic connection; if it is at some D.C. potential with respect to actual ground, connect to ground through a .5 to 1 mfd. condenser. All shieldings should be connected to ground. If you are in doubt as to whether a certain line or shield or part is at some D.C. potential above ground, measure it with a voltmeter. If zero make a direct ground connection, otherwise use a condenser. Of course, no long audio line should carry a D.C. current if you possibly can prevent it by a redesign.

MAIN POWER SUPPLIES

The circuit diagrams of a number of amplifiers which you can build are shown in the P.A. texts, although it was pointed out that you would be better off if you purchased complete amplifiers. They are shown to give you some idea of the kinds of power supplies you may encounter in practice. In general you will be confronted with the following sources of supply:

1. 110 volts—60 c.p.s.
2. An odd frequency and voltage.
3. 32, 110, or 220 volts D.C.
4. Batteries, dry and secondary.
5. Mechanical power; gasoline engine.

In general, standard P.A. equipment is made to operate



An A.C.-D.C. Universal Class A Amplifier capable of delivering 5 watts of undistorted output. Push-pull stage requires a C battery as shown, which may be shunted with a 200 volt-2 mfd. condenser. Note the filament connections *AB*, *CD*, and *EF*. Thordarson parts recommended are: Interstage transformer, T-5741; Output transformer, T-6754; Choke, T-6749. Loudspeaker should have a 1500 ohm field and the proper output transformer secondary connected directly to the voice coil.

directly from a 110 volt 60 c.p.s. source of supply. For low power use, less than 40 watts audio power, any wall outlet may be used. Where audio powers of 50 and 100 watts or more are involved and particularly where class B amplifiers are used, a direct supply connection from the power line meter should be made. Of course, this may only be considered for a permanent installation.

When the A.C. supply is 220 volts-60 c.p.s., a step-down transformer is the only device required to operate 110 volt-60 c.p.s. equipment. On the other hand, if 25 c.p.s. line is encountered you may either buy equipment designed for this frequency, or buy a motor-generator set. Always get quotations for the equipment both ways before making your decision. The rotating machinery should be located some distance away from the amplifiers, mounted on a concrete or heavy wood beam base and cushioned with rubber or cork.

Amplifiers are made to operate directly from 110 or 220 volt

D.C. sources. To be sure the audio power output is limited. If large audio powers are needed, it is wise to use A.C. equipment and employ a D.C. to A.C. power converter. A 32 volt D.C. to 110 volt 60 c.p.s. converter may be used, although you may use a battery operated amplifier supplying the filament directly from the 32 volts (using limiting resistors where needed), the tube electrode supplies furnished by means of a dynamotor or a vibrator unit.

Battery operated amplifiers may be operated directly from a storage battery and B battery blocks, the storage battery feeding the tube filaments. Quite often in mobile installations, the storage battery drives a dynamotor or a vibrator B unit, furnishing the required high D.C. potentials.

For large P.A. installations where an electrical supply source is not available and where batteries cannot be economically used, a gasoline engine driven A.C. generator is recommended. In sound trucks, the car engine can be belted to an A.C. generator using the

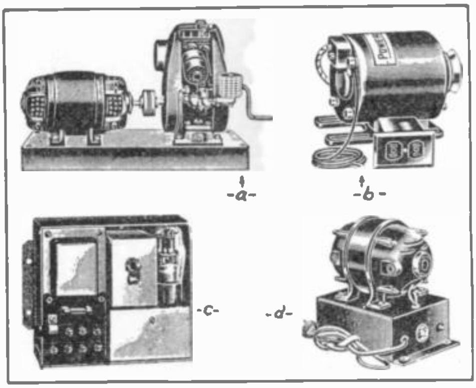


FIG. 7
Types of power supply units. The portable gasoline engine-driven generator at *a* should be used for a portable high-level P.A. system to make it independent of any power supply condition which might be encountered.

fan belt. If there is no objection to a larger initial outlay of money it is wiser to use a gasoline driven A.C. generator, so the equipment may be used with the car engine turned off. The generators should deliver 110 volts 60 c.p.s. current so standard P.A. equipment may be employed. An exception to this practice may exist in some automobile or sound truck installations. The filaments of the amplifier are fed directly from the car battery, which in turn is kept fully charged by the car generator. The car engine drives a D.C. generator having a potential sufficient to operate the high voltage circuits of the amplifier.

When the car storage battery is used as a power source, it is wise to connect a second battery in shunt. Dynamotors should be selected which will deliver the amplifier's total plate currents and other supply demands. Rotary converters and gasoline engines should be purchased on the basis of volt-ampere (apparent watts) output. Estimate for a class A and a class A prime amplifier approximately 4 times the power audio output; for a class B amplifier about 3 times the audio power output. Always buy the nearest highest power output power supply. All rotating electrical machinery should have ripple or spark filters attached; large power units should have a switchboard.

A number of power supply units are shown in Fig. 7. In Fig. 7a you will observe a small gasoline engine driven A.C. generator. They may be procured in output ratings of 300 to 1200 volt-amperes. Filter and switchboard are not shown. At *b* you will note a typical A.C. generator designed to be driven by the fan belt of an automobile engine; the field is excited by the car battery. The generator is mounted so the fan belt runs over the generator pulley. The generator itself regulating so it gives constant voltage over wide ranges of engine speed, and are available in 50, 100

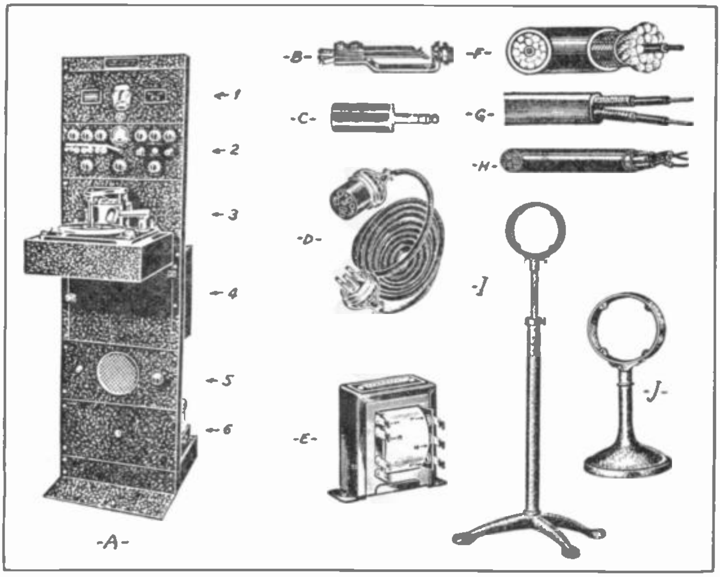


FIG. 8

and 175 watts output. A small vibrator-tube B supply unit is shown at *c*, and should only be used on small amplifiers. Figure 7d is a typical converter for changing 32 or 110 volts D. C. power to 110 volts 60 c.p.s. power. The filter is built into the base. They are available in sizes from 80 to 300 watts output. A similar appearing unit is available providing a 6 volt to 220 volt 100 milliampere D.C. conversion. In the latter case the dynamotor is operated from a 6 volt storage battery.

ESSENTIAL EQUIPMENT

There are few more details that you should be familiar with. The question definitely arises, how shall the equipment be mounted. As a rule most technicians build some sort of a narrow bookshelf, the separations high enough to house the equipment. For a more businesslike job; the control, amplifying and monitor equipment may be mounted on racks as shown in Fig. 8A. In this illustration: *1*, is the radio tuner; *2*, is the microphone and pickup controls, the meter used to measure the microphone button currents; *3*, is a phono-pickup and automatic record changer; *4*, is a record storage compartment; *5*, is a monitor loudspeaker; and *6*, is the main power supply and amplifier.

Many concerns selling P.A. equipment will rack the equipment they sell at an additional cost. Many sound technicians assemble the equipment on racks which they can buy. The standard rack is 19 inches wide and 25 or 36 rack units high. Each rack unit is equal to 1¾ inches. The panels are therefore cut 19 inches wide and some multiple of 1¾ inches high; for example, 8¾, 10½, 12¼, 14, 15¾, 17½. It is wise to cut each panel 1/32 of an inch less in height to allow for clearance. The steel rack uprights come drilled with many holes, in sets of two, the two holes 1¼ inches apart, each such set separated ½ inch. Therefore there will be no difficulty in finding symmetrical panel holes to mount any panel. Use 10-32 machine bolts. Most sound technicians use heavy gauge aluminum panels (⅛ inch thick) and paint the finished panel jet black before mounting the equipment on them. Crystalline black steel panels may be purchased and, of course, are less expensive than aluminum but more difficult to cut.

Illustration *B* shows a triple contact jack, which engages with the triple contact plug shown at *C*, both used for double button carbon microphone connections. Twin contact plugs and jacks are extensively used, the closed jack for current meter plug-in, open jacks for patch cord connections. A slightly different 3 way cable with plug and receptacle used with D.B.C. mikes is shown in Fig. 8D. *E* is a typical impedance matching transformer. *F*. *G*. *H* are shielded cables. *F* is for high impedance two wire connections; *G* is a lead covered twin conductor used extensively for power audio lines; *H* is a three wire shielded cable for D.B.C. mike extensions.

Microphone stands are also essential equipment. *I* shows an adjustable floor model; *J*, a desk model. The ones shown are suitable for D.B.C. and astatic crystal mikes which are held in place by springs (not shown). Other microphones are screwed to the top of the sliding rod, the upper circular piece removed.

Typical P.A. Systems

A progressive energetic sound technician will find a ready market for amplifier equipment wherever a need for sound reinforcing or sound distribution is indicated. Salesmanship will be needed, for the average buyer cannot supply the enthusiasm for a device that he is not familiar with. When an installation has been made to serve a definite purpose, you may point to that job as a sample of what a similar installation will do under like conditions. Keep a scrap book collection of photographs of jobs that you have completed. Even a list of satisfied rentals will help sell more temporary installations. Which all goes back to the fundamental business principle, a satisfied customer is a booster.

Sound amplifying and distribution systems are to be found in the most unusual places; in fact, it would be an almost endless task to give a complete list of places where they may be used. Every application suggests another. You must survey your locality and lay your own plans of getting to the managers of the places you feel need amplifier equipment. A partial list where portable and permanent sound reinforcing equipment are used or persons who have used them would include: airports, amusement parks, apartment houses, armories, arenas, athletic fields, auction rooms, auditoriums, band stands, banquet halls, camps, clubs, conventions, dance halls, dancing schools, demonstrators, elocution schools, factories, fairs,

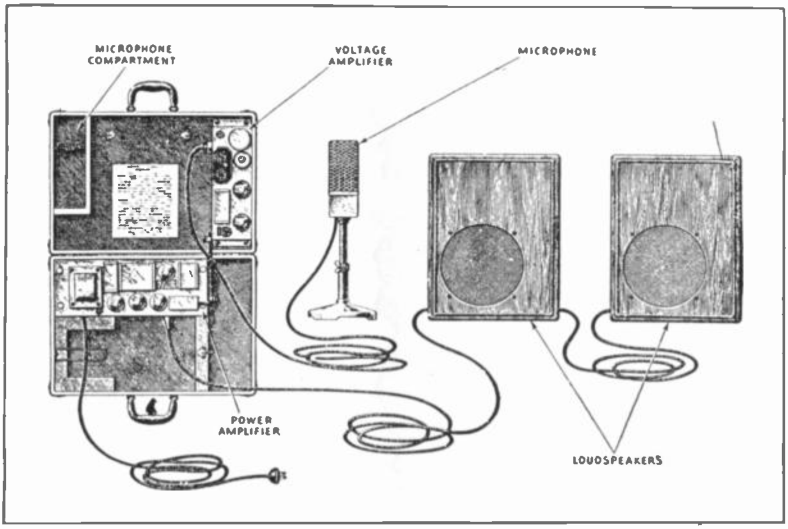


Fig. 9

funeral parlors, gymnasiums, halls of all kinds, lecture rooms, hotels, lodges, lunch rooms, meeting rooms, music schools, night clubs, orchestras, playgrounds, picnics, political gatherings, race tracks, railroad stations, retail stores, ships, steamship piers, stock exchanges, summer resorts, teachers, theaters, trucks, vaudeville, yacht clubs, window demonstrators—a long but hardly a complete list.

Let us consider a few typical installations, in a general way.

PORTABLE EQUIPMENT

Every active sound technician requires a portable sound system, because there is a large demand for a temporary sound reinforcing system. Rentals often lead to permanent installation; or a permanent installation will be purchased only after a temporary portable installation has been tried out. Many beginners make the mistake of using inefficient systems, thereby ruining future rentals or the possibility of selling a permanent set-up. You may find it a financial strain to start with good portable equipment, but if you can, your progress in the field will be quite rapid. Good equipment need not be excessive in cost.

Figure 9 shows a well designed portable sound reinforcing system, the R.C.A.-Victor Type PG-62 Universal Amplifier. It is a good guide in selecting similar equipment. The device delivers 20 watts of undistorted power into two cone dynamic loudspeakers. A high grade velocity microphone feeds into a voltage amplifier containing a microphone and a master level control. A phonograph pickup (housed with its motor and turn table in a portable carrying case, which is not shown) is optional equipment and the plug on its extension cord is inserted into a jack in the voltage amplifier. The level of the phono-pickup is controlled by an attenuator at the turn table. This prevents overloading the first tube of the voltage amplifier. The voltage amplifier also contains a tone control and speech clarifying switch.

At right angles to the voltage amplifier (to reduce hum induction) you will find the power amplifier and power pack, the latter operated from a 60 c.p.s.-110 volt outlet. Other power sources may be used by suitable adaption. The two loudspeakers have a long interconnecting cable, for as you know, the mike should be placed between the loudspeakers, and in line. The two loudspeaker cases lock together when they are not used and their extensions are housed within the carrying case, which also forms the baffle. The mike is detached from its stand, the power and mike cables are coiled and placed in the carrying case before the latter is closed. The equipment is equally useful for indoor and outdoor use, although for outdoor needs a detachable flared baffle could be adapted to the loudspeakers.

SOUND TRUCK

A great many sound technicians prefer a sound reinforcing system installed on a light delivery truck. There is no doubt that it lends itself to a more complete rendering of service than a portable system in a carrying case. The sound truck has come into universal use, because it can be driven slowly through the streets to get quick attention; taken to an outdoor event; or to some indoor job, where the equipment is dismounted and temporarily erected indoors. Obviously a sound truck should be designed for universal use, at least, until the number of outdoor jobs you get demand one for continuous outdoor use.

Figure 10 shows a typical sound truck, built by an N.R.I. graduate. This truck is also used on regular service calls, attracting favorable attention while on the way to a job. Observe that four highly directive flared baffle cone dynamic loudspeakers are used, each 10 watt capacity. The cone is housed in a weather proof sound absorbing box. The loudspeakers may be rotated in any direction or taken down for indoor use.

An installation of this type should contain a radio tuner with a roof antenna for mobile and a reel antenna for stationary outdoor needs. There would be a single microphone pickup probably of the double button type, but arrangements to use the other types for indoor jobs should be included; and there would be a phono-pickup.

A sensible amplier installation would start with a 3 watt good fidelity amplifier followed by at least two 20 watt power amplifiers. You could, at the beginning, use one 20 watt unit and gradually add one and then two units. The purpose of having controllable output is to meet all sound needs. Only 20 watts would be needed while moving through the streets or in an indoor space. Forty to sixty watts may be needed at picnics, outdoor conventions or at athletic fields. Flexibility is an essential feature.

All of the equipment within the truck should be housed in per-

Fig. 10

forated steel cases with handles. Each unit should be mounted on a floating shelf to absorb road shock; and dismounting should be quickly accomplished. Use large wing nut bolts to fasten the units to the floating shelves. So any power condition can be met, the power supply should be a 60 c.p.s.-110 volt generator preferably run by a small gasoline engine.

PERMANENT OUTDOOR P.A. SYSTEMS

In laying out a permanent outdoor job, the real problem resolves itself down to loudspeaker placement and housing. All other factors depend on the service to be rendered and are solved in the accepted manner. The number of loudspeakers used will depend on the area to be covered, and if this area is broken each section should be treated separately.

In the case of a band stand, or a grand stand the loudspeakers may be placed under a protective roof, the loudspeakers facing the gathering or directed to them from the rear. The exact procedure to take will be quite obvious when a job is surveyed. A race track or large open space may be well covered by placing the loudspeakers in the center of the area, erected on some elevation. A number of typical situations are shown in Fig. 11: *A* is for a sector of a stadium, the horns pointing from the front to the gathering; *B* is a typical placement for a football or similar athletic field, the horns directed slightly toward the people; *C* is the usual way of covering a large circular area, or by pointing the horns in the same general direction a long sector may be covered; *D* is a good way of covering a race track or similar circular outdoor arrangement, the horns directed to the crowd.

Either trumpet moving dynamic unit or flared baffle dynamic cone loudspeakers should be used, the directional effects being very important. Figure 12A shows a typical permanent tower for the loudspeakers. Only the loudspeakers are housed in the tower, the A.C. power leads and power audio lines coming from the remote amplifier room. Figure 12B shows a round mast on which slides a metal ring and pipe. The dynamic units are clamped to the ring. The trumpets are supported by guy wires fastened to this pipe. It is wise to arrange a pulley and flexible cable raising system, so the loudspeakers may be taken down and stored away when not in use. In a typical case, the A.C. wires and the power audio lines were drawn through steel pipe buried under the ground, terminating in a steel box fastened to the base of the mast. This box housed the rectifier unit that furnishes field current. The matching transformers were also placed in the steel box and a low resistance line runs up the pole to the moving coils. A few of the details are indicated in Fig. 12C. The loudspeakers are originally assembled on the ground, guy wires snapped in place (using snap clips) and the assembly hoisted up in place.

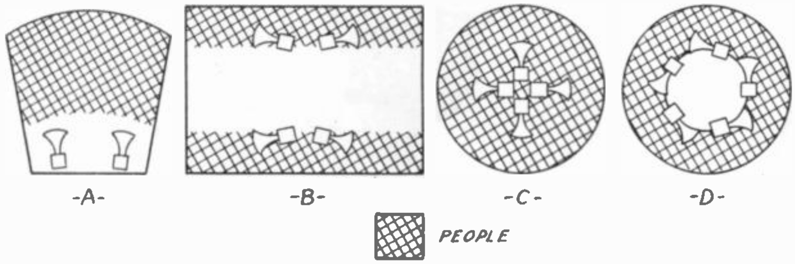


Fig. 11

Above all be sure you use a 500 ohm long line—keeping the line resistance as low as you can. For example, if you need 60 watts for the loudspeakers and the line loss is 1 db, about 76 watts must be supplied at the amplifier. Line loss is easily kept down, if you remember to use large gauge wire.

A FACTORY CALL SYSTEM

Voice calling systems in factories (see Fig. 13), hospitals, warehouses, attendant quarters in hotels are rapidly replacing gong, bell and annunciator calling methods. First because the mention of a name attracts prompt attention and secondly a direct message may be given. A number of small trumpet loudspeakers (2 to 5 watts) may be used in noisy places as in a machine shop, while ½ watt magnetic loudspeakers may be employed in quiet surroundings as in hospital corridors and warehouses.

When all the loudspeakers are of the same power and input impedance rating, and connected to the same feeder line, the line

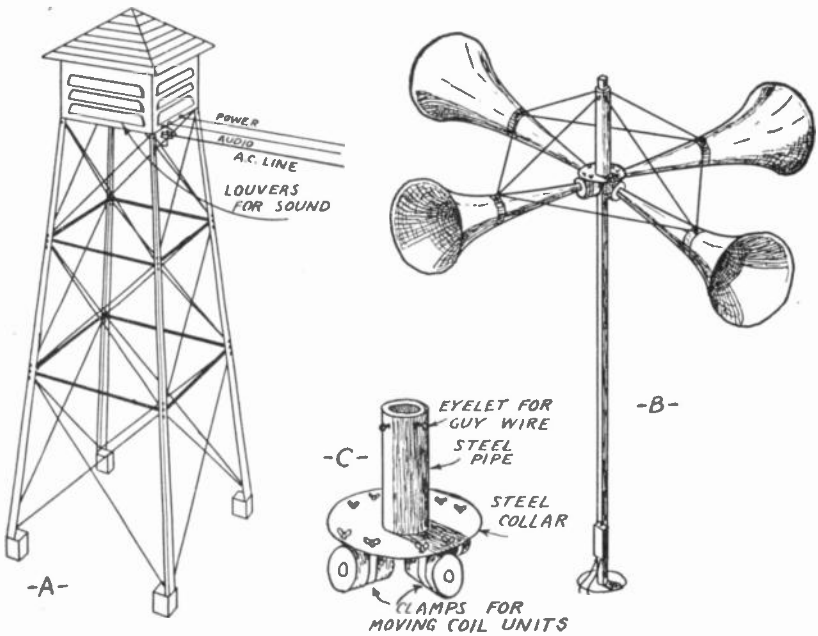


Fig. 12

input impedance is: *impedance of one loudspeaker ÷ the number of loudspeakers.* The total power drawn is the sum drawn by the loudspeakers.

When loudspeakers of different power rating are used in the same system, a more difficult situation arises. If loudspeakers of the same wattage and impedance can be confined to their own feeder, and the power input to each of the feeders are the same; then equalize the input impedance to each feeder, connect them in parallel and match the net impedance to the output of the amplifier. If a single feeder is used, loudspeakers of low power rating should have high input impedance. By selecting 5 watt loudspeakers with a 500 ohm input impedance, and ½ watt magnetic loudspeakers with a 5,000 ohm input impedance, each will be fed with its correct power if the net input impedance to the line is matched to the amplifier. The trick is to figure 500 and 5,000 ohm loads in parallel on a single feeder, a rather simple task if you remember the fundamentals of radio. The watts input is the total of the separate loudspeakers.

The microphone and the amplifier should be placed in the office of the supervisor. The amplifier should use filament type tubes, so it can be used the instant that power is turned on. When the amplifier selected uses heater type tubes the filaments of the heater type tubes should be disconnected from the supply in the power pack, and fed by a filament transformer constantly connected to the line. It may be wise to employ an L type attenuator at each loudspeaker so its sound level may be set at a suitable value above surrounding noise.

CENTRALIZED SCHOOL SYSTEM

A school sound installation exemplifies a condition where many services are required, but not in rapid sequence. In every case, the principal of the school should be consulted and his requests fol-

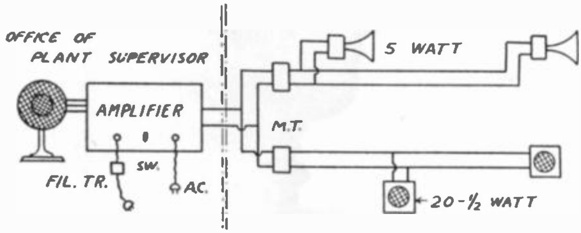


FIG. 13

lowed. In general, there should be provisions for: picking up local educational radio broadcasts (a radio tuner); reproducing recorded music and lectures (a phono-pickup and automatic record changer); talks or announcements from the principal or operator (a mike); and finally a means of picking up and reinforcing sound in the auditorium (a remote microphone pickup in the auditorium). Figure 14 shows in schematic fashion, provisions for these four services. A modern astatic crystal microphone and phono-pickup has been suggested as their outputs are relatively high and have fair fidelity.

These units are switched into the low level amplifier (*S.A.*) by means of a 4 point double deck switch. *S.A.* is a 3 to 4.5 watt amplifier which feeds into two or more 20 watt amplifiers. The connection is through a volume indicator (+30 db maximum) so a definite indication of peak levels is obtained. The input to each high level amplifier (*L.A.*) is made through a D.P.D.T. toggle switch, so when an amplifier is not in use the connection is terminated in a load equal to the input impedance of *L.A.* Of course, a matching transformer connects *S.A.* and the various *L.A.* amplifiers, which are in parallel. One *L.A.* feeds two 10 watt dynamic directional loudspeakers located in the auditorium. The other 20 watt large amplifier feeds a bay of 20 one watt permanent dynamic loudspeakers, one in each class room. Each class room loudspeaker terminates in a 500 ohm matching transformer and an L type variable attenuator, the latter used to control the power level or to shut the loudspeaker off entirely. The bay starts with a matching transformer and an open type jack, the latter to take a monitor loudspeaker, which has a high impedance so it draws negligible power when used. Additional bays may be used by adding 20 watt amplifiers and changing the matching transformer MT-1. The output level of each bay is adjusted by a volume control in its high level amplifier and once set is not disturbed.

A microphone amplifier should be used with the auditorium

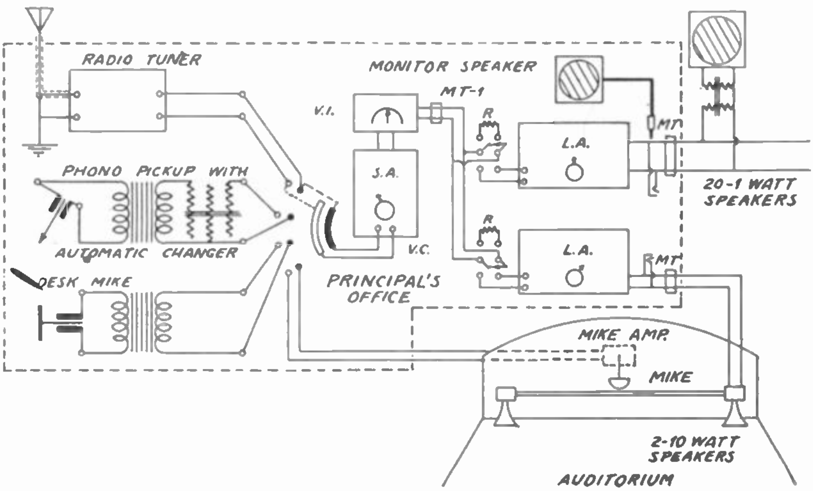


FIG. 14

microphone, if this assembly room is some distance from the principal's office, the usual location for the control and amplifier racks. Power supply for the microphone amplifier and the fields of the loudspeakers are made at outlets in the auditorium and turned on by an operator prior to their use.

The installation man should instruct the principal and other persons designated by him in the use of the equipment, especially in the use of the switches, the volume control on the low level amplifier, and monitoring with the volume indicator. He should be told that the *V.C.* on *S.A.* should be constantly adjusted so the needle of the *V.I.* never goes above +27 db (3 watts) on peaks. He should be instructed that before a pickup change is made, *V.C.* on *S.A.* should be set to zero otherwise an annoying "plop" will be heard. A log of control positions and full instructions should be typed and posted at the control rack. This log should be prepared after you have carefully tested the system; found the correct positions of the pickup volume controls to give the same output level; varied the load resistors *R*, so the level is the same for an amplifier or dummy connection; adjusted the volume control for each *L.A.* amplifier; and, finally, tested the level regulation in each class room.

CENTRALIZED RADIO SYSTEM

A means of distributing a choice of local radio broadcasts is fast finding favor in hotels and apartment houses. Here is an example of a single service. The most involved work is the estab-

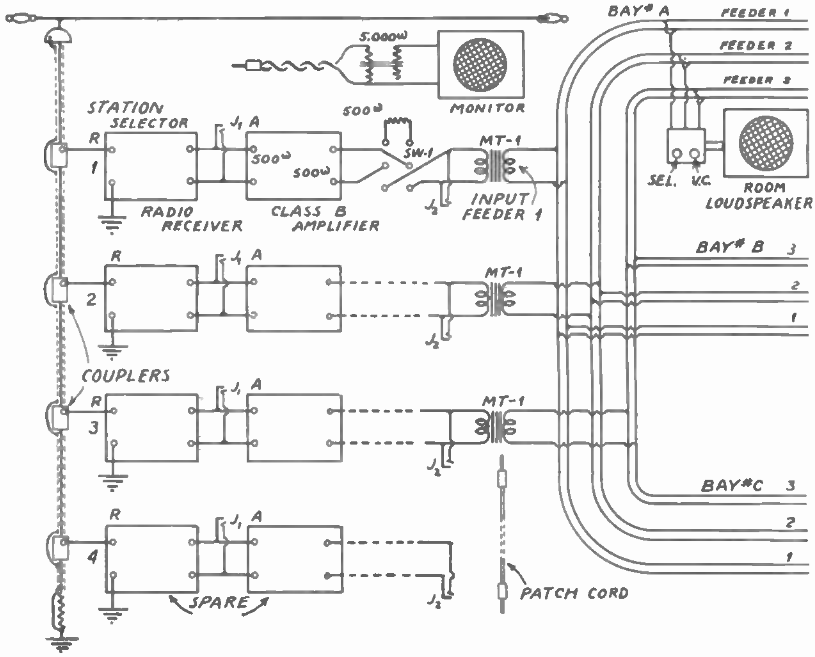


FIG. 15

lishing of a network of feeder wires from the amplifiers to the apartments or hotel rooms, a job for a capable licensed electrician. Study the house plans; arrange the feeders into bays,* each branch of a bay being closely associated and in a vertical line (floor above floor). It is easier to pull BX cable vertically through walls, than from one room to another that are on the same floor. In a building that is going up, the installation is greatly simplified and you may arrange the bays in any desired manner. All bays meet at a common junction as shown in Fig. 15 and common feeder leads joined

* In this discussion a feeder is any twin line that eventually connects to one broadcast; a bay is a physical section of the building and in this case incorporates 3 feeders.

together. Each cable has as many twin twisted leads as your plan provides stations for selection. The one shown permits a choice of three stations at one time. Each apartment or hotel room has a magnetic loudspeaker, preferably recessed into the wall, and a control plate, as shown in Figs. 15 and 16a. A magnetic loudspeaker capable of handling 1 watt should be selected.

The station selector in the wall plate is a double pole multi-position twist switch, especially made for this service. It is so designed that when a set of contacts are not used, a resistive load equal to the average impedance of the loud speaker shunts that feeder. Thus the load on any feeder line is constant whether used to reproduce or dissipate the audio signal. Figure 16b shows such a selector and Fig. 16c shows a typical constant input impedance L type control.

Returning to the main schematic, observe that a multi-receiver antenna is employed. The actual positions of the couplers are in the control room. As a rule, the apparatus is placed near the telephone operator, or desk clerk. The antenna feeds four receiver-

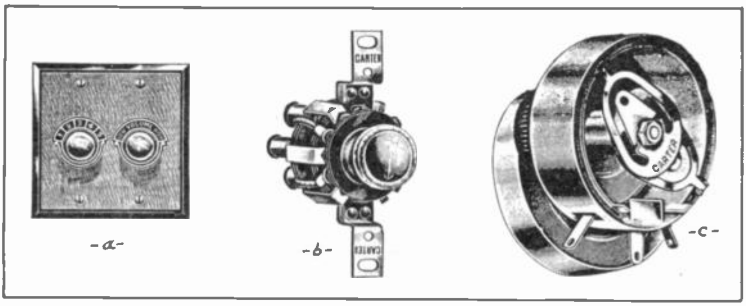
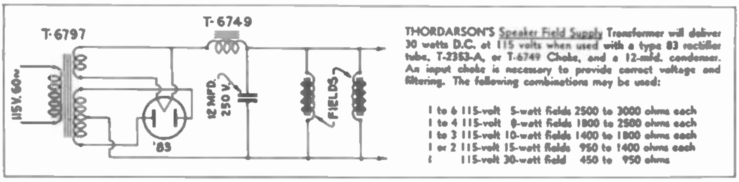


FIG. 16

amplifier sections, one used as a spare in case of breakdown. Ordinary normal fidelity receivers are used, and those having a class A push-pull output of 5 watts will be needed. Each receiver feeds into its own class B power amplifier, the two properly matched. If a monitor loudspeaker is used the connection shown should be followed. This loudspeaker is identical to ones used in the rooms and has an L type input variable attenuator. If its input impedance is 4,000 ohms, it will draw about one-eighth the total power, producing negligible mismatch. Of course, the monitor is not continuously used so its load is not figured in. A jack and plug connection is used.

Each class B amplifier feeds into three branches of the same feeder line, one to each bay. A feeder matches each amplifier by means of transformer *MT-1*. The input to each feeder may be shunted with an open type jack, for reasons to be shortly explained. Note that the *SW-1* toggle permits you to switch each class B amplifier into a dummy load. Thus, you can plug-in the local monitor loudspeaker, feed the power amplifier into a dummy load, tune and adjust the receiver without disturbing any loudspeaker connected to the feeder systems. When a section breaks down, the spare is tuned in and connected to the correct feeder by means of the patch cord and jack. The complete set-up for only one feeder is shown, the others are identical.

Suppose there were 60 loudspeakers and you plan an average input level of 1 watt. Each class B amplifier would have to supply 60 watts. There should be no difficulty of getting an amplifier to deliver 60 watts when fed with 5 watts. Assume each loudspeaker to have an average impedance of 4,000 ohms. A feeder input impedance will be 4,000 ÷ 60 or 67 ohms. A 500 to 67 ohm 50 watt



A loudspeaker supply

matching transformer (*MT-1*) will be required. The dummy load connected to *SW-1* would be a 500 ohm 50 watt resistor; each dummy resistor at the wall plate in each room connecting to a feeder should be a 4,000 ohm one watt resistor. A 4,000 ohm one watt L type attenuator will be required at each wall plate.

If voice announcements or phonograph recordings are to be included in a centralized radio system, the signal from a microphone or phono pick-up could modulate a well shielded R.F. oscillator, tunable in the broadcast band, its output connected to the input of any receiver, provided the antenna lead is disconnected. A S.P.D.T. switch should be used in a permanent connection for quick changeover.

TEST QUESTIONS

Be sure to number your Answer Sheet with *the number* appearing on the front cover underneath the title of this text.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your Course, and the best possible lesson service.

1. What is the lowest level a microphone may have to override objectionable circuit and tube noise?
2. Draw the battery circuit diagram for a double button carbon microphone including the surge filter.
3. In making a pickup change in a system such as shown in Fig. 14, how would you avoid the possible annoying "plop"?
4. What are the two important amplifier characteristics?
5. What type of power supply would you use with a portable high level P.A. system which would be independent of any power supply condition which might be encountered?
6. How would you include a simple voice announcing system in an existing centralized radio system?
7. What line impedance is preferred by technicians to reduce hum and noise pickup?
8. Is there any objection to connecting high and low level loudspeakers to the same feeder, if the net input impedance is matched to the power amplifiers?
9. Briefly, how could you adapt an amplifier using heater type tubes to a call system?
10. Of the following microphones, which require closely associated mike amplifiers: double button carbon, astatic crystal, crystal pile, velocity and condenser mikes?

1. Not lower than -100 db.

2. See Fig. 1A.

3. By turning V.C. on S.A. down before a change is made.

4. Power output and overall gain.

5. A gasoline driven A.C. generator.

6. Connect a microphone to an R.F. oscillator, the latter fed to the input of one of the radio receivers.

7. A 200 ohm pickup line.

8. None whatsoever.

9. Reconnect the filaments to a transformer which is then permanently connected to the line during the calling period.

10. Crystal pile, velocity and condenser microphones require closely associated microphone amplifiers.

REQUIREMENTS OF A TELEVISION SYSTEM

55RH-1

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

INTRODUCING TELEVISION

With this lesson, you begin your special training in the field of television. This first lesson will give you a comprehensive picture of a complete modern television system, showing how it is possible to see, on the screen of a cathode ray tube in a receiver, a scene which is at that same instant being viewed by the television camera many miles away in a studio.

Opportunities in television for trained men are increasing more rapidly than ever before in history, in two distinct branches.

Men who have specialized training in radio servicing and have mastered the fundamentals of television as presented in this course will be logical choices for jobs involving the installation and servicing of television receivers, for they will be qualified to handle both the sound and picture sections of modern television receivers.

Men who possess specialized training in radio communication and radio station operation, supplemented by a knowledge of the fundamentals of television, will be chosen to operate the television cameras, monitor the picture programs at the control boards, and operate both the sound and picture transmitters in a television system.

In the N. R. I. television lessons you will find, presented in a simple, logical and understandable manner, the important principles underlying all phases of modern cathode ray television systems. After mastering these lessons, you will find it remarkably easy to keep in step with new developments in this exciting and rapidly growing field.

J. E. Smith.

NATIONAL RADIO INSTITUTE

WASHINGTON, D. C.

1942 Edition

A LESSON TEXT OF THE N. R. I. COURSE
WHICH TRAINS YOU TO BECOME A
RADIOTRICIAN & TELETRICIAN
(REGISTERED U. S. PATENT OFFICE) (REGISTERED U. S. PATENT OFFICE)

NCP16C642

Printed in U. S. A.

Requirements of a Television System

Television as a New Service

THE process of scanning which breaks up a televised scene into successive signal elements results in a frequency range for picture signals of from nearly zero to more than 4,000,000 cycles (4 megacycles, abbreviated 4 mc.) per second. Radio waves constitute a logical carrier for bringing these picture (video) signals to a large number of people at any one time, but only ultra-high-frequency carriers are suitable for carrying through space a signal which has a frequency range of over 4 mc.

Ultra-high-frequency signals are bent only slightly by moisture in the air, and are not satisfactorily reflected by the Kennelly-Heaviside sky layer; this means that reliable television reception is limited to points which can be reached by signals traveling in straight lines from the transmitter. With receiving and transmitting antennas at practical heights, the maximum range of reliable reception from a given transmitter is about 50 miles. The transmission of television signals over radio carriers is therefore essentially a local service. Each community must have its own local transmitting station, serving television receivers within a radius of about 50 miles. These local stations can be connected

Courtesy Philco Radio & Television Corp.

The quality of the picture produced by a modern television receiver is evident in this image produced on the screen of a Philco television receiver (showing Mr. Larry E. Gubb, president of Philco Radio & Television Corp.). The actual image as viewed on the screen is much clearer, for considerable detail is lost in photographing the image and in reproducing the photo as a half-tone cut.

to one another and to a central source of television programs either by special coaxial cable or by ultra-high-frequency radio relay transmitters when national coverage is to be secured for a particular program. Direct reception of distant television programs will be decidedly a rarity.

Television, or seeing by radio, will be a new service to mankind; obviously it must be accompanied by sound in order to be fully appreciated. Talking motion pictures have completely replaced the silent movies, and audiences will naturally expect to have talking television pictures. All plans for television assume that both sight and sound are transmitted simultaneously. Television will in no sense replace sound broadcasting; the reception of sound programs by radio will continue to expand as it has in the past, and television will simply be an added service to listeners for some time to come.

Television is an Extension of Radio Principles

A television camera is needed to pick up picture signals in a television studio, and a special reproducing device is required at the receiver to reproduce the transmitted picture; between these two special devices, however, we find a great many familiar radio circuits. At the television transmitter there is a master oscillator which generates the ultra-high-frequency carrier, together with power r.f. amplifiers, a modulator, linear power r.f. amplifiers and a transmitting antenna. At the receiving location the television signals are picked up by an antenna, and are amplified and selected in the preselector of the television receiver. This receiver, if of the superheterodyne type, will have its local oscillator, mixer-first detector, i.f. amplifier, demodulator and picture signal amplifier, all of which prepare the received signal for the picture-producing device. The sound accompaniment for a television program is handled in essentially the same way as an ordinary radio program.

Television equipment has its full complement of tubes, coils, resistors, condensers, wires and transformers, just as does ordinary sound radio equipment. Television circuits may be identical with radio circuits, or may be entirely new circuits developed to meet the special requirements of picture transmission and reception.

Sounds, no matter how complex, are inherently a succession of signal intensities. Unfortunately, a scene does not exist in this desired state; *a scene must therefore be converted into a succession of signal intensities by a process of scanning*, as the first step in sending images by radio or wire. The television camera provides this scanning, and feeds into the television system a signal corresponding to that fed into a radio system by a microphone. The succession of signal intensities in a television signal is handled by the transmitting and receiving systems in a more or less conventional manner. These varying intensities must be reassembled in proper sequence and position by an image-reproducing device at the output of the receiver in order to reconstruct the original scene. The image reproducer in a television system corresponds to the loudspeaker in a sound receiver.

To insure proper step-by-step reconstruction of the scene at the receiver, the circuit which controls the scanning at the television camera must also control the image-reconstructing process at the receiver; this control is referred to as *synchronization*. The synchronizing signals are produced by unique oscillator circuits, are sent out on the carrier along with the picture signals in a more or less conventional manner, and are separated from these signals at the receiver by special circuits which do not exist in the usual sound receiver. In the final analysis, however, all of these special circuits are based upon extensions of well-known electrical and radio principles.

Once the requirements of a television system are recognized, the special circuits in television transmitters and receivers will seem quite natural and obvious rather than something strange and new. By studying the process of scanning first, giving special emphasis to the synchronizing signals and the circuits which handle these signals, we can make television circuits seem just as logical and understandable as ordinary radio circuits. This lesson is primarily intended to get you acquainted with the important problems in television.

Breaking up a Scene into Elemental Impressions

When we look at a picture or scene, we see various colors and various shades in each color, arranged side by side or blended together according to the nature of the scene. An ordinary photograph, on the other hand, appears to be in various shades of one color. If we were to examine a photograph under a strong magnifying glass or microscope, however, we would see countless small dots, each a different shade of gray ranging from white to black; each dot is one grain in the photo-sensitive emulsion on the surface of the photograph. I mention this merely to show that all photographs, whether in black and white or in natural colors, have a grain or a dot formation which is so small that it normally blends together like a natural scene and is invisible to the naked eye. For practical television purposes we can consider a photograph as being equivalent to an actual scene.

There is as yet no printing process which will give perfect reproduction of a photograph which contains many shades of gray or another color blended together. It is necessary for the engraver to break up the photograph into a series of dot impressions, then make a "cut" or "plate" which will print these dots. Careful examination of any photographic reproduction in a newspaper, magazine or book will reveal these dots to you; it may be necessary to use a magnifying glass in some cases, for the dots are very small in high-quality printing on a smooth, glossy paper. Note that in the darker or black areas the dots are largest, and that they become smaller and smaller as you examine increasingly lighter shades of gray.

FIG. 1A. A perfect printed reproduction of a line drawing, made by means of a zinc "cut."

FIG. 1B. Line drawing reproduced as dots of various sizes, with 60 dots per inch.

A line drawing like that in Fig. *1A* can be reproduced accurately by a printer without being broken up into large and small dots, and consequently we can use this drawing as an example and show how it appears originally and when broken up into various numbers of dots or lines. If we break up this drawing into 60 dots per inch in each direction, and make the size of each dot correspond to the average darkness over its corresponding 1/60th-inch square area in Fig. *1A*, we secure the half-tone reproduction shown in Fig. *1B*. The dots are arranged horizontally and vertically here for purposes of illustration, but in the usual photographic reproduction they are run diagonally so the screen pattern will not be so noticeable to the eye.

The dots in Fig. *1B* are clearly visible at a normal reading distance, but if you hold this illustration about four feet away from your eyes, the dots will blend together to give the impression of a picture composed only of gray and black areas. Increasing the number of dots in a given area has the same effect as holding the illustration at a distance. Figure *2A* has twice as many dots per inch on any one line as has Fig. *1B*. Note that these dots blend together at a distance of about 2 feet from your eyes. The more dots there are per square inch in a photographic reproduction, the better is the quality of reproduction. A large number of dots gives what is known in television as "high definition."

Lines of varying widths may be used in place of dots for photographic reproductions; an example of this is shown in Fig. *2B*. The method of image reproduction used in television is essentially the same as this, except that in television the lines are of constant width and vary in intensity of illumination. There are 120 lines per inch in Fig. *2B*, and there may be even more than 120 variations in line thickness for each inch of line length. Obviously, it is possible to get high definition with lines as well as with dot patterns. This is an important factor in the reproduction of television images.

When reproducing pictures by the process of printing, there are no real difficulties involved in securing as many as 200 dots per inch on a line, giving what is commonly referred to as a 200-line screen. In television, however, there is a limit to the amount of detail or definition which can be secured without exceeding the practical limits of the equipment. The number of dot elements per line and the number of lines per picture are definitely limited in television by the maximum frequency range which can be handled by the system.

The *larger* the image size produced by the television receiver, the *farther away* must be the viewers if they are to see a properly blended picture rather than an assemblage of lines and line variations. For example, if we enlarged Fig. *1B* to twice its size, giving 3,600 dots in a 2-inch square illustration as shown in Fig. *3*, we

FIG. 2A. Line drawing reproduced as dots of various sizes, with 120 dots per inch both horizontally and vertically.

FIG. 2B. Line drawing reproduced as horizontal lines of varying thickness, with 120 lines per inch.

would find it necessary to move twice as far away (to a distance of about 8 feet) in order for the dots to blend together.

Transmission of a Scene

We have seen how a scene can be divided into elemental impressions which, when reproduced as a series of dots or variable-intensity lines, will show almost as much detail as the original scene. Now let us see how the line variations in Fig. *2B* can be sent to a distant point in proper sequence, either over a wire or by means of a radio carrier signal.

Imagine a lens and photocell combination which can "see" only one small area of the picture in Fig. *1A* at a time. Assume that this "electric eye" looks first at the upper left-hand corner of the picture, then moves gradually over to the upper right-hand corner, looking carefully at each elemental impression along this uppermost horizontal line of the picture. At the end of this line a mechanical force shifts the electric eye back to the left and down a little to the start of the second line. Assume that this "scanning" from left to right continues until the electric eye has looked over the bottom line, at which time another mechanical force moves the electric eye back to its starting point at the upper left-hand corner. This action constitutes one complete scanning of the picture. The varying amounts of light reflected into the photocell by the elemental areas of the picture cause the voltage output of the cell to vary from instant to instant, and this varying picture signal voltage can be sent through space or over wires by a television system.

At the receiving end of our television system, let us imagine that we have a small nozzle which is spraying on paper a stream of ink which always covers the same definite area. This nozzle is so designed that the amount of ink which is delivered at any instant can be controlled electromagnetically; furthermore, the nozzle is so mounted that it will start spraying at the upper left-hand corner of the paper, and will travel horizontally to the right at a uniform speed corresponding as nearly as possible to the travel of the electric eye at the television scanner. The television signal which is picked up by the receiver is amplified and made to control the amount of ink flowing from the nozzle at any instant. A mechanical force returns the nozzle to the start of the second line at the same instant that the electric eye reaches the corresponding position on the original picture, and thus the nozzle delivers, for each elemental area of the paper at the receiver, an amount of ink proportional to the darkness of the corresponding elemental area on the picture. The result is that when the nozzle has completed the bottom line of the picture, it has painted with ink an almost exact reproduction of the picture at the transmitter. In a properly designed circuit, a low current value would open the valve and deliver a large amount of ink; large currents would close the valve, reproducing the white portions of the original scene.

In this imaginary television system,

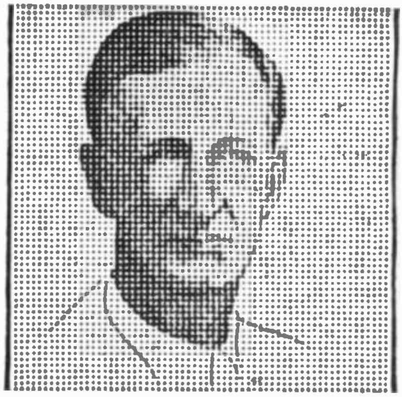


FIG. 3. When Fig. *1B* is enlarged to twice its size, we get this result. There are now 30 dots per inch, but the total number of dots in the picture is the same as in Fig. *1B*.

it is essential that the electric eye and the ink nozzle start moving at exactly the same instant, travel at the same speed, and at the end of each line fly back to the start of the following line in synchronism with each other. This could, of course, be accomplished with automatic manual mechanisms, but there would be no assurance that the two devices would keep in step. Even if the nozzle happened to be only slightly slower or faster than the electric eye, there might be as much as half a line difference or error after a few lines. We therefore arrive at this conclusion: *The television transmitter must, at the end of each line, send a signal impulse which will serve to swing the reproducing device back to the start of the following line in synchronism with the television camera.* With this requirement met, we know that the transmitting and receiving devices will start each line at the same instant, even though they may vary in speed a certain amount during a given line. The impulse which is sent at the end of each line for reproducer-controlling purposes is called the *line synchronizing impulse* or the *horizontal synchronizing impulse.* In a practical transmitter this impulse is not produced by the electric eye, but rather by an impulse generator in the transmitter which directly controls the travel of the scanning eye and which, by means of the connecting medium (wires or radio carriers), controls the travel of the reproducing device.

We must likewise provide means for returning the reproducing device from the lower right-hand corner to the upper left-hand corner at exactly the same instant that the electric eye makes this movement. This means that the transmitter must send an end-of-the-picture impulse to the receiver along with the varying line signals and the end-of-the-line impulses. This end-of-the-picture impulse is called the *picture synchronizing impulse, the frame synchronizing impulse or the vertical synchronizing impulse.*

The left-to-right scanning motion along a line is commonly called the *horizontal sweep.* The quick right-to-left return motion from the end of one line to the beginning of the next is called the *line fly-back, horizontal fly-back or horizontal retrace.* The downward line-by-line movement from the top to the bottom of the picture is called the *frame sweep* or *vertical sweep.* The quick bottom-to-top motion is called the *frame fly-back, the vertical retrace* or *the vertical fly-back.*

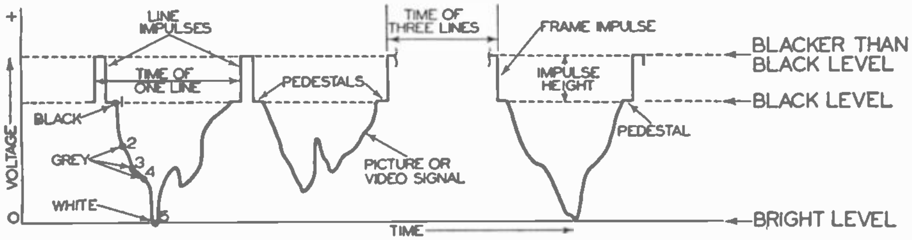


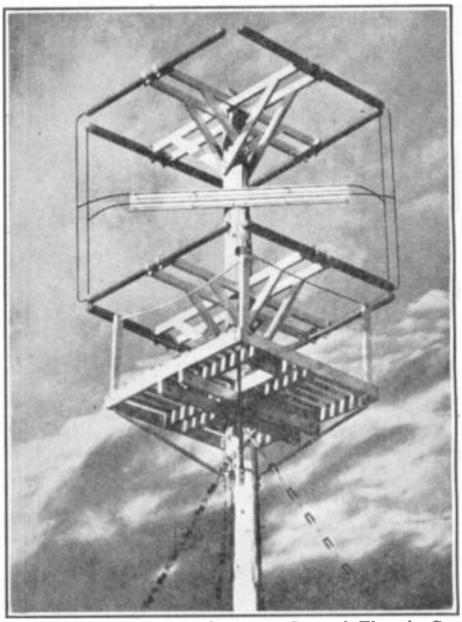
FIG. 4. This diagram shows the three essential components of a television signal—the video signal, the line impulse and the frame impulse. This is a modulated d.c. signal. Since the picture signal voltage swings in a negative direction for increases in brilliancy, we say that this signal has a *negative picture phase.* If the picture signal voltage swings in a positive direction with increases in line brilliancy, we have what is known as a *positive picture phase.*

The mechanical picture-sending and receiving system just described corresponds to one practical scheme for picture or facsimile transmission (the sending of photographs from one point to another by wire or radio; also known as wire-photo). As you have just seen, the three important signals which must be transmitted on the picture carrier in an electronic television system are: *1.* The *picture signal* or video signal, which is obtained by breaking up the picture into a number of elemental areas and scanning each of these in an orderly sequence; *2.* The *line synchronizing impulses* or horizontal synchronizing impulses; *3.* The *frame synchronizing impulses* or vertical synchronizing impulses.

Actual Television Transmission. During the transmission of a television signal, the line impulse exists for an instant after each line has been scanned, and the frame (picture) impulse exists for a longer period after each frame has been scanned. The video signals need not exist while these impulses are being transmitted; in fact, it is wise to stop them entirely during these periods. The line and frame impulses must be sufficiently different in character so they can be readily separated at the receiver and each applied to the proper control circuit. In actual television systems, this difference involves making one type of impulse last a longer time than the other.

The three essential components of a television signal (the picture signal, the line synchronizing impulses and the frame synchronizing impulses) may be transmitted in a number of different ways, but the signal arrangement shown in Fig. *4* comes nearest to satisfying the requirements of the television receiver. The r.f. carrier will be considered later and hence is not shown in this diagram. First of all, notice that this television signal is a pulsating d.c. signal with all its components above the zero-voltage line, which is known as the *BRIGHT LEVEL.* The video or picture signal varies between the *BRIGHT LEVEL* and the *BLACK LEVEL.* The synchronizing impulses are all between the *BLACK LEVEL* and what is commonly known as the *BLACKER THAN BLACK LEVEL.* The frame impulse lasts about three times as long as the time for one line. Experts have agreed that the *BLACK LEVEL* should not be higher than 80% of the maximum television signal amplitude.

Notice that points *1*, *2*, *3*, *4* and *5* along the video signal, corresponding to elements along one line of the picture being scanned, are for increasing values of brightness, with point *1* corresponding to a black elemental area on the picture, points *2*, *3* and *4* for gray areas, and point *5* for a white area. When increases in brilliancy make the picture signal voltage swing in a negative direction in this manner, we say that the signal has a *negative picture phase.* The synchronizing impulses are kept in a region not ever occupied by the video signal in order to make possible the use of a biased diode or triode tube for separating these impulses from the video signal. Notice also that before and after each impulse the television signal voltage remains constant for a short interval of time. These constant-voltage com-



Courtesy General Electric Co.

Cubical transmitting antenna of General Electric 10-kw. television station W2XB, located in the Helderberg hills 12 miles outside of Albany, N. Y. The antenna consists of eight hollow copper tubes each four inches in diameter and about seven feet (one-half wavelength) long, arranged to form a perfect cube which will radiate horizontally polarized waves for both picture and voice carriers in the 66-72 mc. television channel. Being atop a 1,500-foot hill, good coverage is expected for distances of 40 miles in all directions.

ponents of a television signal are known as *pedestals.*

When an ultra-high-frequency r.f. carrier is modulated with the television signal shown in Fig. 4, the bright components of the video signal will exist as low or zero carrier currents, and the impulses will exist as large r.f. carrier currents. This type of modulation is known as *negative modulation,* and is the exact opposite of the positive modulation scheme used in transmitting sound signals. (In radio broadcasting, the largest carrier currents correspond to the loudest sounds, and low carrier currents represent weak sounds). Negative modulation is used in television to insure having synchronizing impulse signals which are sufficiently strong to over-ride any interference noises which may be present. Furthermore, experience has shown that negative modulation gives more accurate synchronizing control at the image reconstructor in the receiver, and makes it possible to build into the television receiver a simple circuit for providing the highly essential automatic gain control action.

The Cathode Ray Tube As An Image Reproducer

Although electromechanical methods of scanning and reproducing (similar to those just described) are perfectly feasible, these methods are far more cumbersome than purely electrical methods. Furthermore, the electrical methods, employing various forms of cathode ray tubes, are far more satisfactory for high-definition home television receivers than are any of the mechanical systems available today. (Electromechanical systems will be described briefly in later lessons.)

The essential elements of one type of cathode ray tube being used for image reconstruction are shown in Fig. 5; they are: *K*—the cathode, which emits electrons when heated; *F*—the filament, which heats the cathode; A_1 and A_2—anodes which accelerate the electrons and focus them into a narrow beam; *S*—the fluorescent screen, which glows when hit by the electron beam; *G*—the control electrode (commonly called the control grid even though it looks entirely different from the grid of an ordinary vacuum tube), which controls the number of electrons entering the electron beam and thus controls the brightness of the spot on the screen; *V*—the vertical deflecting electrodes, which move the beam up and down on the screen; *H*—the horizontal deflecting electrodes, which move the beam horizontally in either direction.

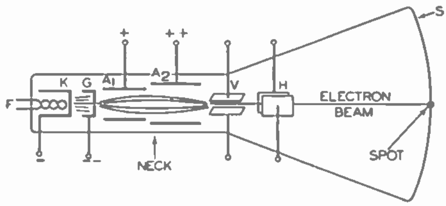


FIG. 5. Essential elements in a cathode ray tube used for image reconstruction in a modern television receiver.

Electrode A_2 is always at a higher positive potential than electrode A_1. These high positive potentials serve to accelerate the electrons in the beam, giving them greater speed; at the same time, the difference in potential between A_2 and A_1 serves to focus the electrons into the desired narrow beam. Control grid *G* is always negative with respect to cathode *K*; the value of this negative potential determines the number of electrons which the cathode can force into the electron beam.

When proper voltages are applied to the various electrodes in a cathode ray tube, with all electrodes located symmetrically with respect to the central axis of the tube, the spot will be in the exact center of the screen. Increasing the negative voltage on control electrode *G* reduces the number of electrons in the beam and thus reduces the brightness of the spot. The negative bias on the control grid is usually set so that the screen is dark when no television signal is present. The television signal must be applied in series with the negative grid bias in such a way that the spot will be dark each time a pedestal is transmitted; this condition is secured when the pedestals line up with the brilliancy cut-off point on the characteristic curve of the cathode ray tube. Video signals must make the control grid more positive than the cut-off voltage, thus varying the brightness of the spot on the screen. Synchronizing pulses must make the control grid more negative than the cut-off voltage, so the screen will be dark during the very short intervals of their duration (these intervals are, of course, too short to be noticed by the human eye).

The spot is in the exact center of the cathode ray tube screen only when there are no voltages on the vertical and horizontal deflecting electrodes. Now let us see how these electrodes can be made to move the spot to any desired point on the screen. Referring to Fig. *6*, notice that we have an electron beam traveling between two oppositely charged metal plates. Remember that the electrons in this beam have negative charges; this means that the positively charged plate will attract these electrons, bending the beam upward and causing it to strike the fluorescent screen at point *b* instead of at *a*, the center. The greater the voltage between these two deflecting plates, the more bending of the electron beam there will be.

But we know that this electron beam must be moved in a definite manner if it is to produce an image on the television screen. You will remember that the scanning process in the television camera involves analyzing the scene element by element in a manner exactly similar to that in which our eyes read a printed page. First of all, then, we require a means for sweeping the electron beam gradually from left to right in a horizontal line, then quickly back again to the left, with this horizontal sweeping motion being repeated continually.

We can secure horizontal sweeping of the beam by applying to the horizontal deflecting plates of a cathode

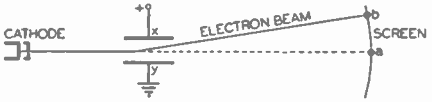


FIG. 6. An electron beam passing between two oppositely charged metal plates is always bent toward the positive plate.

ray tube a voltage having the characteristics shown in Fig. *7*; this is known as a *saw-tooth a.c. voltage*. Observe that this voltage is zero at points *1*, *2*, *3* and *4*, is positive at points *8* and *9*, and is negative at points *5*, *6* and *7*. If this voltage is applied to plates x and y in Fig. *6*, and plate y is grounded, plate x will be positive when the voltage is following path *1-8-2*, and plate x will be negative when the voltage is following path *2-6-3*. Plate y will always be at zero or ground potential. We can think of the voltage wave in Fig. *7* as showing variations in the charge on plate x. When this charge is at point *1*, the deflecting plates will have no effect upon the electron beam and the spot will be in the exact center of the screen. As the charge on plate

x approaches the positive value at point *8*, the electron beam will be attracted gradually and uniformly toward plate x. As the charge drops to zero again at point *2*, the spot will move rapidly back to the center of the screen. From point *2* to point *6*, plate x will become increasingly more negative, repelling the beam and bending it toward plate y. From point *6* to point *9* the beam will move gradually from plate y toward plate x, and from point *9* to point *7* the beam will move rapidly back toward plate y again.

We have seen that a saw-tooth voltage of the form shown in Fig. 7 will produce the desired sweep of the electron beam. If this saw-tooth volt-

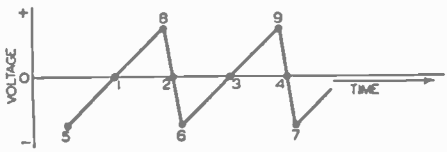


FIG. 7. Wave form of the saw-tooth voltage which is used for sweeping the electron beam back and forth in a television cathode ray tube.

age is applied to horizontal deflecting plates H in Fig. *5*, it will cause the spot to sweep slowly from left to right across the screen, then return rapidly to the left again. If this voltage is applied to the vertical deflecting plates V in Fig. *5*, it will cause the spot to move gradually from top to bottom and return rapidly to the top again.

In later television lessons in this course you will study the special vacuum tube circuits which are used to produce these saw-tooth voltages. None of these circuits are absolutely steady in frequency, however; it is therefore necessary to send impulse signals along with the television signal for the purpose of controlling and stabilizing the sweep circuits. One saw-tooth oscillator circuit is required for the horizontal or line sweep and another for the vertical or frame sweep. The line sweep circuit builds up its voltage uniformly from point *5* to point *1* to point *8* in Fig. 7; at point *8*, corresponding to the end of the line, a line impulse arrives with the television signal and causes this voltage to drop back to point *6* rapidly. The building up of voltage starts again, only to be stopped at point *9* by another line impulse. Since the drops in voltage are accurately controlled by the transmitter through the line impulses, we know that the electron beam in the reproducing device will be swept horizontally in exact synchronism with the scanning device at the transmitter. The vertical sweep circuit operates at a considerably lower frequency, and is controlled in the same manner by the frame impulses broadcast by the transmitter.

Now let us follow the movement of the spot on the screen of an actual television cathode ray tube as it sweeps back and forth and up and down under the influence of the impulse-controlled sweep circuits. During the first few moments after the receiver is turned on, the spot will be in the center of the screen (in any electrical circuit, it takes a short interval of time for the system to reach a steady-state condition; this is referred to as the *transient time*).

Once the beam is under the control of the horizontal and vertical sweep voltages, we can consider its starting point to be point *1* in Fig. *8*, at the upper left-hand corner of the screen. From this point the horizontal sweep voltage gradually allows the beam to "unbend" or return to the center of the top line, then gradually bends the beam in the opposite direction until the spot reaches the right-hand edge of the screen; during this action the vertical sweep voltage is gradually moving the spot in a downward direction a distance equal to the spacing between two lines.

At point *2* a line impulse arrives from the transmitter, causing the horizontal sweep voltage to move the spot almost instantly back to the left-hand side of the screen along the dotted-line path *2-3*. This return motion is very rapid, but sometimes, if the receiver is not properly adjusted, it will produce on the screen a faint line which is known as the *retrace* or *fly-back line.*

This process continues for each other line until the spot is swept to point *36* at the end of the last line. At this time the first frame impulse arrives from the transmitter, stopping the gradual build-up of the vertical synchronizing voltage and causing the spot to move back up to the top of the screen. Even though this vertical sweep voltage drops back to its starting value at a rapid rate, the change does take more time than is required for a complete horizontal sweep. As a result, the spot actually takes a zig-zag path from side to side as it is being returned to the top of the screen. This zig-zag path is not ordinarily seen on the cathode ray tube screen, so for simplicity the vertical retrace is shown as straight-line path *36-1* in Fig. *8*.

The scanning path just described, going from point *1* down to point *36* and then back to *1* again, constitutes one complete normal scanning of the scene. The entire process is repeated for each succeeding scanning.

No television picture signals exist while either a horizontal or vertical impulse is being sent by the transmitter, hence the appearance of any retrace lines would only cause lines or diagonal streaks in the picture, marring the reproduction. The synchronizing impulses are applied to the control grid of the television cathode ray tube in the receiver in such a way that these impulses drive the grid highly negative, causing almost complete cut-off of the electron beam and thereby preventing either the horizontal or vertical retraces from showing.

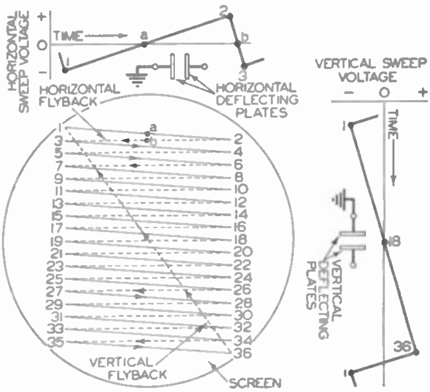


FIG. 8. The path traced on the fluorescent screen of a television cathode ray tube by an electron beam under the influence of horizontal and vertical saw-tooth sweep voltages is shown in this diagram. The wave forms of the sweep voltages are shown above and at the right of the screen; these voltages are applied to the ungrounded deflecting plate in each case. Thus, when the ungrounded horizontal plate is highly negative (at *1*), the spot will be at the extreme left side of the screen at point *1;* when this plate is at zero potential *(a)*, the spot will be at *a* in the center of the screen; when this plate is highly positive *(2)*, the spot will be at the extreme right side of the screen at *2;* when the saw-tooth voltage drops suddenly back to the highly negative value *(2* to *b* to *3)*, the spot flies back from *2* to *b* to *3* on the screen. Likewise, when the ungrounded vertical plate is highly negative *(1)*, the spot will be at the top of the screen at point *1;* when this plate is at zero potential, the spot will be half-way down the screen at point *18;* when this plate is highly positive *(36)*, the spot will be at the bottom of the screen at point *36;* when the saw-tooth voltage drops suddenly back to the highly negative value *(36* to *1)*, the spot flies up from *36* to *1* on the screen over a zig-zag path which for simplicity is shown here as a straight line.

Image Detail

A consideration of the processes of scanning and reproduction just described should make it clear to you that the video signal exists only while the spot is traveling from left to right along a line; at all other times the television transmitter is sending out pedestals and synchronizing impulse signals. The changes in the intensity of the video signal from one instant to another produce the essential picture detail; the more changes there are per line for a given actual scene being scanned, the greater will be the amount of detail in the reproduction of that scene at the receiver.

Naturally it would be useless to have considerable detail in a single line if there were only a few lines in the complete picture. This means that if greater detail is desired, the number of lines per picture and the number of changes per line must be increased proportionately. In television we find it more convenient to think of a reproduced image as being made up of a number of square dots, somewhat like the image in Fig. *3;* with this thought in mind, we arrive at the basic fact that it is desirable to have as many dot impressions per inch along a line as there are lines per inch.

Frequency Range. We can now consider the maximum frequency involved in a video signal. Since frequency is expressed in terms of cycles per second, we must review the fundamental definition of one cycle: *A cycle is a complete reversal or change.* If the elemental areas along a line of a televised image are alternately light and dark like a checkerboard, it will take two elemental areas to give a change. This means that the shortest cycle in a television image is equal to the time duration of two elemental square areas along a line. We seldom have a perfect checkerboard pattern in television, and hence it may take a longer interval of time—a whole line, half a frame or an entire frame —in order to give the change which constitutes a cycle. We have a maximum number of cycles when the elemental square dots are alternately light and dark, so by assuming this condition to be present we can figure out the maximum video frequency. Let us see what this frequency is for the existing television standards.

Television engineers in this country have agreed that there shall be 441 lines in a picture. If the picture were square, there would be 441 times 441, or a total of 194,481 square dot elements in this square picture. But television studios expect to use standard motion picture film for some transmissions, and the frames in motion picture film are never square. These frames are always wider than they are high; in fact, they are actually 1/3 wider than their height, so that a projected picture which is 3 feet high will be 4 feet wide. This ratio of width to height is known as the *aspect ratio.* The standard 4/3 aspect ratio for motion pictures has also been adopted for television; since this will increase the length of each line by the factor 4/3, we must multiply the value 194,481 by 4/3. This gives us 259,308 square dot elements in a standard television picture.

Television engineers have also agreed to the sending of 30 complete pictures per second. Multiplying 259,308 by 30 gives us 7,779,240 dot elements per second. Since 2 dots are required to give the shortest possible cycle, we divide 7,779,240 by 2, and get 3,889,620 cycles per second as our maximum video frequency under the conditions so far presented.

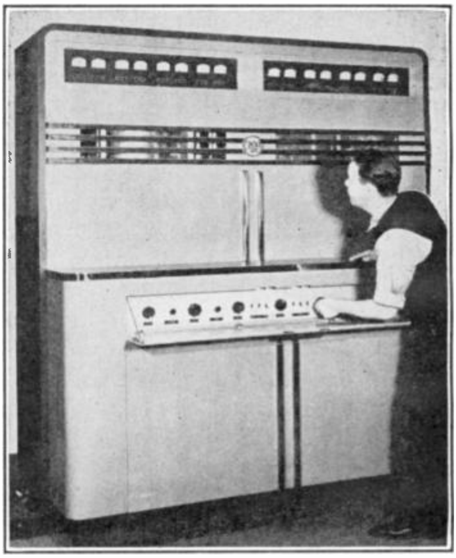
This last figure assumes, however, that video signals are being transmitted all of the time. We know that this is not true, for about 15% of the transmitting time is used for the horizontal flybacks. This leaves 85% of the total time for video signals, and means that our maximum frequency of 3,889,620 cycles must be sent in 85/100 of a second. We must divide 3,889,620 by .85, giving 4,576,023 cycles per second as the true maximum frequency for a 441-line image.

In earlier days of television, the construction of a system which would respond uniformly to frequencies ranging from a few cycles per second to 4,576,023 cycles per second was an extremely difficult and costly task. Investigation revealed that for the average size of television image, the maximum frequency could be reduced to about 60% of the value just specified without seriously impairing the quality of the image. For some time, a maximum video frequency of about 2.5 megacycles (approximately 60% of 4,576,023 cycles) was considered satisfactory. Television research has resulted in ways and means for handling considerably higher frequencies, so that today an upper limit of about 4.25 megacycles is being considered the goal for high picture detail.

Theoretically, the lower limit of the video frequency to be transmitted is zero, corresponding to a scene which is all the same brightness (all white, all black, or all the same shade of gray). It is very difficult, if not impossible, to construct apparatus which will handle frequencies from 4.25 megacycles right down to zero, but practical experience has shown that a lower frequency limit of about 10 cycles per second will give satisfactory reproduction of ordinary scenes if the video frequency amplifier in the receiver is properly designed.

Flicker

The human eye is peculiarly sluggish in its response to moving objects, for it continues to see an object even after the object has disappeared. Motion pictures depend upon this *persistence of vision* characteristic of the human eye; 24 separate still pictures are flashed upon a motion picture screen each second in sequence, but the eye sees a continuous action rather than a series of separate pictures. The eye can detect individual views up to a rate of about 10 pictures per second, but above this value the scenes blend together, accompanied by pulsating light impressions which give the effect of flicker. At about 20 pictures per second the blending of pictures into motion is almost perfect as far as the eye is concerned; flicker is greatly reduced at this rate but still is not entirely absent. Even at 24 pictures per second, the standard in the motion picture industry, flicker can still be noticed. It is for this reason that motion picture projectors have a shutter in front of the lens which breaks up each still picture into two separate views, giving the effect of 48 pictures per second even though not more than 24 of them are different.



Courtesy RCA Mfg. Co., Inc.

RCA one-kilowatt television transmitter, developed to enable experimental stations to render a satisfactory service over a reasonable area without too great an initial expense for equipment.

In television, the frequency of the available a.c. power has considerable effect upon the choice of a frame frequency (number of pictures transmitted per second). Since the power line frequency in this country is standardized at 60 cycles, ripple voltages at this frequency or some multiple of it will get into the video signal and the sweep voltages, tending to cause ripple effects, wobbling of the picture, and random movement of bright bands on the image if the number of pictures is increased to 48 or even to 72 in order to eliminate flicker. By using a frame frequency equal to some sub-multiple of 60 (such as 30 or 20) or some multiple of 60 (such as 60, 120 or 240), these ripple effects can be removed or at least made stationary so they will be less objectionable. Frame frequencies of 20 or 30 are still too low to eliminate flicker entirely; on the other hand, a frame frequency of 120 pictures per second would increase the maximum frequency of the video signal to an extremely high value. There is left, then, a scanning rate of 60 complete frames per second, which imposes quite a burden upon the transmitting system insofar as maximum frequency range is concerned. With a 441-line image being scanned 60 complete times each second, the upper frequency limit for high definition becomes more than 8.5 megacycles. It is not impossible to make amplifiers which will handle a range of from 10 cycles to 8.5 megacycles, but the cost of these is so high that the production of inexpensive television receivers becomes a serious problem. We need a scanning rate of 60 pictures per second to prevent flicker from being objectionable, but the use of this scanning rate in a normal manner makes receiver costs prohibitive; let us see how television engineers have solved this problem.

Interlaced Scanning

A simple scanning trick which makes the maximum video signal frequency correspond to that of a 30-picture-per-second transmission while still keeping the scanning rate at 60 pictures per second is the solution which television engineers have developed for the problem of flicker. In this system, which is known as *interlaced scanning,* only half of a picture is transmitted during one complete scanning; the other half is transmitted in the next complete scanning. A simple scheme has been developed whereby lines *1, 3, 5, 7* and all other odd lines are covered during one

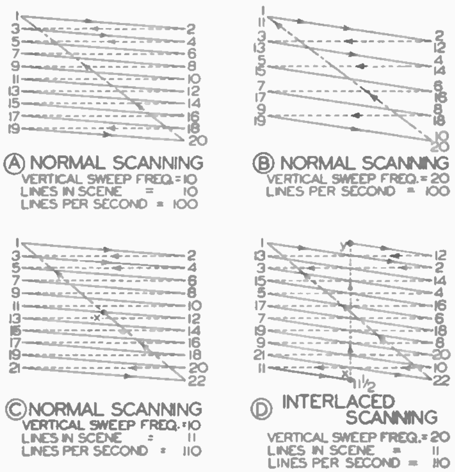


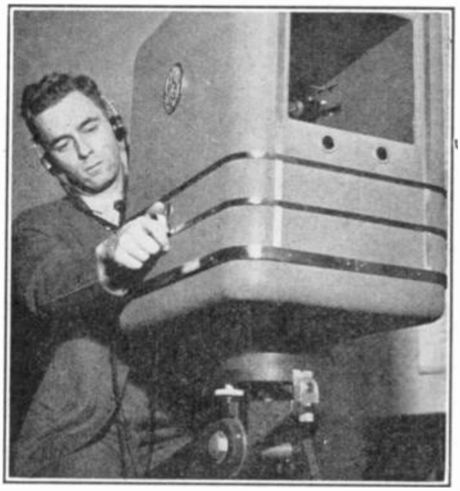
FIG. 9. These diagrams show that interlaced scanning can occur only when there is an odd number of lines in the scene and the vertical sweep frequency is twice the rate for normal scanning. Under these conditions, the same number of lines is transmitted each second with either normal or interlaced scanning.

scanning, and lines *2, 4, 6, 8* and the other even-numbered lines during the next scanning. Two complete scannings are therefore required to cover every elemental dot area on the scene being televised. At the receiver there must likewise be two complete scannings to give a complete reproduction of the image. With interlaced scanning, the frame or picture frequency is 30 per second since that is the number of complete pictures transmitted. For each complete picture the scene is scanned twice, so the *field frequency* *(vertical sweep frequency)* is 60 times per second.*

The two requirements for double interlaced scanning of a given number of lines per second at a given frame frequency are: *1*. An odd number of lines per picture; *2*. A vertical scanning rate which is twice the frame frequency. This automatically gives scanning of the odd-numbered lines during one vertical sweep and scanning of the even-numbered lines during the next vertical sweep, with odd and even line scanning alternating automatically. An example will best illustrate how this is done; since an example based upon a 441-line image would be too cumbersome, a lower number of lines will be used to illustrate the principles involved.

Suppose that we divide our picture into 10 lines, as shown in Fig. *9A*, and that we scan this complete scene 10 times per second (giving a vertical sweep frequency of 10 per second). This means that one complete scanning of the scene, starting at point *1*, proceeding to *2*, *3*, *4*, *5*.... *18*, *19*, *20*, and then returning to *1*, will take 1/10th of a second. *Assuming that fly-back time is negligible* in these examples, we can also say immediately that it will take 1/100th of a second to scan one line, moving from point *1* to point *2* and back to the start of the next line at point *3*.

Suppose, now, that we scan this same scene (having an even number of lines, 20 times per second by doubling the vertical sweep frequency, without changing any of the other conditions in Fig. *9A*. We will still be scanning the same total number of lines per second, and it will still take 1/100th of a second to scan one line, but now only 5 lines will be covered in one complete scanning from top to bottom. Referring to Fig. *9B*, the scanning path starts at *1* and goes to points *2*, *3*, *4*, *5*, *6*, *7*, *8*, *9* and *10* during one complete scanning of the scene. Vertical fly-back now brings us to point *11* at the upper left-hand corner and we cover exactly this same scanning path for the second scanning of the scene. Obviously, a television system using an even number of lines per picture cannot secure interlaced scanning by doubling the vertical sweep frequency.



Courtesy General Electric Co.

A typical television camera in operation.

Now let us see what happens when we have an odd number of lines (11) per picture and we use a vertical sweep frequency of 10 per second again, as indicated in Fig. *9C*. All 11 lines are covered in one complete scanning, and vertical fly-back takes us directly from point *22* back to the starting point at *1*.

* A *field* is the area covered during one vertical sweep of the scene. In normal scanning, the field is the entire scene; in double interlaced scanning, the field is only half the scene.

A *frame* is one complete scanning of every elemental area in a scene. In normal scanning, this occurs for each vertical sweep; in interlaced scanning, two vertical sweeps are required for a frame.

Next, suppose we double the vertical sweep frequency, giving 20 complete scannings of the picture per second without changing the total number of lines transmitted per second. This doubles the speed at which the scanning spot is moved downward, so that we will arrive at point *x* in Fig. *9D* (at the bottom of the picture) in exactly the same time it took to reach point *x* in the middle of the picture in Fig. *9C*. In Fig. *9D*, however, we have scanned only half of the lowest line when vertical fly-back moves the spot up to point *y* for the following scanning. This time we scan along path *12, 13, 14, 15, 16, 17, 18, 19, 20, 21,* and *22,* midway between the lines scanned the first time; *we are thus securing interlaced scanning of the complete scene.* From point *22* the spot goes back to point *1* for the start of the next complete scanning.

Interlacing twice, as illustrated in Fig. *9D*, is considered standard practice; to secure this without changing the total number of lines scanned per second (without changing picture detail), the vertical scanning frequency must be *twice the frame frequency* and there must be *an odd number of lines per frame.* If the vertical scanning rate is made three times the frame frequency and there is an odd number of lines per frame, we secure triple interlacing. With the vertical scanning frequency increased to four times the frame frequency, quadruple interlacing is secured.

Now let us consider interlaced scanning in terms of the standards in use in this country for television. With 441 lines per frame, a vertical scanning frequency (field frequency) of 60 per second, and double interlaced scanning, the total number of lines scanned per second must correspond to that scanned normally with a frame frequency of 30 per second. Multiplying 441 by 30 gives 13,230 as the total number of lines scanned per second in American television systems. This means that *the frequency of the horizontal sweep is 13,230 cycles per second,* and *vertical scanning frequency is 60 cycles per second.*

The detail in the image will correspond to that of 30 complete scannings per second of all lines in a 441-line image.

In an actual modern television system, a few lines at the top and bottom of each picture are blanked out by the blanking signal associated with the vertical synchronizing impulse, for reasons which will be taken up later. The synchronizing impulse itself prevents vertical fly-backs *x-y* and *22-1* in Fig. *9D* from being visible.

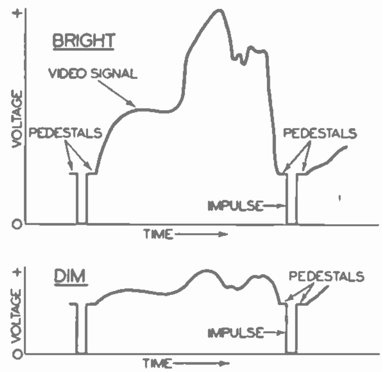


FIG. 10. The television signal which is applied between the grid and cathode of a cathode ray tube must have a constant pedestal voltage for scenes with all degrees of brightness, and must have a positive picture phase as shown here, so that the video signal will be *positive* with respect to the pedestal voltage, and the impulse signals will all be *more negative* than the pedestal voltage.

Brightness and Contrast Controls

It is essential that the television signal which is applied between the control grid and the cathode of the television cathode ray tube shall be of a *pulsating d.c. nature* and have a *positive picture phase,* so that synchronizing impulses will cause darkness, and video signals will give various degrees of spot brightness. Another requirement for faithful reproduction of a televised scene is that the pedestals shall all line up with each other at the input to the cathode ray tube despite variations in the brightness of a scene. For example, the pedestals at the output of the video demodulator in a television receiver should be the same voltage for a brightly-lighted scene (Fig. *10A*) as for a dimly-lighted scene (Fig. *10B*). Incidentally, with the exception of a reversal in phase, the signals shown in Fig. *10* have essentially the same form as those produced by television transmitters.

Now let us see how a cathode ray television tube reacts to signals of the type shown in Fig. *10* when the pedestals are lined up with each other. Remember that the various anodes in this tube have operating voltages which serve to focus the electron beam to a small spot on the screen, and that the negative voltage applied to the control grid of the tube determines the brilliance of this spot. The control which this grid has upon spot brilliancy is more or less linear with respect to the applied grid voltage, except that complete cut-off or darkening of the spot occurs at a definite high negative grid bias voltage. The graph in Fig. *11* shows these facts; note that reducing the negative bias on the control grid (driving it in a positive direction) increases the spot brilliancy. Points *2*, *3* and *4* are increasingly more brilliant, and correspond to increasingly more positive control grid voltages. This E_g-*BRILLIANCY* characteristic is quite similar to the E_g-I_p characteristic curve of the average triode vacuum tube.

The negative bias on the control grid of a television cathode ray tube must be so chosen that the pedestals in the applied television signal will be at the brilliancy cut-off point (point *1* in Fig. *11*) on the E_g-*BRILLIANCY* characteristic curve of the tube. Under this condition the video signal will swing the grid more positive than cut-off, giving various degrees of brilliancy, and impulse signals will drive the grid more negative than cut-off (into the blacker-than-black region).

When the video portion of the television signal shown in Fig. *11* is acting on the grid-cathode of the cathode

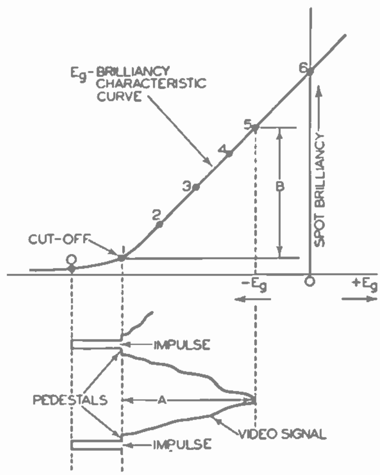


FIG. 11. Typical grid voltage-brightness characteristic curve for a cathode ray tube in a television receiver. Point *1* is considered the brilliancy cut-off point for the tube, as it corresponds to a spot brilliance weak enough to appear as a black spot to the human eye.

ray tube represented by this characteristic curve, the instantaneous control grid voltage will vary between points *1* and *5* on this curve, and spot brilliancy will vary over the region indicated as *B*. The impulses associated with this television signal swing the grid beyond the apparent cut-off point (beyond *1*) and hence cannot produce a spot on the screen. As long as the pedestals line up with the cut-off point, impulses will not produce a visible spot even with weak video signals, and weak video signals corresponding to a dim line or a dark scene will cause brilliancy to vary in the desired manner over the lower portion of the characteristic curve, such as between points *1* and *2*.

Suppose that the television signal in Fig. *11* was applied in such a way that the pedestals lined up with point *2*. The video signal would swing the grid voltage positively from point *2* up along the curve to point *6*, which is quite all right, but the impulses would only swing a small amount beyond cut-off and would not darken the spot completely. As a result, both the line and frame retraces would be clearly visible at the beginning and end of each line and frame. Obviously this is not a desirable operating condition.

Now let us consider another condition, that where the pedestals are beyond cut-off and line up with point *O*. Portions of the video signal will now swing into the dark region beyond cut-off, causing dimly-lighted portions of a scene to appear black instead of gray. Obviously this operating condition is just as undesirable as that where the pedestals are to the right of cut-off.

The television signal at the input to the cathode ray tube in a television receiver can be shifted in two different ways, in order to make the pedestals line up with the black level (cut-off) of the cathode ray tube. One method involves adjusting the fixed C bias on the cathode ray tube; the control in a television receiver which changes this bias is commonly known as the *brilliancy control*, for the most noticeable effect of changing the bias is a change in the brilliancy of the reproducing image. We can also shift the pedestals in one direction or the other to make them line up with the cut-off point by changing the amplification (gain) of one or more stages through which the television signal passes in the receiver. The receiver control which changes gain is commonly known as the *contrast control*, for its most noticeable effect is a change in the amount of contrast between bright and dark areas of the reproduced image.

We will want to decrease the amplification if screen brilliancy is too great or if the signal is so strong that it drives the control grid of the cathode ray tube positive (this causes the grid to draw current, narrowing the range of frequency response). If receiver amplification is too low, giving us a gray picture with insufficient contrast, we will want to increase amplification until we get the desired contrast between light and dark areas on the picture.

Another requirement for a clear image is that the electron beam be focused to a clearly-defined spot of the correct size on the screen. An adjustable control called the *focus control* is usually provided to correct for errors in focusing due to natural aging of the cathode ray tube or to other causes.

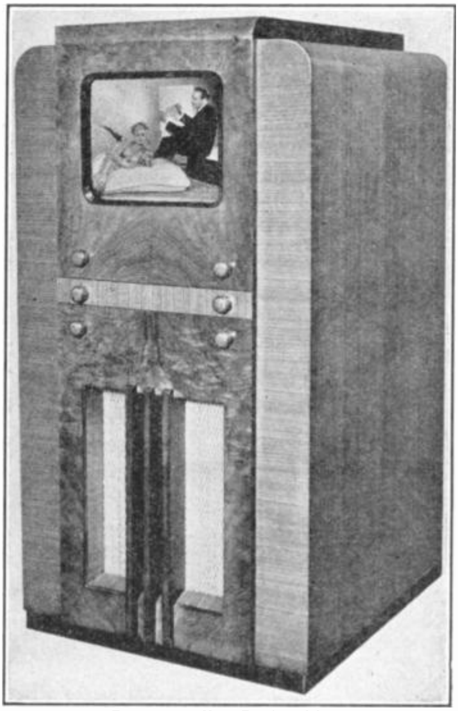
The adjustable controls required in the sight section of a television receiver are thus the *brilliancy control*, the *contrast control*, the *focus control*, and the *tuning control*. These must be adjusted to give a reproduced image which has the proper brilliancy and the correct contrast between elements along a line, with no line and frame retraces visible. When the brilliancy control is adjusted, the contrast control will also require resetting in most cases, and vice versa, for there is some interaction between these two controls.

Television Signal Standards

In order for a television system to be successful, the receiver must be easy to adjust, the cost of the receiver must be relatively low, and the transmitter must have as much control as possible over the receiver. This last requirement means that the receiver and transmitter must be interlocked and synchronized. Furthermore, the type of transmission employed must be standardized to a certain extent, for radical changes in the method of transmission might make all existing television receivers obsolete. At the same time, it would not be advisable to set up standards in such a way that it would be impossible to make improvements in the transmitting and receiving circuits. Standards are essential for a successful television system, but these standards must be sufficiently broad to permit future improvements which might make interlock and synchronism more reliable or increase the definition of the reproduced scene.

A set of television standards which takes all these factors into consideration has been approved by the Radio Manufacturers' Association (R.M.A.) for television systems in the United States. There is no assurance that these standards will remain as originally set up indefinitely. Changes are bound to come, but immediate changes will not be so drastic as to make receivers obsolete in the near future. Minor changes in transmitters may require certain changes in television receivers, but these should present no problems to an experienced Teletrician. These R.M.A. standards for television will now be presented, as you have covered enough of the principles of television systems to understand their significance.

1. *Television Channel Width; Channel Allocations.* The present standards provide for single side-band transmission and reception (suppression of one set of side frequencies), for with this method of operation, sufficient detail for a satisfactory image can be transmitted in a definite channel width of *6 megacycles.* Seven 6-megacycle wide channels have been allocated by the Federal Communications Commission for television transmitters, as follows: 44 to 50, 50 to 56, 66 to 72, 78 to 84, 84 to 90, 96 to 102, and 102 to 108 megacycles. Twelve more 6-megacycle wide channels have been allocated for television relay purposes, such as for linking the television studio to the transmitter by radio, for linking a mobile pick-up station or remote pick-up point to the transmitter by radio, or for linking



Courtesy Allen B. Du Mont Labs., Inc.

This attractive Du Mont console model 182 sight-sound television receiver uses a 14-inch diameter c.r. tube which gives brilliant images at least 8" by 10" in size. A high-fidelity electrodynamic loudspeaker behind the lower grille provides the sound accompaniment. The set uses a total of 22 tubes. Power consumption on 110 volts, 60 cycles a.c. is 250 watts. The cabinet is 44" high, 22½" wide and 25" deep. There are six controls: INTENSITY (brilliance), FOCUS, CONTRAST, ON-OFF, VOLUME, and TUNING.

together television stations in different cities and towns to form a network; these channels are as follows: 156 to 162, 162 to 168, 180 to 186, 186 to 192, 204 to 210, 210 to 216, 234 to 240, 240 to 246, 258 to 264, 264 to 270, 282 to 288 and 288 to 294 megacycles. The ultra-high-frequency channels in between those allocated for television purposes are for other radio services, including amateur, army, navy, aviation and commercial needs.

2. *Video and Sound Carrier Spacing.* Obviously the audio and video signals which make up a modern television program cannot be modulated on the same r.f. carrier; each must have its own carrier. By agreement, *the sound carrier must be exactly 4.5 megacycles higher in frequency than the picture carrier.* To prevent interference between adjacent television channels or between a television carrier signal and services operating on adjacent carrier frequencies, it has been further agreed that there must be a .25-megacycle wide guard band at the high-frequency end of each television channel. All these facts are illustrated by the chart in Fig. *12*, which shows a typical distribution of signals in one 6-megacycle wide television channel.

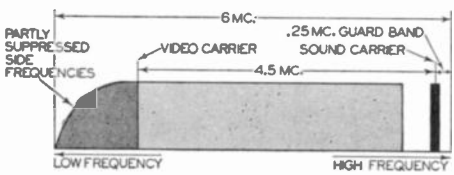


FIG. 12. **Distribution of signals in a 6-megacycle wide television channel.**

3. *Frequency Relation Between Video and Sound Carrier.* An example will best illustrate the frequency relationship existing in a television channel. Suppose that the 44 to 50-megacycle channel is assigned to a particular television station. To give the required .25-megacycle guard band at the high-frequency end, the audio signal carrier must be placed at 49.75 megacycles. According to the R.M.A. standards, the video carrier must be 4.5 megacycles lower, or at 45.25 megacycles. Since it is not as yet practical to remove all of the side frequencies below the frequency of the video carrier, a portion of the channel must be provided for those frequencies which cannot be removed. This portion is indicated by the cross-hatched lines in Fig. *12*. With this arrangement of a 6-megacycle channel, the frequency range of television equipment can be improved up to a maximum of about 4.25 megacycles without making existing television equipment obsolete.

4. *Type of Modulation; Black Level.* Negative modulation of the picture carrier signal is standard for the United States. As we have already pointed out, negative modulation means that *bright elements of a picture are transmitted at low carrier levels,* and *dark elements at high carrier levels.* The R.M.A. standards further specify that the black level or pedestal level at the transmitter shall be at a definite carrier level which remains fixed regardless of variations in impulse signals or in video signals. The black level at any one point in a television system is the voltage which must exist at that point to give a just barely black spot on the screen of a properly adjusted receiver.

5. *Impulse Amplitude.* Both line and frame impulses must be transmitted as carrier values higher than the fixed carrier level (black level). These impulses must not be more than 25% nor less than 20% of the maximum carrier amplitude transmitted, however. The video signals may vary in amplitude from the black level down

to zero carrier level. The general appearance of a typical modulated video carrier signal as it is fed into the television transmitting antenna is shown in Fig. *13*. When there is no modulation, the r.f. carrier will have amplitude *A*, corresponding to the black level. Any increases in carrier amplitude must be for the synchronizing impulses; any decreases in carrier amplitude must be for the video signals. Since we are primarily interested in the impulse and video signals in any study of television, we can neglect the r.f. carrier itself and concentrate

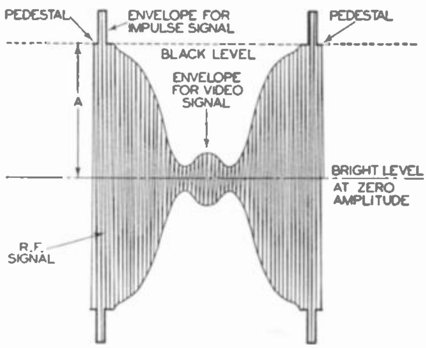


FIG. 13. Modulated r.f. carrier signal, with the amplitudes varying in accordance with a television signal.

our attention on its modulation envelope.

6. *Line, Frame and Field Frequencies.* The establishment of standard values for these three frequencies was based upon the need for high image definition with a minimum of flicker. A vertical scanning frequency (field frequency) of 60 times per second is now standard, for this value minimizes any trouble due to 60-cycle power ripple. (In England, where 50-cycle power lines are used, the field frequency has been standardized at 50 vertical scannings per second.) Since double interlaced scanning is used in the United States, two field sweeps are required to analyze all of the details once in a particular scene; these two vertical or field sweeps constitute a frame (one complete transmission of the picture), and consequently the standard for the frame frequency is 30 frames per second. As we have already seen, there are 441 lines per frame; this means that there are 220.5 lines per field. With a 441-line picture being sent 30 times each second, the line frequency becomes 441 times 30, or a total of 13,230 lines per second. The value 441 was chosen as the number of lines per frame because it gives a line frequency which is a harmonic of 30, the frame frequency, thereby making it possible to use a single standard-frequency source to control both the line and the frame frequencies at the transmitter.

7. *Aspect Ratio.* This ratio has been standardized at 4/3, corresponding to existing motion picture standards and giving a width-to-height ratio of 4 to 3.

8. *Synchronizing and Equalizing Impulses; Blanking.* The ability of a television transmitter to control the reproduced picture at the receiver depends entirely upon the synchronizing impulses. Many years of research have been spent on this problem, and many different forms of impulse signals have been tried; as a result, R.M.A. recommends synchronizing impulses of the form shown in Fig. *14* as being best suited to present and future requirements of television in this country. Pattern *A* shows the synchronizing impulses recommended for the end of a frame; these will move the spot up to the top of the picture along the retrace path for the beginning of a new frame. Pattern *B* shows the impulse signal sequence recommended for the end of the first half-frame (the end of the first field); this moves the spot from the bottom to the top of the picture for the beginning of the second interlaced field

scanning. A careful study of the diagrams in Fig. *14* will reveal five outstanding characteristics of a television signal as recommended by R.M.A.:

I. The horizontal synchronizing impulse which is transmitted at the end of each line is not exactly rectangular. The enlarged diagram in Fig. *14C* shows the exact shape of this synchronizing signal.

II. The video signal is blanked out for a short interval before and after transmission of the horizontal synchronizing impulse at the end of a line, in order to insure blanking out the horizontal retrace. R.M.A. specifies that the total time for this horizontal blanking shall be 15% of the time from the start of one line to the start of the next line (this is designated as .15H at the right in Fig. *14C*). Note that the horizontal synchronizing impulse ocupies about half of this blanking time, and that the front (leading) edge of the impulse is near the start of the horizontal blanking. The two portions of this blanking signal which are on each side of the horizontal synchronizing pulse are known as *pedestals*, and are originally at the black level.

III. The vertical synchronizing impulse exists for an interval of three lines, but this impulse is divided into six small pulses, each acting for half a line. This serrated pulse is shown in Fig. *14A*. Each vertical impulse is divided into six small pulses or serrations *in order to maintain horizontal impulses at all times*. These serrations will be explained in detail later.

IV. Six equalizing impulses precede and six follow each vertical impulse period. The purpose of these will also be covered later.

V. The vertical blanking period starts slightly ahead of the first equalizing impulse and extends considerably beyond the last equalizing pulse; this vertical blanking period should take between 7% and 10% of the time for one vertical sweep. Note that horizontal synchronizing pulses are transmitted during the latter portion of the vertical blanking period.

Explanation of R.M.A. Standards. As long as we have 60 vertical sweeps per second and a scanning of 13,230 lines per second, interlaced scanning will continue automatically throughout a transmission. The vertical fly-backs or retraces will be 1/60th second apart; they may occur either near the beginning or near the end of the vertical synchronizing impulse interval, but must occur at the same point in each impulse (this point is controlled by the design of the receiver).

Although the leading (left-hand) edge of the vertical synchronizing impulse in Fig. *14A* is directly above the leading edge of the vertical synchronizing impulse in Fig. *14B*, these actually occur 1/60th of a second apart due to interlacing. For this reason, the horizontal impulses at *A* and *B* in Fig. *14* are not in line.

Experience has shown that no matter what happens, the horizontal or line synchronizing impulses must not stop even for a single line. If the vertical synchronizing impulse were made three lines long without breaking it up, no horizontal impulses would exist for this period. To avoid the situation, the vertical impulse is serrated or separated into six smaller impulses.

To visualize why the vertical impulse must be broken up, let us first assume that it is broken up into three impulses as shown in Fig. *15*, and see what occurs under this condition. For the moment we will forget about the equalizing impulses. Pattern *A* in Fig. *14* shows the last horizontal synchronizing impulse (just before the bottom of the picture) as being one whole line ahead of the start of the vertical blanking period, while pattern *B* shows this last horizontal impulse as only half a line ahead of the vertical blanking period; these are actual conditions for successive field sweeps, so we must consider them in Fig. *15*. Line impulses must exist for the entire vertical blanking period; this means that there should be line impulses at points *2*, *3*, *4*, and *5* in Fig. *15A*. At each of these points there is a break or serration in the vertical impulse; since the leading edge of an impulse or serration is sufficient to control the horizontal sweep in the receiver, this will give adequate control of the horizontal sweep.

When we turn to pattern *B* in Fig. *15*, however, we find that horizontal

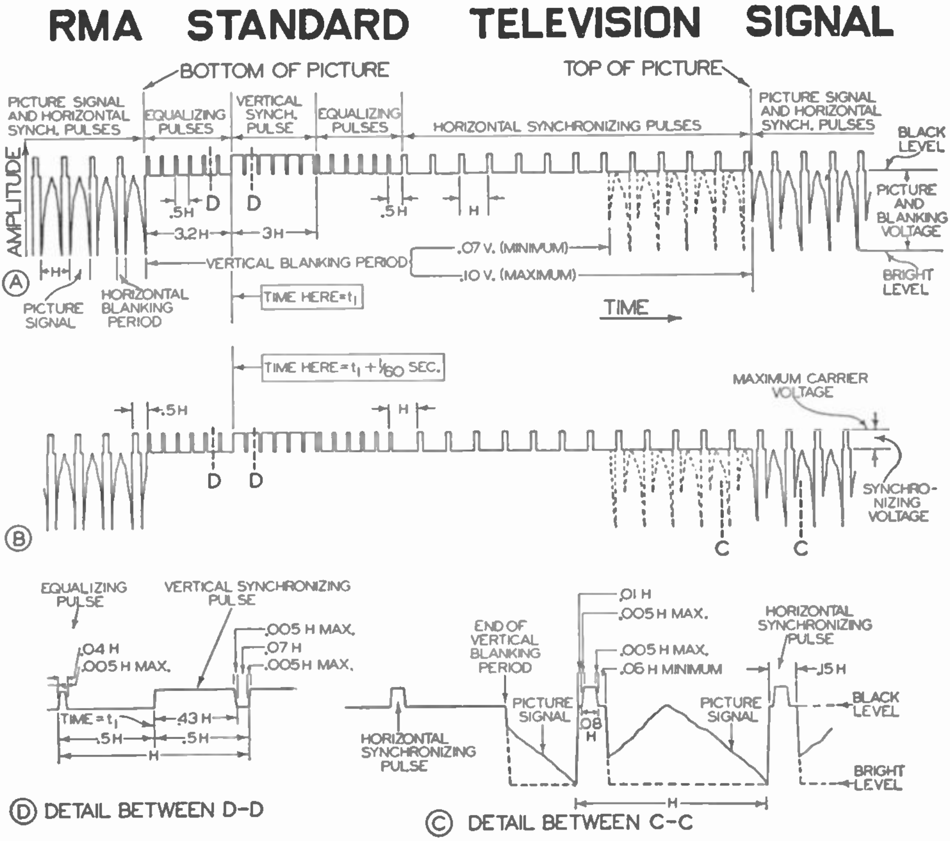


FIG. 14. Specifications for the RMA standard T-111 television signal for 441-line pictures transmitted at the rate of 30 frames per second with double interlaced scanning, giving 60 fields per second. In these diagrams, *H* is the time from the start of one line to the start of the next line, and is equal to 1/13,230 second. *V* is the time from the start of one field to the start of the next field, and is equal to 1/60 second. This means that *V* is equal to 220.5*H*.

Diagrams *A* and *B* show blanking and synchronizing signals in regions of successive vertical blanking pulses. The synchronizing voltage can vary between 20% and 25% of the maximum carrier voltage. Horizontal dimensions in these diagrams are not drawn to scale. The receiver vertical retrace shall be complete at the end of .07 *V* during the vertical blanking period. The length of the vertical blanking period produced by the transmitter may vary between .07 *V* and .10 *V*. The leading and trailing edges of both the horizontal and the vertical blanking pulses have slopes (not indicated in *A* and *B*), which should be kept as steep as possible.

Diagram *D* is an enlarged detail view, drawn accurately to scale, of the signal between points *D-D* in diagrams *A* and *B*.

Diagram *C* is an enlarged detail view, drawn accurately to scale, of the signal between points *C-C* in diagram *B*.

impulses should occur at points *2*, *3*, and *4*. There are no steep leading edges at these points to control the line sweep, and consequently three serrations in the vertical impulse are not adequate for pattern *B*, which occurs for every other scanning of the picture. If the vertical impulse is divided into six parts as shown in Figs. *14A* and *14B*, we secure the desired steep front at points *2*, *3*, and *4* in pattern *B* in Fig. *15*.

A circuit cannot be changed suddenly from one frequency of operation to another; there must always be an adjustment period. For this reason, the six equalizing impulses are introduced ahead of the vertical impulse interval to prepare the horizontal sweep circuit for the serrated vertical impulses, and six equalizing impulses are transmitted after the vertical impulse interval to prepare the horizontal sweep circuit for normal horizontal impulses again.

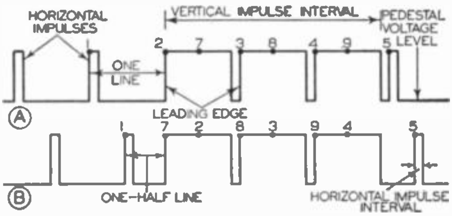


FIG. 15. These diagrams tell why the vertical synchronizing impulse signal must be broken up into six smaller impulses.

Important Circuits and Controls In a Television Receiver

Let us imagine that a radio wave having characteristics similar to those shown in Fig. *13* is being broadcast by a television transmitter, and consider just how this would be received and converted into an image by a television receiver having the essential sections shown in Fig. *16*. First of all, the receiving antenna must be designed for efficient operation at the ultra-high frequencies employed in television. The radio waves radiated by the transmitter are generally polarized horizontally, and can therefore be picked up by a horizontal doublet antenna. Ignition interference from automobiles is a serious problem in cities and towns, and consequently the horizontal pick-up section should be located as far as possible from these sources of interference. For the same reason, the vertical transmission line must be shielded or otherwise designed so as to prevent pick-up of vertically-polarized interference signals. The antenna and its transmission line must be designed for efficient operation in the desired television channels and must have reasonably flat response over the entire 6-megacycle channel occupied by one station.

Either a tuned radio frequency circuit or a superheterodyne circuit could be employed for the r.f. amplifier section of a television receiver (ahead of the video demodulator), but when sight and sound signals are transmitted on carriers only 4.5 megacycles apart, good selectivity is highly essential. Superheterodyne circuits will provide this required selectivity and the necessary video pass band with a minimum number of stages, and consequently the superheterodyne circuit is used almost exclusively for simultaneous sight and sound (television) reception.

A practical superheterodyne circuit for a television receiver will have a preselector amplifying stage or at least one tuning circuit ahead of the mixer-first detector. This preselector must have essentially flat response over a 6-megacycle band, and must have sufficient selectivity to keep out television signals in other channels which could produce image interference.

To produce an i.f. signal, we naturally require a local oscillator; this must be reasonably stable in frequency. Since we feed two different r.f. carrier signals (one for sight and the other for sound) into the mixer-first detector, we get out two i.f. signals, one carrying the picture modulation and the other the sound modulation.

The local oscillator frequency will be *higher* than both the sound and picture carrier frequencies, according to the accepted standards. The video i.f. value will be about 13 mc.; this modulation range of the audio i.f. signal is not more than 10 kc., this i.f. amplifier can be quite selective as compared to the preceding circuits. Too much selectivity is not desired, however; the sound i.f. channel must be sufficiently broad to allow for a certain amount of drift in the local oscillator frequency.

You will recall (Fig. *12*) that the entire band of side frequencies *above* the video carrier frequency is transmitted; this upper side-band extends for 4.25 megacycles according to present-day standards, so we have side

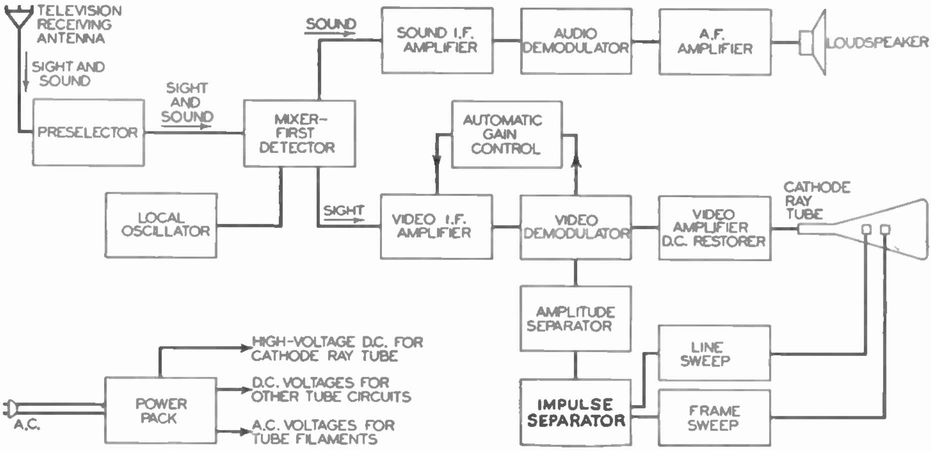


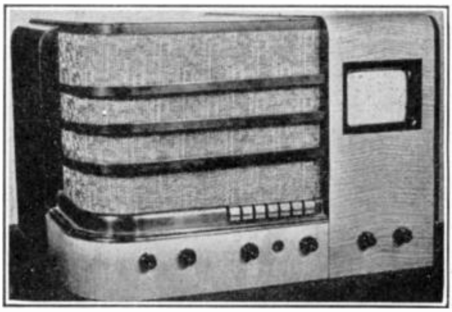
FIG. 16. Essential sections in a modern cathode ray television receiver. The amplitude separator is also known as the *clipper*, and the impulse separator is often called the *frequency separator.*

means that if the incoming video carrier is 45.25 mc., the local oscillator frequency will be 58.25 mc. Since the sound carrier is 4.5 mc. higher than 45.25 mc., or is 49.75 mc., the i.f. value for sound signals will be the difference between 58.25 and 49.75, or an audio i.f. value of 8.5 megacycles. By using two separate i.f. channels, one tuned to 8.5 mc. and the other to about 13 mc., we automatically separate the two signals. Notice that the video and audio i.f. signals differ by 4.5 megacycles, just as did the video and audio carriers. Since the maximum frequencies in the range from 45.25 megacycles to 49.5 megacycles in the example we are analyzing. In the video i.f. amplifier this band will extend from 13 mc. (the video i.f. carrier value) to 8.75 mc. The video i.f. amplifier should therefore be flat in response from 8.75 mc. to 13 mc., and the sound i.f. amplifier which is tuned to 8.5 mc. must be sufficiently selective to eliminate 8.75 mc. video i.f. signals.

The sound i.f. amplifier will be followed by an audio demodulator stage, an audio amplifier and a loudspeaker, and will very likely have automatic volume control on its i.f. stages. Since this sound i.f. amplifier is highly selective and is interlocked with the video i.f. amplifier through the common oscillator and mixer-first detector, the tuning of a television receiver simply involves tuning for maximum volume and clarity of the sound signal; this automatically tunes in the video signal properly.

Automatic gain control (a.g.c.) is a very desirable additional circuit in a television receiver. Like automatic volume control in an ordinary sound receiver, a.g.c. compensates for fading and also serves to supply the demodulator with an essentially constant signal. Of course, normal fading due to interaction between ground and sky waves does not exist in a television system, but it is perfectly possible for an effect like fading to occur due to swaying of the receiving antenna or the transmission line in the wind, or to reflection of radio waves by a moving automobile in the path between transmitter and receiver. If there are two or more television stations in a given locality, one may provide a stronger signal than the other at a given receiving point, causing different signal levels at the demodulator. Automatic gain control can compensate for all these effects. The circuits associated with or following the video detector are in some cases adjusted according to the amplitude of the television signal; this means that for reliable reception it is important that the video demodulator be fed with a reasonably constant signal. This condition can be met if automatic gain control is provided.

In sound receivers, the a.v.c. system is actuated by the average carrier level; in a television system, however, the average carrier level varies with the nature of the video signal being transmitted at any instant. In sound broadcasts, the positive and negative peaks of modulation are nearly equal, but this condition likewise does not exist in a video broadcast signal. The one fixed characteristic of a television signal is the black level; for a given station this is fixed and corresponds to a definite carrier level. The synchronizing impulses, which are transmitted at amplitudes above the black level, are likewise fixed from instant to instant, so by feeding the television signal from some point in the receiver where the pedestals line up with each other (such as at the output of the video demodulator) and using a filter which makes the output follow the peaks of the impulses, we can secure for the a.g.c. system a d.c. voltage whose value varies with the true carrier level of a television transmitter.



Courtesy General Electric Co.

Typical table-model home television receiver, a General Electric sight-sound set using a five-inch diameter television cathode ray tube. The 3" x 4" image is viewed directly on the fluorescent screen. Push-button tuning is provided for seven different television channels.

The video demodulator will usually be followed by one or more video frequency amplifier stages. The exact number of stages used depends upon *the amount of gain required* and *the phase of the television signal* at the input of the video amplifier. Stability becomes another important consideration when a large number of stages is employed and amplification at low video frequencies is essential. Video frequency amplifiers will invariably be of the resistance-capacitance type, capable of providing uniform amplification for all signals from about 10 cycles up to about 4 megacycles. These amplifiers should really be of the d.c. type, in order to maintain the d.c. characteristic of the television signal, but this is impractical. A d.c. amplifier which will provide the required gain is not only excessively high in cost but also has a tendency to produce undesirable low-frequency oscillations. A conventional a.c. amplifier with resistance - capacitance coupling is ordinarily used instead; with this, the d.c. component is temporarily removed from the signal, and we amplify an a.c. signal.

Up to the video demodulator stage, the television signal is a modulated carrier having negative modulation, in which the video components of the television signal are negative in voltage with respect to the black level. The television cathode ray tube requires a modulated d.c. signal with a positive picture phase, in which the video components of the signal voltage are positive with respect to the black level.

The television signal can be removed from a diode detector as a d.c. signal with either positive or negative picture phase, as desired. We have this additional fact to keep in mind, that a resistance-capacitance-coupled amplifier will reverse the phase of a signal voltage (reverse the picture phase). This means that if we supply to the diode detector a carrier signal having negative modulation, and remove from the detector a positively-modulated d.c. signal (a signal with a positive picture phase), we must use two video amplifier stages in order to secure a positive picture phase for the cathode ray tube. If we remove the television signal from the detector as a negatively-modulated d.c. voltage (a signal with a negative picture phase), we must use either one or three video amplifier stages to give the proper phase at the input of the cathode ray tube.

If the video amplifier amplifies only the a.c. component of the television signal, as is usually the case, *a d.c. restoring circuit* should be used just ahead of the television cathode ray tube to restore the d.c. component.

Courtesy General Electric Co.

General Electric console model sight-sound television receiver with 12-inch diameter t.c.r. tube mounted vertically. The image is viewed in a mirror on the under surface of the lid, which is raised at an angle when watching a program. Seven push-buttons provide for reception on any one of the first seven television channels assigned by the Federal Communications Commission for television broadcasting.

This d.c. potential must be restored in such a way that the pedestals will all line up with each other again, for they may be thrown considerably out of line by the video amplifier stages. All of the components in the television signal, including the video signal itself, the horizontal and vertical synchronizing impulses, the equalizing impulses and the pedestals, are applied to the control electrode of the cathode ray tube.

In order to make the electron beam in the cathode ray tube sweep both horizontally and vertically, we need two saw-tooth sweep oscillators; these must be of such a nature that they can be controlled by the horizontal and vertical synchronizing impulses in the television signal. The impulses must be separated from the video signal before they can be applied to these sweep circuits; this is accomplished by the stage known as the *synchronizing separator,* the *amplitude separator,* or the *clipper.* The television signal voltage which is fed into the amplitude separator must be *a modulated d.c. signal voltage with the pedestals lined up.* When this signal is fed into a negatively-biased diode tube or into a triode tube which is negatively biased so that only the impulses can get through, the desired separation of impulses from video signals is secured.

After the impulses have been separated from the video signal, there will remain the problem of separating the horizontal impulses from the vertical impulses. A separate circuit is required for this job; this circuit is called the *impulse separator* or *frequency separator,* and supplies the synchronizing impulses to the line and frame sweep oscillator circuits.

Power packs are an essential part of a television receiver, since the various tubes used will require both a.c. and d.c. operating voltages.

Adjustments must be provided in the video section of a television receiver for controlling the amplitude separator, the impulse separator, the horizontal and vertical sweep oscillators, and the d.c. restoring circuit; these controls may be of the screwdriver type, however, for once they are set properly, they will remain in adjustment for long periods of time. There is also need for a control which will adjust the beam of the cathode ray tube to the exact center of the screen when no voltages are applied to the horizontal and vertical deflecting plates, for even with modern tube-making machinery it is not possible to align the various electrodes with sufficient accuracy to keep the spot at the exact center of the screen Centering of the spot is accomplished with simple circuits which introduce adjustable biasing voltages in series with the horizontal and vertical deflecting plates. The size of the picture and the aspect ratio can be varied by changing the magnitudes of the sweep voltages.

Although the controls just described are essential for preliminary adjustment, they are rarely if ever used by the owner of a television receiver. The essential picture controls which require adjustment by the owner include a tuning control (either a manually-rotated knob or a push-button tuning system) for simultaneously tuning in the video and audio signals from the desired station when there are several television stations in a locality, a focus control, a contrast (gain) control for the video amplifier in order to adjust picture contrast, and a background brilliancy control which adjusts the d.c. bias applied to the control grid of the cathode ray tube and thereby places the pedestals of the television signal at the cut-off point on the grid voltage-brightness characteristic curve of the tube. In addition, the sound section of the receiver will have a volume control and sometimes a tone control. The on-off switch is usually combined with the volume control.

Looking Forward

In this first advanced lesson on television, we have surveyed the important needs of a television system. In some cases brief explanations of these needs have been given, while in other cases we have simply made statements because the explanations would be lengthy and not essential to the clearness of this "bird's-eye view" of the entire modern television set-up. The various methods for producing sawtooth sweep signals, for providing interlocks and for separating impulse signals will all be taken up in later lessons, along with typical circuits for the various other sections described in this lesson.

We cannot overlook the electromechanical television methods which have been used in the past. It is claimed by some experts that these mechanical systems will, if developed properly, give successful reproduction of television images on large screens. For this reason, and in order to make our study of television as complete as possible, we will give some attention to the various electromechanical systems and to the principles of optics and geometric optics which apply to both the electromechanical and the electronic television systems. These optical principles will be taken up next, before we continue with our study of electronic television systems.

TEST QUESTIONS

Be sure to number your Answer Sheet with the *number* appearing on the front cover underneath the title of this text.

Place your Student Number on every Answer Sheet.

Send in your answers for this lesson immediately after you finish them. Doing this insures that the graded answers will reach you while the subject matter is still fresh in your mind, and you will get the greatest possible benefit from our speedy personal grading service. *Never hold up a set of lesson answers.*

1. What is a scene converted into by the process of scanning?
2. If the size of a television image is increased, should you move closer or farther away from the receiver to see a properly blended picture?
3. What three important signals must be transmitted on the picture carrier in an electronic television system?
4. One requirement for double interlaced scanning of a given number of lines per second at a given frame frequency is a vertical scanning rate which is twice the frame frequency. What is the other requirement?
5. What three adjustable controls are required for the sight section of a modern television receiver in addition to the tuning control?
6. In a standard 6-megacycle wide television channel, what is the frequency relationship between the sound carrier and the picture carrier? (State how many megacycles higher or lower the sound carrier is than the picture carrier.)
7. What is meant by negative modulation of the picture carrier signal?
8. Why is each vertical synchronizing impulse divided into six serrations?
9. If the video amplifier in a television receiver amplifies only the a.c. component of the television signal, what circuit should be used just ahead of the television cathode ray tube?
10. What should be the nature of the television signal voltage which is fed into the amplitude separator section of the television receiver?

Requirements of a Television System. No. 55 RH-1

1. A succession of signal intensities.

2. Farther away.

3. 1. The picture signal; 2. The line (horizontal) synchronizing impulses; 3. The frame (vertical) synchronizing impulses.

4. An odd number of lines per picture (per frame).

5. The brilliancy control, the focus control and the contrast control.

6. The sound carrier is 4.5 mc. higher in frequency than the picture carrier.

7. Bright elements of a picture are transmitted at low carrier levels, and dark elements at high carrier levels.

8. In order to maintain horizontal impulses at all times.

9. A d.c. restoring circuit.

10. A modulated d.c. signal voltage with pedestals lined up.

THE THEORY OF LIGHT

56RH-1

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

WHY STUDY ABOUT LIGHT?

It is perfectly evident that photoelectric controls and television are closely related to light. The easily satisfied student assumes the attitude that light is merely "something which we see," but the energetic, conscientious student realizes that a complete understanding of the nature and behavior of light is required for a mastery of these two important branches of electronics.

This book, "The Theory of Light," gives the reasons for conditions which you have already studied and which you will study further in connection with photoelectric controls and later with television apparatus. You cannot master this book in one or two readings, nor do you have to now; study it carefully, then place it in your library for reference purposes. After you have completed this Course and are active in one of these fields, a rereading of the entire book will be very helpful, for its greatest value will be as a reference book.

J. E. SMITH.

NATIONAL RADIO INSTITUTE

WASHINGTON, D. C.

1942 Edition

A LESSON TEXT OF THE N. R. I. COURSE
WHICH TRAINS YOU TO BECOME A
RADIOTRICIAN & TELETRICIAN
(REGISTERED U. S. PATENT OFFICE) (REGISTERED U. S. PATENT OFFICE)

NCP15C1241 Printed in U. S. A.

The Theory of Light

BASIC FACTS

Electromagnetic Waves. You are already familiar with electromagnetic waves utilized in radio transmission and reception. These waves vary in length from several inches to a couple of miles. Now we wish to extend your knowledge of the spectrum of radiant energy so as to include visible and invisible light waves. Figure 1 shows the succession of electromagnetic wavelengths. The very small region marked "visible" has been studied more exhaustively and over a greater period of years (indeed centuries!) than any other portion of the spectrum. But only recently, through the advent of motion pictures, television and light controlled devices, have engineers realized the usefulness and applicability of the fundamental principles of light and its property of color. Furthermore, with the rapid advances made in ultra-high radio frequencies, an adequate knowledge of the long established concepts of optics

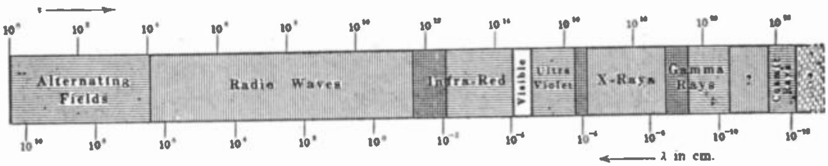


FIG. 1

In upper scale, ν represents frequency in c.p.s.; in lower scale λ represents wavelength in centimeters.

is indispensable to every technician in the laboratory and in the field. Indeed, the subject of physical optics is becoming more and more the guide and tool in the development of quasi-optic* radio. It is important that you have a thorough knowledge of the theory of light, and from all angles, as every day radio technicians are using them more and more.

Interference. Consider for a moment the subject of radio interference. Under certain conditions, "fading" may exist at a receiving station because two transmitters or two antennas some distance away are operating at the same frequency. Do you realize that fading from this double source means periodically adding two signals of the same strength to get no signal at all? With a suitable optical arrangement, you may add light to light and get dark-

* Radio waves less than 10 meters long behave like light waves and are therefore called quasi*(like)*-optic.

ness as a result. Before explaining how this is accomplished, you must get certain notions of light clear in your minds.

Thus far the assumption has been made that light—that electromagnetic energy which is capable of causing the sensation of sight—is a wave phenomenon. Many noted scientists of the 18th century headed by Sir Isaac Newton challenged that belief and maintained that luminous bodies throw off material particles which travel in straight lines and by their mechanical impacts on the retina of the eye cause the sensation of vision. In 1802 Young devised a simple light interference demonstration which convinced the world that light is a form of wave motion.

Young's Interference Experiments. In Fig. 2a let S_1 and S_2

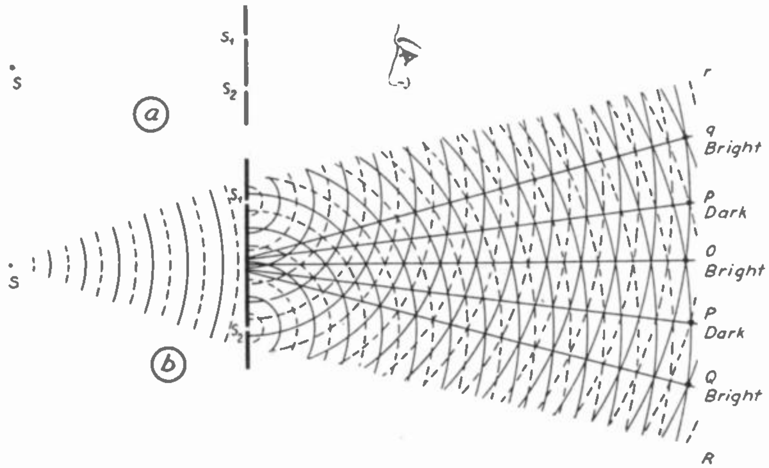


Fig. 2

represent two narrow slits about .01″ apart which you have scratched on an old photographic plate by means of two razor blades clamped together. The experiment is simple enough for you to try yourself. S is a straight filament-lamp six or eight feet away. Be sure the lamp is not frosted. Upon viewing directly the lamp-filaments parallel to the slits, your eye will observe a series of alternating dark and light colored bands. By placing a red glass between the lamp and the slits, a series of red and black bands is seen. Suppose that S_1 or S_2 is covered, the other remaining open. Now you will find that the bands have disappeared and the light is now continuous; there are no dark spaces between bright bands. If it were possible for you to measure the intensity of illumination (signal energy) of a bright band, for example, q in Fig. 2b, you would find it more than double the intensity at the same place when but a single slit is open. Whereas, in the space between the two adjacent bright bands, such as *p* (between the two bright bands *q* and *o*) there is practically no illumination when light comes from both slits. You will observe normal illumination at this point when light comes through a single slit.

Perhaps you can better understand Fig. 2b in terms of radio transmitters and receivers. Assume that slits S_1 and S_2 represent two transmitters radiating in phase, signals of the same intensity and frequency; and, *p*, *q*, *r*, etc., are a group of receivers on a line parallel to S_1S_2. Suppose that S_1 alone is now transmitting (you are to consider the ground wave only). Any receiving station along the line *Q*, *q* will receive approximately the same intensity of signal. At a fixed time it is arranged that both S_1 and S_2 go on

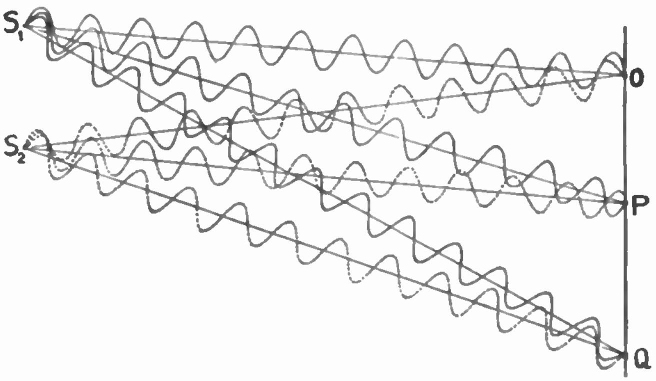


FIG. 2c

the air and all stations along *Q* and *q* are again measuring signal energies. Now it will be found that the signal energy at *q* is more than twice what it was when S_1 alone transmitted; and, at *p*, the signal energy is practically zero. We may explain this as follows:

Upon careful examination of the two waves traveling to a definite point as shown in Fig. 2c, you will see that where a crest falls on a crest or a trough falls on a trough, the result is a crest twice as high or a trough twice as deep. But where a crest coincides with a trough, they neutralize or cancel one another, resulting in no disturbance at the receiving point. The addition of two wave motions resulting in no wave motion is called *destructive interference*. When the wave motion is doubled either by the addition of crests or troughs, it is known as *constructive interference*.

The only plausible explanation for the fact that two beams of light (or two radio signals) may be so united as to destroy each other's effect at one place and to reinforce each other at another place is that light is a wave motion.

These principles of light interference have important practical applications, such as (1) comparison of length gauges, (2) precise alignment of machinery, (3) color photography.

Wave-Front. You have noticed that if a stone be dropped into a quiet pool of water, your eye will perceive a series of ever widening ring-waves, their diameters increasing with equal speed. Similarly, if *O*, Fig. 3, be a luminous point in an isotropic medium * light waves will travel outward in all directions with equal speed in the form of a spherical shell, like an expanding rubber ball. Observe that each concentric ring or sphere moves out as a whole and keeps a fixed distance from the one in front of it as well as from the one behind it. Each ring or spherical surface marks the location of all points in the same state of motion or in the *same phase*. Such a surface is known as a *wave-front*. At a certain time the inner circle, points *m, a, p, q, r, s* in Fig. 3, represents a section of a spherical wave-front which originated at point *O*. An instant later it will have taken the outer circle position. All points in this new wave-front *A, B, C* will be vibrating with the same motion possessed previously by the corresponding points of *a, b, c*. How are these wave-fronts connected and how can we pass from the condition existing at *a, b, c* to that of *A, B, C?*

To most of us this would appear simply a consequence of the principle of wave interference which we have just studied. Unfortunately, however, this question was asked by the opponents of the wave theory of light over one hundred years before Young proved his idea of interference.

In 1678 Huygens answered this question. Let us see how this condition may be explained. Consider each point on a wave-front as a new center of disturbance from which waves are sent out first as if it were the original center. Thus if points *p, q, r* are taken as centers and about them are described small circles representing the limits reached by the secondary waves in a short interval of time, then the disturbance at any point *Q* will be the resultant of all the secondary waves that reach that point. Likewise the new wave-front *A, B, C* is the total net effect of all secondary waves which started simultaneously from the wave-front *a, b, c*. The larger circle thus becomes the new wave-front and each point in it is the center of new secondary waves.

---

* An isotropic medium is so called because it has identical physical properties in all directions among which air, water are examples. Crystals like quartz; strained glass, that is glass rapidly cooled during manufacture, are not isotropic materials.

Rays. It is not usual to represent light radiation in the manners just described. Lines called *rays* are more commonly used on diagrams to indicate *the direction in which light energy travels.* In an isotropic medium rays are always perpendicular to the wave-front. Rays of a spherical wave as *Om* or *On*, Fig. 3, spread out, that is, they are *divergent.* If *O* were extremely far away from us, at an infinite distance, the wave-front would be plane * instead of *spherical* and the rays would become *parallel.* It is natural for light or a radio signal to diverge. To make rays come together, or *converge,* a source of light must have a mirror or a lens.

Rectilinear Propagation. Common experience teaches us that in a homogeneous medium † light travels in straight lines from the source to the eye. This is called rectilinear propagation of light

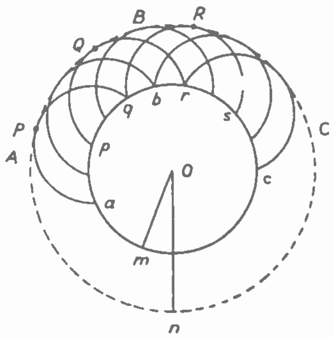


Fig. 3

and passes through *transparent* material. The formation of shadows affords a simple proof of the rectilinear propagation of light. An *opaque* object—one which does not allow light to pass through it—is illuminated only on the side facing the light source, as exemplified by the sun, *S*, and the moon, *M*, in Fig. 4. The edges of the object and the source of light may be connected by straight lines casting a shadow on the screen because light does not bend around the object. This is true whether the luminous body—the source—is larger or smaller than the opaque body, as

* It is easy to convince yourself that the wave-front is a plane. Draw a circle with a radius of 1 inch. Draw another with a 12 inch radius. Lay a ruler along the circumference. In the case of the large circle, a large part of the circle will appear parallel to the edge of the ruler. The earth also is round, but to our senses it appears to be flat.

† A medium every part of which is exactly the same in structure or is made of the same material as any other part.

shown in Figs. 4 and 5, respectively. In Fig. 5 the rays *1* to T and *2* to B_1 are the edge-rays or boundary rays which limit the area on the screen from which light is entirely excluded. This part of the shadow, T to B_1 is known as the *umbra*. The light is only partially excluded between B to T and B_1 to T_1. This area is called the *penumbra*.

If in Fig. 4 the earth takes the place of the imaginary screen, we can readily understand what is meant by a partial or total solar eclipse. For if the eclipse occurs at a time when the distance between the earth and the moon is least, then the umbra may reach the earth and every point on the earth touched by the shadow cone A to D will experience a total eclipse. Whereas, if the distance between the earth and the moon is its greatest, the eclipse will only be partial because the penumbra alone will touch the earth.

Diffraction. So far the idea that light travels in straight lines

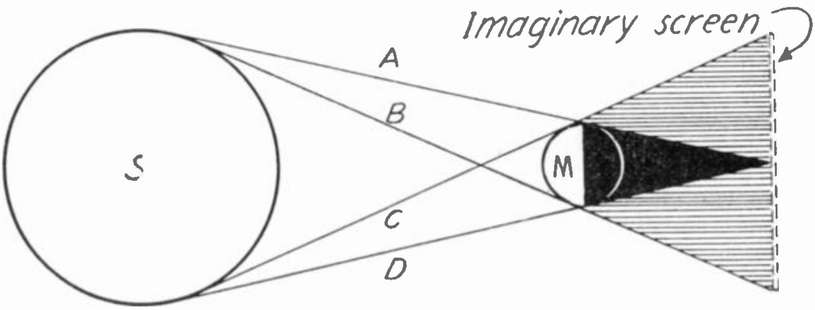


FIG. 4

is reasonably well established by ordinary observations and the foregoing illustrations. However, upon closer examination and by taking special precautions, you will find that light does bend round corners. When the source of light is small, or is made small by a narrow slit, and the opaque object is a hair or a fine wire, you no longer find sharp black shadows as required by our notions of rectilinear propagation. In fact, the region immediately behind the fine wire, where ordinarily you would expect a total shadow on the screen, you find maximum illumination, as if the wire split the light beam on the side facing the source and reunited it on the opposite side. The bending of light round the edges of an obstacle is known as *diffraction*.

The phenomenon of diffraction is readily observed when you look at a distant lamp or at the sun through a stretched handkerchief. You see two series of lamps at right angles to one another, the actual one at the center. The bordering lamps are colored and get fainter as they become more distant from the center. The greater the number of threads per inch, i.e., the finer the handkerchief, the more widely separated will be the lamps.

There are many other ways of showing that light does not travel in straight lines but bends around obstacles. However, the important facts for you to learn from these experiments is one which you can use in *all* the applications of wave motion, i.e., in sound, radio, light, etc. The general principles are:

1. Whenever you deal with a source and an obstacle which are much larger than the wavelengths involved you may expect approximately straight line travel, and well defined shadows will exist.

2. Whereas, if the wavelengths are quite large in comparison

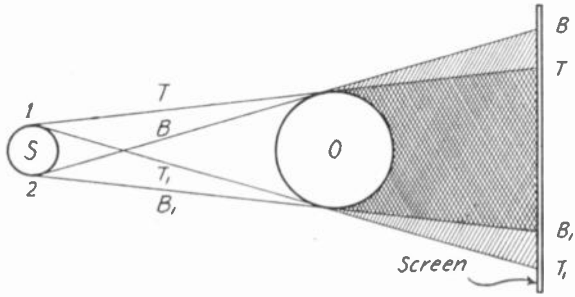


Fig. 5

with the sizes of the obstacle and source, then the waves will readily bend around them.

COLOR

Our lives are affected by color to a greater extent than we realize. Nearly every human service is influenced by it. Therefore every well trained technician should be fully aware of the various color effects and how they are produced. In the art of television or industrial application of electronic devices color and color interpretation plays a very vital part. The possible applications are so great that we feel it wise to tell you the fundamental facts so that the various applications as they come up in actual practice will mean more to you. You should know that the sensation of color belongs to the study of physiology, that is the behavior of the human body, particularly the human eye.

There is quite a physical difference between the colors you see in a rainbow and the color of objects such as you see about you every day. The rainbow appears to have red, orange, yellow, green, blue and violet colors. Actually on close examination it has many shades of these colors, best referred to as monochromatic colors, and each shade of light being nearly the same wavelength. On the other hand, a yellow object may actually send to the eye color of many wavelengths. All this is to be made clear.

Wavelength and Monochromatic Color. Referring again to Fig. 1, observe that there are an infinite number of different wavelengths in this *electromagnetic spectrum.* Just a limited range of frequencies are distinguishable to the eye as color. In other words, any wave in the spectrum can be specified by giving its length or its frequency. However, visible light waves also have color as a means of identifying them.

The table below gives the range of wavelengths dealt with in visible light, when they exist in our atmosphere, that is free space. The colors referred to are monochromatic colors as they are due to a single wavelength.

TABLE 1

Color (Monochromatic)	*Wavelength in Centimeters*	*Frequency f in cycles per second*
Infra red end of visible spectrum	.0000676	4.44×10^{14}*
Red	.0000650	4.64×10^{14}
Orange	.0000609	4.93×10^{14}
Yellow	.0000576	5.52×10^{14}
Green	.0000536	5.60×10^{14}
Blue	.0000498	6.03×10^{14}
Indigo	.0000460	6.58×10^{14}
Violet	.0000442	6.79×10^{14}
Ultra-violet end of visible spectrum	.0000424	7.08×10^{14}

The values in the second and third columns may be calculated from a relation well known to us in radio, namely:

Frequency in cycles per second

$$= \frac{\text{Velocity of the wave in centimeters per second}}{\text{Wavelength of the wave in centimeters}}$$

The velocity of all electromagnetic radiation in free space is 30,000,000,000 centimeters per second. By knowing the wavelength, as you would in radio, you find the frequency by dividing the velocity by the wavelength. The above expression is given in that form because it is easier to find the wavelength of light and calculate if necessary its frequency. Wavelengths of light are most conveniently expressed in Angstrom units, abbreviated A.U., or just Å, named after the investigator who first constructed a table of wavelengths. There are 100,000,000 A.U. to the centimeter, so

* 4.44×10^{14} cycles is the same as 444,000,000,000,000 which may be stated if you wish as 444 megamega cycles.

that the range of the visible spectrum extends from about 7,000 A.U. to 4,000 A.U. Another unit often used to express wavelengths of light is the micron, abbreviated μ; $\mu = 10{,}000$ A.U. $= .0001$ cm.

The list of colors shown in the table is an arbitrary division of the visible spectrum. There are many gradations of each of these spectral colors. Besides, there are certain mixtures of colors which do not appear in the color spectrum at all, yet to the unaided eye these are indistinguishable from some monochromatic (one color) light. Black and white are not colors. Black is the absence of color, whereas white is a combination of all colors. Remember too, that a monochromatic red light and red light that we would observe in colored motion pictures are not the same.

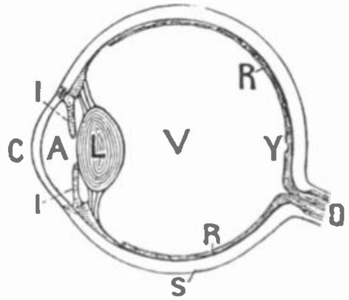


FIG. 6

S is the outer enclosure of the eye. *C* is the cornea, a strong transparent membrane, which forms a front covering for the eye. *I* is the iris, which is the colored part of the eye, with a central orifice (opening or adjustable shutter) called the "pupil" which admits light to the lens *L*. Through this lens images are thrown onto the retina, or screen, *R* situated at the back of the eye. The nerve centers which cover this screen are stranded together like the wires in a cable and are joined to the optic nerve *O* which connects with the brain.

The Eye and Primary Colors. As an optical instrument, the human eye (see Fig. 6) performs several functions. One of these is color discrimination. It is desirable to know how it does this job, and to learn of the color peculiarities attributed to the eye.

The Young-Helmholtz theory of color vision claims that there are three sets of nerve terminals distributed over the retina of the eye, and one set of nerves, if stimulated gives the sensation of blue, the second a sensation of green and the third the sensation of red light. Each set of nerves need not be excited by a monochromatic color identical to the impression it gives to the mind. It can be excited to some extent by lights of other monochromatic colors as in Fig. 7 giving a red, green or blue sensation depending on which set of nerves it stimulates. For example, the red sensitive cones or nerve-ends can be stimulated by blue light and green light, but give to this set of nerves a faint sensation of red. The strongest sensation of red is experienced from a red light which has a color content, similar to that shown in Fig. 7. Such a color is referred to as a primary red. There are three *primary colors* and what is most interesting and valuable to know is that all possible colors as you see and know them may be produced by combining these three. The fact that colored motion pictures can be reproduced by these three primary colors leads us to believe that the Young-Helmholtz theory affords a plausible explanation of how the eye behaves.

The eye does not respond to any light unless it is strong enough to stimulate the nerves. This minimum quantity of light required for nerve excitation is called *threshold quantity*. Color is not recognized below the threshold quantity. When all three sets of nerves are stimulated to the same degree, the impression received is white. The eye is most sensitive to yellow-green light

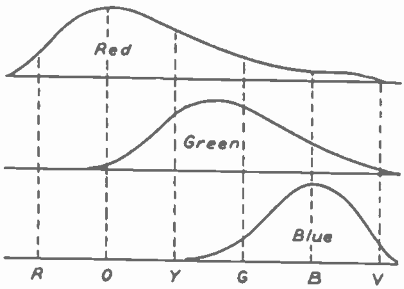


Fig. 7

and objects appear with clearer definition in that light. That means that it requires many times the light energy in blue or red compared to yellow-green to appear equally bright to the eye. The relative wavelength sensitivity of the eye compared with a modern photocell is shown in Fig. 8.

Production of Color. Every object that we see is visible because it either *a*, gives off light, that is, it is luminous; or *b*, it reflects light, that is, it throws back light which falls upon it. All bodies when raised to a sufficient temperature will emit visible light, for example burning coal, filament in a vacuum tube. The color of a body will depend upon its temperature if it is self-luminous; or, upon the light which falls upon it and illuminates it.

Typical examples of the production of color by emission are the incandescent lamp, used extensively for purposes of lighting and in control devices; the new sodium street lamp; the neon glow lamp and the mercury vapor lamp.

Bodies which reflect light, generally do so selectively. That is, certain wavelengths of the incident light * are converted into heat within or at the surface of the object; the others are reflected. A red tile roof reflects only the red components of sunlight (contains all colors) and turns into heat all other rays of the sun. In moonlight, the red roof appears black because there is no red in the light falling on the roof which it can reflect selectively. Thus in order to show the true color of an object in artificial light, it is of utmost importance to have the proper light components in the source.

Similarly, transparent bodies like colored glass owe their colors to selective absorption. If a red glass (ruby glass) so essential in a photographer's dark room, is held between the eye and a daylight lamp, the glass will subtract or absorb all other colors of the white light falling upon it and transmit only the deep red light.

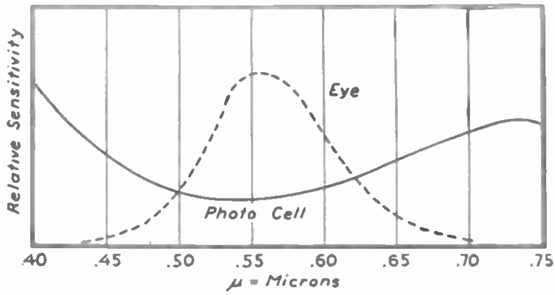


FIG. 8

It is used in the dark room because the deep red light does not affect the ordinary photographic plate. If now a piece of blue glass is placed over the red so that the white light must pass through one glass after the other, none of the components of the white light will be transmitted and no light will be visible. The red glass absorbs the green, blue, and violet from the white light; the blue glass absorbs the red, orange and yellow; that is, each of the two glasses absorbs those colors which the other transmits.

Addition of Colored Light. You were told that white light is a combination of all colors. However, the sensation of white may be produced by the proper addition of two colors. For example, certain blue and yellow light projected upon a white screen will produce the effect of white upon the unaided eye. In general, when

* The incident light or ray is the light before striking the reflecting or refracting body.

any two colored lights are combined to produce the sensation of white they are called *additive complementary colors.*

For stage lighting and the other color effects, the color triangle, Fig. 9, is very helpful. The primary colors blue, green and red are at the corners.* Between green and red are represented various colors, the midpoint representing yellow. (The color at point X is what you would have when y amount of green and z amount of red primary colored lights are mixed.) A similar series of colors are represented on the other sides. This color triangle is used in the following manner. When a line is drawn from blue through the center point, which always represents white, it will end at the yellow point. If blue light to the value of a and yellow light to the value b are mixed the sensation of white light will be obtained. Similarly red and peacock blue in suitable proportion, green and magenta, colors represented by P and Q combination whose lines pass through the point *white* will give the sensation of white light.

Mixing Paints. The process of adding colored lights must not be confused with that of mixing paints or dyes, which is a subtraction process, as in the case of colored glasses mentioned above. For example, when yellow and a blue primary color are added they give white as a result. Whereas, if we mix yellow and blue paints, we get green paint as a result. The difference lies in the fact that when paints are mixed, the light suffers an absorption for each paint in the mixture. The yellow paint takes out (absorbs) from the white light all but the red, yellow and green components. The blue paint absorbs all the colors except the blue and the green. When the paints are mixed, green is the only color not absorbed by either paint and it is therefore reflected.

We must not overlook the fact that if a photocell replaces the human eye, the photocell must respond in the case of a colored light to the wavelengths constituting the color and in the case of reflected light to the wavelengths actually reflected.

Luminescence. Another color phenomenon is observed in certain substances which, after exposure to strong light of one color, emit a glow of a different color for some time after the exciting light has been removed. This action is known as *phosphorescence.* Sulphides of barium and calcium, both special chemicals, show this form of luminescence and are used for painting articles which otherwise would be difficult to find in the dark.

---

* The primary colors are represented by the curves in Fig. 7. Color filters may be obtained which if placed before a daylight lamp allow a primary color to pass.

Screens painted with material like calcium tungstate are utilized in X-ray examinations by the medical profession, and in the cathode ray oscillographs so widely used in radio and television work. In the case of a cathode ray tube this screen is placed in a funnel shaped bottle, the air removed and the screen agitated by bombarding it with electrons flying at it at high speeds. Light is then produced. This phenomenon is called *fluorescence* and there is no appreciable time lag between the exciting radiation falling on the screen and the glow. Both fluorescent and phosphorescent substances convert radiations of shorter wavelength into waves of greater length. The only difference in the two cases lies in the duration of the effect. The color seen is predominately green or

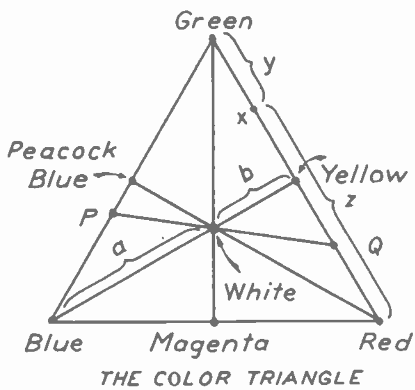


Fig. 9

greenish blue and if strong enough may have the appearance of white light.

HOW LIGHT RAYS TRAVEL

Refraction. One of the most important of all optical instruments for studying light and color is the prism. By means of it Sir Isaac Newton was able to reproduce the colors of the rainbow. Figure 10 shows a beam of sunlight which is admitted through a small opening in a shutter of a darkened room and directed to this prism. The white light, upon passing through the prism, is not only bent (refracted) from its original path, but is also spread out (dispersed) into an array of colors listed in Table 1. First get a clear idea of refraction. It was said that light usually travels in straight lines so long as the light remains in the same isotropic medium in which it started. But when *slanting* rays of light pass from one medium to another, for example air to water or air to glass, there is a change in the direction of the ray which is called *refraction.*

Figure 11 shows a beam of light of width *at* traveling in air and falling obliquely on a surface of glass and a surface of water. The angle that the oncoming or incident rays *xy* and *x'y'* make with the normal (perpendicular) to the glass and to the water is the same. That is, θ is the angle of the rays striking the glass and water mediums. But, when the light has entered the glass and the water, the rays travel in straight lines since they are again in uniform media. However, the direction of travel has not only changed from the original course, but the bending or refraction is different for each medium. The ray in the glass has been turned toward the normal a greater amount than the ray which entered the water. In fact, you will notice that during the interval of time that the wave traveled a distance of *pb* or *qd* in air, it has advanced a length

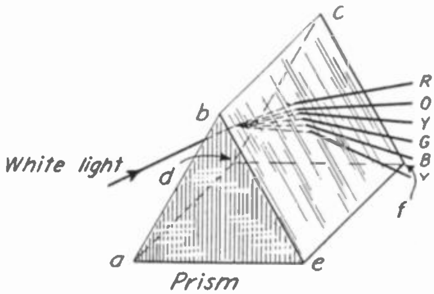


Fig. 10

cs in water and *ar* in glass. This shows that light travels more slowly in glass than it does in water and that it travels faster in air than in either water or glass.

To sum up these and other experimental facts concerning refraction, remember that:

1. The speed of light or of other electromagnetic waves in a vacuum (air, for our purposes) is the same for all wavelengths and is greater than in any other known substance.

2. All transparent materials (those which permit light to pass through them) retard light waves and reduce their speed upon entering these materials from the air.

3. The variation in speed depends upon the substance as well as upon the color of the light passing through. The slower the speed compared to air the more refractive is the medium.

4. The larger the angle the beam makes with the perpendicular

to the refracting surface (see Fig. 11), the more strongly is the ray refracted.

5. The ratio $\frac{\text{speed of light in air}}{\text{speed of light in substance}}$, is known as the *index of refraction* of the substance. For example, the index of refraction of water is 1.33, which means that the speed of light in water is about ¾ that in air. It is for this reason that a fish appears to the eye to be only ¾ of the depth it actually is.

Figure 12 is a simple illustration of the phenomenon of refraction. A penny so placed in a metal tank that the side of the tank just hides the coin from view when the tank is filled with air. Now, without changing the position of the eye, water is poured into the tank and the penny becomes visible. So long as the tank is

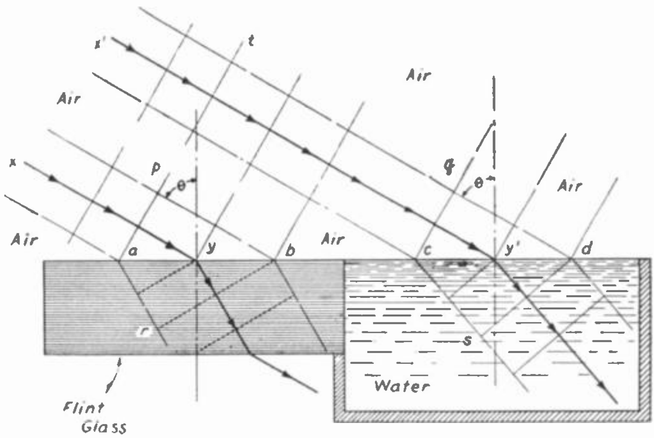


Fig. 11

empty the rays of *O'O* travel in straight lines in air and the eye does not see the coin. But as soon as water is poured into the tank, each ray such as *PQ* suffers an abrupt change of direction at the surface of the water and the penny becomes visible. However, it appears to be located at *r'r* because we are accustomed to straight line propagation. The ray *PQA* will retrace its path in either direction. That is, if the penny were put in place of the eye and the latter located at *O'O*, the coin would be visible in the same position now occupied by the eye.

Dispersion. So far we have discussed refraction as if all light were of the same color and of one wavelength. But it is well known that a prism does more than merely bend a beam of white light. It separates and spreads the white light into all shades of color from red to violet as shown in Fig. 10. If these colors are allowed to fall on a screen, we notice that the red is bent or deviated least and that the violet suffers the most deviation. The angle of spread between the violet and the red waves is known as the *dispersion* of these two wavelengths.

Thus we see that since the various colored rays are deviated by different amounts in passing through the prisms, each ray must travel through the glass with a different velocity. That is, the index of refraction of the glass is different for different colors. Incidentally here is a means of analyzing the components of a beam of light, for example the primary colors of blue, red and green.

The same property of the prism which has made it so useful in spectrum analysis * because of its ability to separate and reveal the identity of various solid and gaseous light sources becomes a

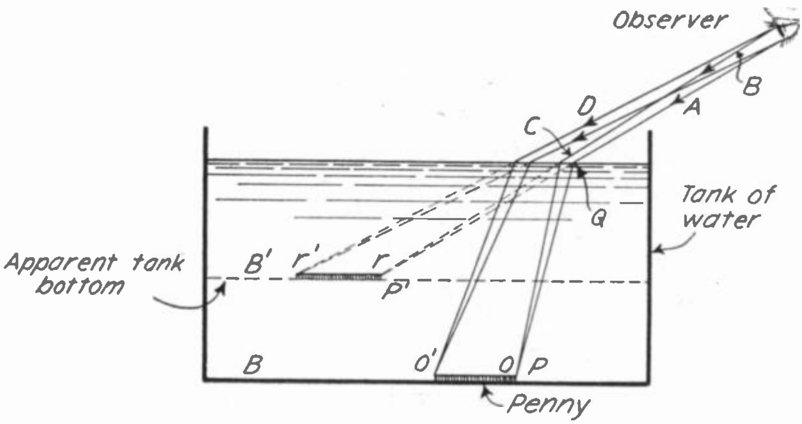


Fig. 12

handicap when the prism is made into the form of a lens † and this lens is used to focus white light. The focal length of a lens, a very important dimension in determining the use of lens, depends upon its index of refraction, which is different for different colored rays. Hence parallel rays of white light are dispersed in passing through

---

* You probably will not have any contact with spectrum analysis as it is not considered a subject for study, although the method is extensively used in practical fields. Light from such sources as an incandescent lamp or carbon arc when passed through a prism produce all colors, a continuous spectrum. If another material is placed in the core of the carbon of an arc lamp characteristic bright colored lines appear. By the use of these lines it is possible to detect the chemical make-up of materials under investigation.

† You are quite familiar with the lens as used in a camera. Elsewhere in the course you will study the lens (geometric optics) and other optical devices of particular interest in your work.

a lens and there is formed a separate focus for each color; the blue being nearest the lens and the red farthest from the lens (see Fig. 13). That is the reason why a distant object viewed in bright sunlight through a cheap telescope or spy glass appears to have colored fringes or borders about the object. This lens defect is known as *chromatic aberration* and is corrected by using two lenses of different kinds of glass.

Bending of rays by a prism or a lens. Before leaving the subject of refraction, it is worth remembering that a ray of light in passing *through* a prism or a lens is always bent toward the thicker part of the prism or lens.

Reflection. From your study of color you have learned that we see objects and their colors by the light which they reflect to our eyes. Details of a surface and its outline are made visible only by means of the light which they reflect. Yet none of these clearly visible objects which reflect most of the light falling upon them would be useful as a mirror. For a true mirror—that is, a perfectly reflecting surface—is invisible. A mirror makes you see an image of the light reflected as if the light came directly from the source to your eye. For example, let the light ray in Fig. 14 come from an incandescent lamp some distance away. Your eye placed along the reflected ray *R* will see a bright image of the lamp and scarcely notice the polished surface which, by its reflecting properties, produces the image. This is known as *regular reflection.* It occurs whenever a beam of light strikes a polished surface and is reflected as a beam in a definite direction. Figure 14 illustrates the following two simple laws which exist for this type of reflection.

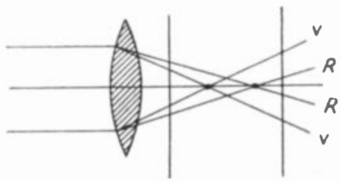


FIG. 13

1. The angle of incidence *I* is equal to the angle of reflection *R*. Both rays and the normal (line *N*) to the mirror where reflection occurs lie in one plane.*

* The line *N* called the normal is drawn from the point where the ray strikes the mirror and so that it is at right angles to the mirror.

2. The plane including the incident and reflected rays is perpendicular to the reflecting surface.

We may extend our application of these laws to all forms of wave motion provided we are dealing with mirror-like or regular reflection. But what is a mirror-like reflecting surface? The highest quality of polished surface obtainable is still much too rough to reflect X-rays. On the other hand, a rocky irregular mountainside readily reflects radio waves in accordance with the above laws.

Therefore, in dealing with regular reflection we must have some elementary rules to guide us. Here they are:

(*a*) Any surface will reflect *mirror-like* provided the roughness of the surface is small compared with the wavelength of the incident beam. So long as the elevations and hollows in the reflecting surface are less than a quarter wavelength, the surface may be considered smooth enough for regular reflection.

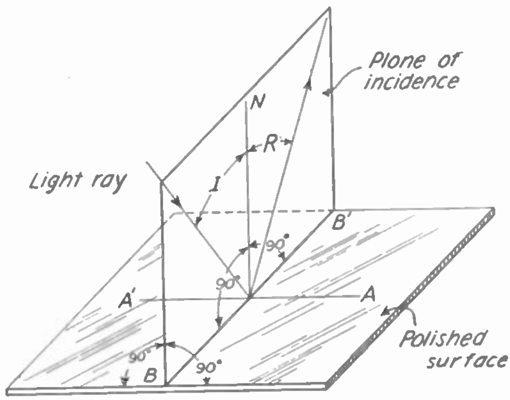


FIG. 14

(*b*) The index of refraction of the reflecting substance must be quite different from that of the medium in which the waves are incident upon the mirror (i.e. air to glass). If the two media are very near alike (i.e. water to glass) in their indices of refraction, the waves will be mostly transmitted and practically no reflection will occur.*

(*c*) The amount of reflected energy depends upon the angle of incidence as well as upon the conditions set forth in (*a*)

* In the case of a transparent material we should recognize the fact that light striking its surface is not only refracted but also reflected. Try holding a piece of window glass against a dim wall and observe that not only do you see the objects in back of the mirror, but objects in front of it.

and (*b*) provided the reflector does not favor some particular wavelength of light.

If you were to measure the light *reflected* from the surfaces in Fig. 11, you would find that more light is reflected from the glass than from the water; that, if the angle of incidence were larger than it is, a still greater proportion of the light would be reflected from each surface; and, of course, less light would enter each medium.

At normal incidence, that is, the light ray is at right angles to the entire surface, the percentage of reflection from some polished metals is as follows: gold 84 per cent, silver 93 per cent, copper 72 per cent, steel 55 per cent, mercury backed by glass 70 per cent, silver backed by glass (French mirror plate) 88 per cent. These approximate values are for light waves of 6000 Å going from air to

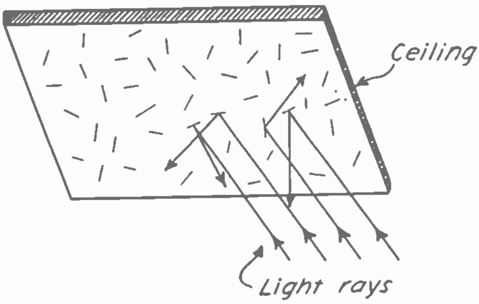


FIG. 15

the polished surface. The importance of these values can be realized when you consider such devices as mirrors used to direct a beam of light, from a source of light to a photocell. Clearly a great deal of the useful light may be lost for operating the electric eye.

Returning to the case where reflection renders a surface entirely visible, let us again look at Fig. 14. Suppose the polished surface is completely covered with white blotting paper, the location of the lamp and your eye remaining as before. There is no longer an image of the lamp *along R* the line of the reflected ray but there is a lot of light *scattered* in all directions by the white paper. At each point in the paper the laws of reflection are obeyed. But all the reflected rays do not form a parallel beam in one direction. This is illustrated in Fig. 15 where the individual light rays are reflected from a vast number of tiny mirrors facing in every possible direction, thus making the ceiling appear to give off light scattered in all directions. Such a surface is rough compared to the wavelength incident upon it, and its reflection is known as *scattered* or *diffused reflection.* The fraction of the total incident light that is reflected by some practically rough surfaces is as follows: white paper 70 per cent, snow 78 per cent, black paper, 5 per cent, black velvet .04 per cent. These figures present the value of various materials as reflecting screens for television purposes.

Summary. Now you have become familiar with some of the fundamental ideas of reflection, refraction and dispersion, the principles of which are utilized in the design and construction of most optical instruments which play an important part in television and light control devices. Figure 16 is a composite optical system which illustrates many of the principles discussed. It is given merely to gather together in your mind the facts that we have discussed. It is a laboratory set-up for determining approximately the energy in the various colors of the spectrum of a concentrated filament projection lamp. In this set-up, the photoelectric cell is calibrated to measure the energy in the different colors of white light emitted by the lamp.

You will find in this set-up several optical devices, with which you have only a slight acquaintance. You will study them in greater detail before you finish your course. Here we merely want to increase your appreciation of them. You first have S_L a source of light which we mentioned is an incandescent lamp; M_1 is a parabolic mirror or reflector as it is often called, which is a mirror so shaped that when the lamp is positioned at a point called the focus, it will reflect the light in parallel rays. This mirror is a total reflector whose efficiency depends on the material used. The two single lenses marked C_1 take the parallel rays called a beam of light and by refraction, direct them, or as we say it, focus them to a point. In order to bend the converging rays to the iris or slit I_1, the plane mirror M_2 is used. Here too the amount of light reflected depends on the efficiency of the plane reflecting surface.

Iris I_1 now becomes the new source of white light, allowing a definite amount of the converging rays to diverge towards the lens L_2, a combination of simple lenses. Of course, iris I_1 reduces the amount of light allowed to pass on. Lens L_2 takes the diverging rays and beams them by refractions, the parallel rays now passing through prism P which you know breaks the white light into the colors of the rainbow. Lens C_3 now focuses the colored lights on the iris I_2 which is a movable slit, allowing the photocell to see only one color at a time. The entire optical system is housed in a shield

S which keeps out undesired light, and which is painted dull black in the inside so rays not under control are absorbed on its surface.

In the applications to television and light controls, you should remember these facts:

1. Plane mirrors displace or change the direction of a beam of light.

2. Curved mirrors and lenses so modify the wave front as to cause the rays to converge or diverge; that is, to concentrate or to spread the beam of light.

3. Prisms, as we know them, are used to separate white light into its various color components.

At this point you should be able to understand the significance of the terms opaque, transparent and translucent.

(*a*) An opaque material is one through which the light cannot pass. Examples: wood, bakelite, steel, etc.

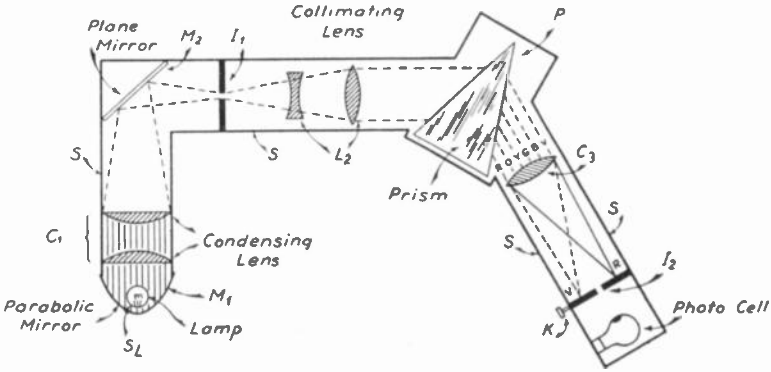


Fig. 16

(*b*) A transparent material is one through which light passes without destroying the uniform direction of the rays. Examples: glass, air, water, etc. Of course, colored glass is selectively transparent.

(*c*) A translucent body is one which allows a large portion of light to pass but so scatters the direction of the rays that objects cannot be seen through them. Examples: waxed paper, frosted glass, heavy smoke, clouds, etc.

PHOTOMETRY AND ILLUMINATION

If you were looking at two incandescent lamps rated at 40 and 100 watts respectively, both equally distant from your eyes, you would experience no difficulty in choosing the brighter of the two. But you could not state with any degree of accuracy how much brighter it is unless you had some precise means of measuring or comparing their intensities. Furthermore, if you were reading a book by the light of one or the other of these lamps, you would most likely find that reading is more comfortable under the brighter lamp because of its more intense illumination on the paper surface which reflects the light to your eye. Thus it is clear that the intensity of a lamp may be judged either by looking at the lamp directly and comparing it with a known lamp; or, by measuring the energy reflected from a surface which the lamp illuminates. The amount of illumination falling upon a surface and the light reflected by the surface to the eye are of great practical consideration in daily life. Therefore, the measurement of direct radiation from light sources is of secondary importance as compared with the evaluation of the *illumination* at a point or the brightness of a surface.

That systematic knowledge which enables us to measure illumination of surfaces and to compare light sources quantitatively is

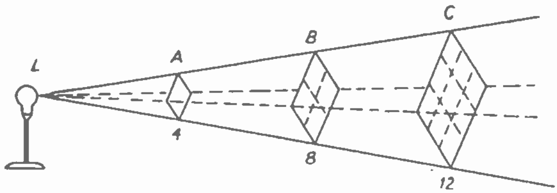


FIG. 17

known as *photometry*. It is of extreme importance in the development of television and light control devices.

Let us carry the above experiment a bit further. Suppose that the 40 watt lamp placed about 4 feet above your book gives just sufficient illumination for your reading. At what distance from your book should the 100 watt be placed to give the same illumination? By a series of "tries" you should find that the larger lamp has to be set somewhat over 6 feet from your book. The distances here considered are all from the lamp and perpendicular to the surface of the book. The reason for this comparatively small increase in distance for a lamp which is 2½ times larger will be evident when you recall the fact that light is propagated in straight lines and in all directions. As a consequence of this, the illumination decreases at a greater rate than the distance from the source increases, in fact inversely as the square of the distance.

Illumination. Figure 17 will help illustrate the well-known law of inverse squares. Let *A* represent the book 4 feet from the lamp L. In that position the open book, which is about 1 foot on the side, receives from the lamp a certain quantity of light. At a distance of 8 feet from the lamp, this same quantity of light illuminates an area of 4 square feet. That is, the book in position B, twice as far from L would receive only ¼ the amount of light which illuminated it at A. At C, 3 times the distance from the lamp, the beam becomes 3 times the size in each dimension it was at A; which means the same light intensity is spread over 9 times the area. This variation in intensity with distance is stated in the law as follows: "The intensity of light varies inversely as the square of the distance from the source."

Solid Angle. Before proceeding with the study of photometry and understanding the terms of the illuminating engineer, it is necessary to learn a little geometry. You may find what is going to be said a little perplexing. Read it several times and slowly. In

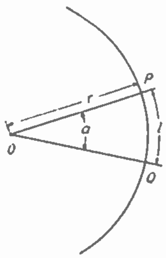


FIG. 18a

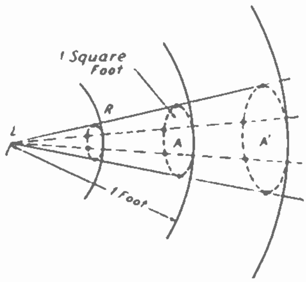


FIG. 18b

plane (flat surface) geometry a *plane angle* is measured by the ratio of the arc length l to the radius r as shown in Fig. 18a. That is, the angle a is measured by dividing the length l by the length r. The value of the angle is given in *radians*. Similarly, a *solid angle* (dealing with bodies) is measured by the ratio of an area A, on the surface of a sphere to the square of the radius (R^2) of that sphere. If the surface you consider is not spherical you would imagine a sphere that can be drawn inside and then draw lines from the center of the new sphere to the edges of the first surface. The area on the sphere divided by its radius twice would be the solid angle. Fig. 18b shows a circular area described on the surface of the sphere and the solid angle is that inside of the cone. If we constructed a sphere with 1 ft. radius and took an area on the surface of 1 sq. ft., that would give us a *unit solid angle* called a *steradian* or a *unit cone*. There are 4π or 12.57 sq. ft. on the surface of a sphere whose radius is 1 ft.; therefore, there must be 4π unit solid angles in such a unit sphere.

Suppose that a small concentrated filament lamp *L* is placed at the center of this unit sphere. Each unit solid angle will contain an equal portion of all the light energy which the lamp radiates. In fact, *each cone* includes $1/4\pi$ of the whole energy of the lamp. As we increase the radius of the sphere, the *same* amount of light energy is present in each *unit solid angle* but the light received per unit area on the surface of the inner sphere is greater than that received on the surface of the outer sphere in proportion as the area *A'* is to area *A*.

Photometric Standards and Units. A candle of certain specifications was the first light standard employed in photometry. At present, incandescent electric lamps of certain construction and operated at a definite voltage are used almost exclusively as secondary standards in commercial work and they are still rated in terms of the candle or candlepower. The primary standard against which any lamp may be calibrated is kept at the National Bureau of Standards, Washington, D. C. A certificate stating the candlepower and voltage adjustment accompanies each lamp which the Bureau calibrates or supplies.

The *candlepower* is a unit of *luminous intensity.* A standard candle placed at *L*, the center of the unit sphere, that is a sphere with a radius of one foot, will fill a unit solid angle (one cone) with one *Lumen* of light energy. The lumen, which is the unit of luminous flux,* is comparable to the watt in electrical flux. In fact about 625 lumens equals one watt. The measurement of candlepower or lumens depends upon the illumination of a surface, whether that surface *reflects* light to the eye or the sensation of brightness is impressed directly upon the retina of the eye.

Thus you come to the subject of illumination or *intensity of illumination* upon a surface. The candlepower is a property of the source of light. It tells us how strong, how intense the lamp is. The concept of the lumen applies to the space around the lamp. In a given solid angle there exists a definite quantity of luminous flux emanating from the lamp. The eye becomes aware of the existence of this energy only by placing in the path of this flux a surface to receive the illumination. Therefore, intensity of illumination is expressed in *lumens per square foot.* A lumen per square foot is numerically the same as a *foot-candle.* In this discussion of pho-

* The word light *flux* is used in the same manner as magnetic or electric flux. The rate of energy flow is really flux and in this case we are considering the rate of flow of light energy, per second.

tometry it is assumed that the lamp is small compared with the distances to the points at which measurements are made, for when this is true the light flux travels uniformly in all directions away from the source.

A numerical example will aid us in getting a clearer understanding of these units. At the center of an imaginary sphere of 10 ft. radius is placed a concentrated 100 candlepower lamp. Now we know that irrespective of the size of the sphere, there are always 4π unit solid angles around it. Therefore, the total luminous flux radiated by the lamp is $4\pi \times 100$ lumens. If we had a unit sphere (1 ft. radius) concentric with this sphere of 10 ft. radius, these 1257 lumens would fall on an area of 12.57 square feet and the intensity of illumination would be 100 lumens per square foot or 100 foot-candles upon the surface of the unit sphere. The area of the larger sphere is 1257 square feet. Therefore, the intensity of illumination is only 1 lumen per square foot or 1 foot-candle. Incidentally, this gives you some idea how light intensities fall off with increased distances. It is because of the units involved in this law that the foot-candle is used (incorrectly) by engineers as a unit of illumination in place of the lumen or flux *per* unit area.

We may express this information in a formula that you will find quite helpful in light control equipment. Here it is:

$$\text{Foot-candles or Lumens per square foot} = \frac{\text{Candles at source}}{\text{Feet from source } \textit{times} \text{ feet from source}}$$

This formula is used as follows: Suppose you have a surface a definite number of feet away from a light source whose candle power is known. If you want to know the illumination of this area in foot-candles or lumens per square foot, merely divide the candles by the distance and divide the result once more by the distance. Often when working with photocells you are told that so many lumens on the photocell will give a definite current output. If you know the illumination, calculated as shown above, all you need to do to get lumens is to multiply the foot-candles by the area of the photocell.

In the case just cited we dealt with light that left a lamp in all directions, a point source. Now consider the very practical case where the light is directed into a parallel beam. If no light is lost in the optical arrangement, the total lumens in this beam will be $12.57 \times$ the candle power of the source. To find the lumens actually falling on a photocell placed in this beam multiply the lumens in the beam by the area of the photocell and divide by the area (cross section) of the beam.

Of course, from your study in this text you know that light is lost when it is reflected or refracted. To get the true light flux on the window of the photocell you would have to multiply your result by the efficiency of transmission, that is, the efficiency of the optical system used. The efficiency of a mirror, or a lens or a prism is roughly 85 per cent. If you use only one device the efficiency of transmission will be .85; if a reflector and a mirror are used, two devices, the efficiency of the optical system will be about $.85 \times .85$ equal to .72; if three elements are used the multiplying factor becomes $.85 \times .85 \times .85$ equal to .61; and so forth.

Photometers. The Rumford Photometer, a device to compare luminous intensities, candlepower, is one of the oldest devices in optical science. Its principle is shown in Fig. 19. Shadows of an opaque rod *R* are cast on a screen by means of light sources at

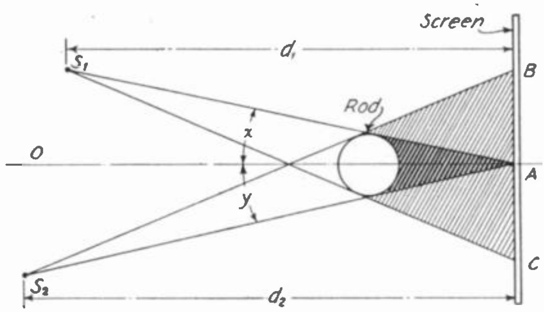


FIG. 19

S_1 and S_2. S_1 will produce a shadow from *A* to *C*, whereas S_2 will produce a shadow from *A* to *B*. By adjusting the positions and distances of S_1, the unknown source, away from the screen *CAB* and also away from the line *OA*, the partial shadows *AC* and *AB* may be made of equal illumination intensity. S_2, however, has a standard intensity; that is, it has an intensity of a certain number of candles. When we have the above conditions, the intensity at the screen from either light source must be the same and we obtain the intensity of the source in candles by the simple formula:

Candles of S_1 =

$$\text{Candles of } S_2 \textit{ times } \frac{\text{distance } d_1 \textit{ times } \text{distance } d_1}{\text{distance } d_2 \textit{ times } \text{distance } d_2}$$

A modern portable illumination intensity meter is shown in Figs. 20a and b which works slightly different. Contained in a small black box is a special electric lamp almost as long as the box, having a uniform filament. The current for it is supplied by a small dry cell. In order that its light intensity can be known and properly adjusted, an ammeter and rheostat are permanently connected in the circuit and placed in plain view on the box.

Directly above the electric lamp is a series of circles placed in a row. These are treated and made translucent in varying degrees.

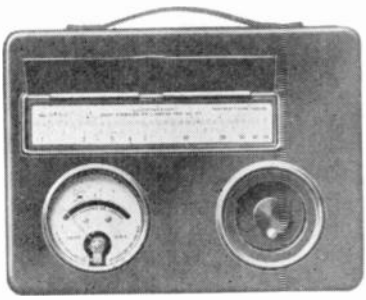


Fig. 20a

The hole at the extreme left may be almost transparent. The hole at the extreme right may be practically opaque. Between these extremes, the holes are of varying degrees of translucency. Each one to the right allows less light to pass through than the previous one.

By means of this device, the amount of light that reaches any

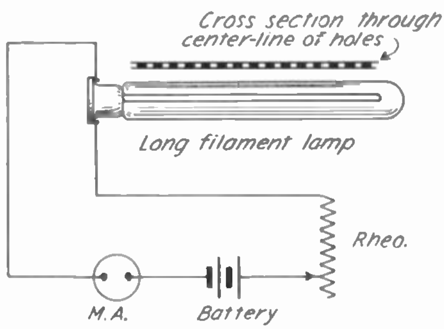


Fig. 20b

point can be measured to a fair degree of precision. The method of operation is as follows: Suppose we want to find out how much light a certain type of lamp affords at some definite place. We place the meter on a desk or wherever it is that the light will be used and adjust the filament for proper intensity. Then we stand away from the meter so the light can shine directly on it. The light from outside the meter will be equal to the amount of light showing through one of the holes. This hole then seems to disappear. By noting the position of the hole and referring to the number below it (the individual holes are calibrated in lumens per square foot) we know just how many lumens per square foot or foot-candles are provided by the light we are testing. Thus we have a rapid means of determining the amount of illumination provided by a lamp for any position or for that matter the illumination at any surface of interest regardless of the source.

As electric and radio technicians you will be more interested in the photocell as an illuminosity meter. A photocell that has a color response similar to the human eye may well serve as a device to measure light flux or illumination. The most practical photocell would be of the photo-voltaic type, that is, one capable of furnishing a voltage when excited. The copper oxide cells are of the photo-voltaic type and the Photox cell manufactured by Westinghouse and the Photronic cell made by Weston are of this type.

Fig. 21

When connected to a sensitive microammeter, the meter deflection is proportional to the light flux intercepted and the readings represent the type of light that the human eye would see. The Weston cell will deliver 120 microamperes per lumen of light flux. Figure 21 shows a Weston model 614 foot-candle meter. By varying the sensitivity of the meter, weak and intense illumination may be rapidly measured. All you need to do is to place the meter so it intercepts the light to be measured or place the photocell at the surface where the light is to be determined. The meter needle reads directly in foot-candles or lumens per square foot.

TEST QUESTIONS

Be sure to number your Answer Sheet with the number appearing on the front cover underneath the title of this text.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your Course, and the best possible lesson service.

1. What important fact was demonstrated by Young's light interference demonstration?
2. When rays of light are shown as lines on a diagram, what do they indicate regarding the travel of light energy?
3. What is light diffraction?
4. Name the colors seen in a rainbow.
5. What is the approximate range of wavelengths in Angstrom units (A.U.) for visible light?
6. To what color light is the eye most sensitive?
7. What happens to the direction of a light ray when it strikes a different medium at a slant?
8. What happens to a light ray when it strikes a mirror?
9. Of these three materials: bakelite (radio panels); smoke; gasoline; which is transparent, which is translucent, and which is opaque?
10. Is there any difference between the illumination intensity of one foot-candle and one lumen per square foot?

The Theory of Light. No. 56 RH-1

1. Light is a form of wave motion.

2. The direction in which energy travels.

3. The bending of light around an obstacle.

4. Red, Orange, Yellow, Green, Blue, and Violet.

5. 4000 to 7000 Angstroms.

6. Yellow-Green light.

7. The light ray is bent.

8. The light ray is reflected.

9. Gasoline is transparent, smoke is translucent and bakelite is opaque.

10. None at all.

GEOMETRIC AND ELECTRONIC OPTICS

57RH-1

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

THE IMPORTANCE OF GEOMETRIC AND ELECTRONIC OPTICS

Just as coils, condensers, resistors and vacuum tubes control the flow of electrons in electrical circuits, so do the plane and curved mirrors, lenses, prisms and polarizing devices which you will study in this text control the paths of light rays in optical systems. If you want to make *light* your servant, then you must understand how these essential optical devices act upon rays and beams of light. Everyone knows that a camera is only as good as its lens; the success of a television system or photoelectric control system likewise depends upon how well the optical system is designed and upon the quality of the optical devices used. In order to install, use, maintain and service any device successfully, you must understand *how* that device operates.

The cathode ray tube is becoming increasingly more important each day in radio servicing work, in television, and in many forms of engineering research; electronic optics reveals the operating principles of this fascinating tube, and that is why the last section of this text is devoted to the behavior of rays of electrons in a vacuum. You will be surprised at the similarity between electronic optics and geometric optics.

This lesson contains a great deal more information than you would ordinarily need in radio work—material which at the present time may seem quite useless, but as you begin actual work with photoelectric control and television systems, you will appreciate more and more the wealth of basic principles and practical ideas presented in this one text-book. Read through the lesson at least twice, answer the questions in the lesson examination, then place the book in your library for future reference.

J. E. SMITH.

NATIONAL RADIO INSTITUTE

WASHINGTON, D.C.

1942 Edition

A LESSON TEXT OF THE N. R. I. COURSE
WHICH TRAINS YOU TO BECOME A
RADIOTRICIAN & TELETRICIAN
(REGISTERED U. S. PATENT OFFICE) (REGISTERED U. S. PATENT OFFICE)

NCP15C742

Printed in U. S. A.

Geometric and Electronic Optics

INTRODUCTION

YOU have already learned a great deal about the nature of light and about how ordinary objects can, because of their light-reflecting properties, become secondary sources of light. In this lesson you study first the light-reflecting properties of various shapes of mirrors, the light-refracting properties of different kinds of lenses, and other devices which affect the transmission of light and come under the general heading of *geometric optics*. Then you take up an entirely new but closely related subject, *electronic optics,* in which you will find that rays of *electrons* can be made to behave much like rays of *light*.

PLANE MIRRORS

Flat or plane mirrors are by far the commonest of all reflectors; these can be either silvered panes of glass or polished metal sheets. Plane mirrors are used in optical systems to change the direction of a beam of

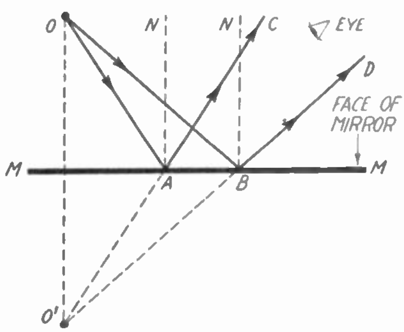


FIG. 1. Reflection from a plane mirror.

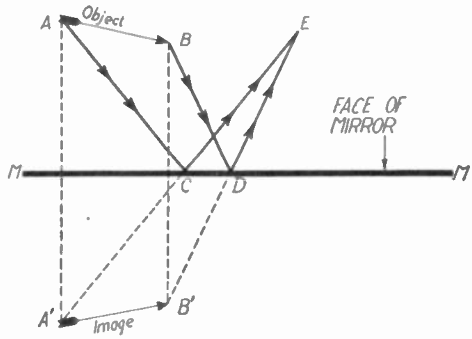


FIG. 2. Locating image for a plane mirror.

light; this change, you will remember, can be predicted in advance by means of a very simple rule: *The angle of incidence is equal to the angle of reflection.* This rule is illustrated by Fig. *1,* where *MM* represents a polished mirror before which is the small object marked *O*. When this object is illuminated in any way, it reflects light and becomes a secondary source of light. Rays from the object strike the mirror at many points and are reflected at various angles; *OA,* which we can consider as one of the incident rays, will, according to the rule, be reflected along the path *AC*. The angle of incidence (the angle made by *OA* with *AN*) is exactly equal to the angle of reflection (the angle made by *AC* and *AN*). Line *OB* represents another ray from *O,* and this will be reflected along the path *BD*; the angle of incidence is greater here, and the angle of reflection is correspondingly increased.

The rays leaving the mirror are divergent (*AC* and *BD* spread apart), but if these rays were continued behind the mirror they would meet at *O'*. To a person looking into the mirror from a position between points *C* and *D* it would appear that *the image O' is located* the same distance *behind the mirror* as the object *O* is in front of the mirror.

Of course, objects in every-day life are much more intricate than the simple point shown at *O* in Fig. *1*, and there are many more light rays reaching the mirror from various points on the object. In the study of optics, therefore, it is customary for purposes of simplicity to represent an object by an arrow whose length corresponds to the greatest length of the object. The arrow *AB* in Fig. *2* thus represents some object which we can assume is reflecting light only from its extreme ends, *A* and *B*. The image of this arrow behind the mirror can be located very easily; draw *any* incident ray from *A* to the mirror, such as *AC*, and another incident ray *BD* from point *B* of the object. You know that the image will be directly back of the object (*O'* was directly back of *O* in Fig. *1*), and that the image will lie somewhere along the projection of the reflected rays *CE* and *DE*; the image is thus located at the intersections of the dotted lines.

A rear-view mirror in an automobile is a familiar example of a practical plane mirror. The image of the car behind, seen in the mirror, always appears to be as far in back of the mirror (ahead of the driver)

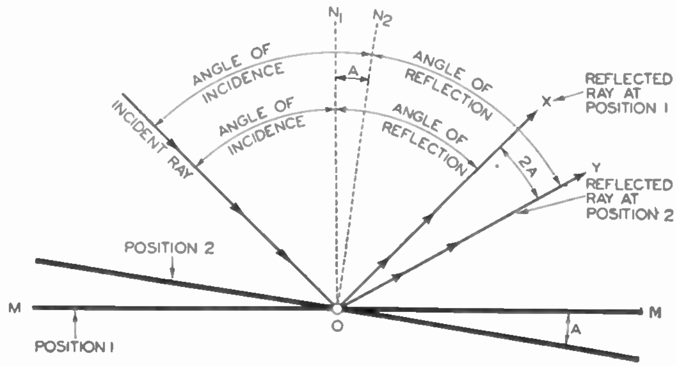


FIG. 3. When a beam of light is directed on rotating mirror *MM*, the reflected ray will move through twice the angle through which the mirror rotates.

as that car is behind the driver. If the driver were at *E* in Fig. *2*, looking into a mirror at *CD*, and *AB* were a passing car, the car seen in the mirror would appear to be at *A'B'*.

The images *O'* in Fig. *1* and *A'B'* in Fig. *2* are called *virtual images*, because each of them has the *appearance* of *an actual object located behind the mirror*. Light does not actually exist at the apparent position of a virtual image, and a screen placed there will not be illuminated. Later on we shall learn about *real images*, which are formed by an actual concentration of light.

From a study of Fig. *2* and from your experiences with mirrors, you can make these conclusions about a *plane mirror: 1*, the image and the object are at *equal distances from*, but are on *opposite sides* of the mirror (the image being behind the mirror); *2*, the image and object are of the *same* size; *3*, the image is upright (not upside-down), but is reversed (that is, the right side of the object becomes the left side of the image and vice versa).

There are many applications for plane mirrors in television; for example, certain types of scanning discs are made up of many small plane mirrors mounted on a rotating drum. In some types of television receivers, a large mirror set into the cover of the cabinet reflects the picture from the cathode ray tube screen to the audience. A mirror mounted in such a way that it can vibrate is used in another form of mechanical television system. Stationary plane mirrors are used extensively in photoelectric control work to send beams of light over desired paths.

The action of a moving mirror is illustrated in Fig. *3*; when mirror *MM*, which is pivoted at *O*, is in position *1*, an incident ray of light from the source is reflected along the line *OX*, since the angle of incidence must be equal to the angle of reflection. Now if the mirror is turned through angle *A* to position *2*, the normal will be rotated through this same angle and the new normal will be N_2. Since the angle of incidence for the ray, with the mirror at position *2*, has been increased by the angle *A*, the angle of reflection must be increased by this same angle, and the reflected ray *OY*, for position *2*, will have moved through twice the angle *A*. All this can be condensed into a simple rule: *A reflected ray moves through twice the angle through which the mirror is turned.*

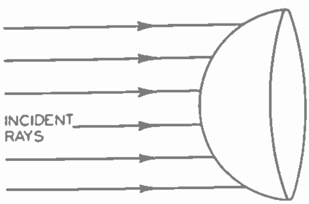


FIG. 4A. Outer surface polished—convex mirror.

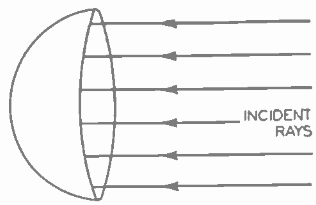


FIG. 4B. Inner surface polished—concave mirror

MIRRORS WITH CURVED SURFACES

Mirrors or reflectors which have curved surfaces have many practical applications, the best known of which is probably the reflector in an automobile headlight. A polished, spherical (ball-shaped) surface is the simplest of curved mirrors and will therefore be studied first. There are two kinds of spherical mirrors; either the outer surface, forming a *convex* mirror as in Fig. *4A*, or the inner surface, forming a *concave* mirror as in Fig. *4B*, may be polished (if of metal) or silvered (if made of glass) and used as a reflector. For any one ray of light, the rule still holds true that the angle of incidence is equal to the angle of reflection, but since a curved surface has a very great number of normals to its surface, we cannot expect that a curved mirror will behave like a plane mirror.

Concave Mirrors. Figure *5A* shows how to locate the image reflected by a concave spherical mirror, such as the inside surface of a portion of a hollow ball, when the mid-point of the object (the mid-point of arrow *AB*) is placed on a line through the center of the mirror's surface and is beyond the center *C* of the sphere. The curved line *PD* represents a cross-section of a spherical mirror whose center is at *C*. Point *C* is known as the center of curvature, and is the exact center of the entire sphere. A radius drawn from *C* to any point on the reflecting surface will therefore represent the normal (the perpendicular to the surface at that point).

Point P, for example, can be considered as a very small flat surface having line PC as its normal.

With these points clarified, we are ready to locate the image of object AB. The steps involved in locating the image formed by a spherical mirror are:

1. Draw a line through the center of curvature C and the center of object AB. This line will be what is called the *principal axis.*
2. Draw line AD from point A through the center of curvature C to the surface of the mirror. This ray will be reflected back on its own path, as the arrows indicate, for it is a radius and is therefore normal to the mirror surface.
3. From the same point A draw line OA parallel to the principal axis.
4. Locate point F on the principal axis *midway between the center of curvature C and the intersection of this axis with the surface of the mirror;* this point F is called the *principal focus* of the mirror, for any ray parallel to and close to the principal axis will be reflected from the mirror through F. The principal focus of all concave spherical mirrors is on the principal axis, midway between C and the mirror.
5. Draw a line OA', extending from O through F. The two reflected rays OA' and DA meet at point A', determining the image of point A.
6. Draw similar lines for point B of the object. These lines will intersect at B', which is the image of point B; joining A' and B' forms the image of object AB. In this particular case, where the object is assumed to lie *outside* the center of curvature C, you would actually see light from the image. For this reason the image is called a *real image.* Notice that it is inverted and is smaller than the object.

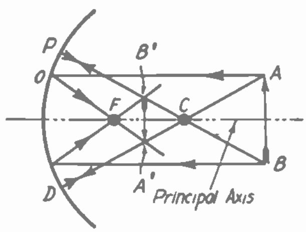


FIG. 5A. Locating image for concave mirror when object (AB) is beyond center of curvature.

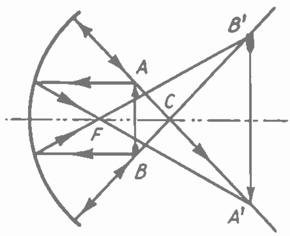


FIG. 5B. Locating image for concave mirror when object (AB) is between C and F.

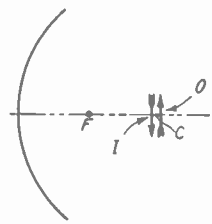


FIG. 5C. Image *I* is near object *O* when object is near *C*.

If you were to stand in front of a concave spherical mirror in a position corresponding to AB, you would see your image as $A'B'$; that is, it would be inverted and smaller. Your image would also appear to be located *between you and the mirror,* rather than behind the mirror as in the case of a plane mirror.

When the object is located somewhere between center of curvature C and the principal focus F, as in Fig. *5B*, the image can be located by a procedure similar to that just described. The image $A'B'$ here appears to be some distance behind the object; it is larger and still inverted. When the object is located very close to the center of curvature, the image will appear to coincide with the object. It will be the same size as the object but inverted, as shown in Fig. *5C*.

Now let us place the object between the mirror and the principal focus. Although the image-locating procedure is essentially the same as that used before, a number of lines will have to be projected behind the mirror, as shown by the dash-dash lines in Fig. *6*, in order to make them intersect and form the image. Notice that the image *A'B'* is here *virtual* (behind the mirror) and erect, not upside-down; it is also larger than the object.

Convex Mirrors. With convex mirrors where the *outer* surface of a portion of a sphere serves as a reflector, the image is always erect, virtual (behind the mirror), and smaller than the object, as shown in Fig. *7*.

In industry and in ordinary life spherical mirrors are more often used to reflect light rather than to produce an image. Inverted spherical reflectors (concave) are used in indirect lighting systems to throw light on the ceiling. Spherical concave mirrors are used in flashlights and in light sources for photoelectric work to reflect light from the sides and rear of the light bulb back into the lens; this light would otherwise be totally wasted, for only that light which passes through the lens is useful in creating a beam. The light source should be placed as close as possible to the center of curvature of a concave spherical mirror.

It is often necessary to design a reflector which will, without the aid of lenses, concentrate light on a single spot. Ordinary spherical mirrors, as you can see by studying Fig. *8*, are usually not suitable for this purpose. Parallel rays of light, coming from a distant source (especially those rays farthest away from the principal axis) and striking the surface

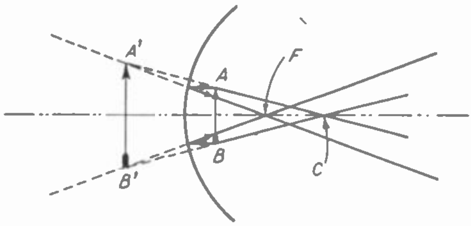


FIG. 6. Locating the image for a concave mirror when the object (AB) is between F and the mirror.

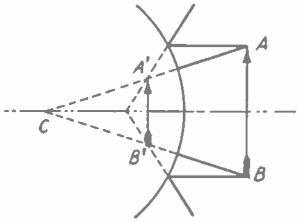


FIG. 7. Locating the image for a convex spherical mirror.

of the mirror, will be reflected to many different points along the principal axis instead of coming to a sharp focus at point *F*; this means that if a source of light were placed at *F* the rays reflected by the mirror would diverge (spread out) instead of being reflected outward parallel to each other to form a beam. If, however, the portion of mirror being used makes an angle of less than 12 degrees with the center of curvature *C* (if angle KCK' in Fig. *8* is less than 12 degrees), the reflected rays will be practically parallel. Small sections of mirrors therefore give more perfect results than do larger sections.

Parabolic Mirrors. When more efficient focusing (more reflected light) than can be obtained with a spherical mirror is desired, a specially curved mirror known as a parabolic * reflector is used. Automobile headlights, some forms of navigation searchlights, airplane beacons and powerful spotlights are generally made with this type of reflector, the shape of which is shown in Fig. *9*. Parallel rays of light, such as those coming from a far distant object or source, are brought to a sharp focus at *F* and conversely, a beam of parallel rays is produced when a point

* Parabolic mirrors have special shapes (not spherical) which give them the properties described here.

source of light is placed at F. With parabolic reflectors, all light reaching the reflector is directed into the beam and the total loss in light (made up of light radiating outward directly from the source at F, outside the limits of the beam, and the losses due to reflection) is low.

Parabolic mirrors are used in television to throw a strong beam of light on the subject being televised; in photoelectric control work parabolic reflectors throw concentrated beams of light on a light-sensitive cell from distances which may be as great as 100 feet.

Another useful form of concave mirror is that shown in Fig. *10*, known as an *elliptical* * *mirror*. When a point source of light is placed at focal point F_1, all rays hitting the mirror will be concentrated at a second focal point F_2; the opposite also holds true—rays from F_2 will be reflected to F_1. The arrows are shown in two directions for each ray in Fig. *10* to indicate these facts. Elliptical mirrors are used extensively in television apparatus which is designed to transmit movie film; the intense light from an arc light at one focal point is concentrated on the movie film at the other focal point.

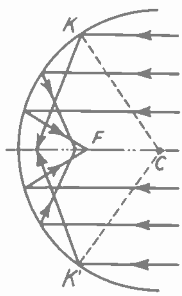


FIG. 8. Distortion in a spherical mirror.

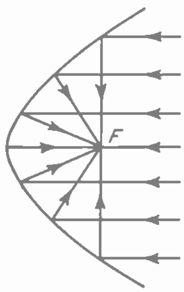


FIG. 9. Cross-section of a parabolic mirror.

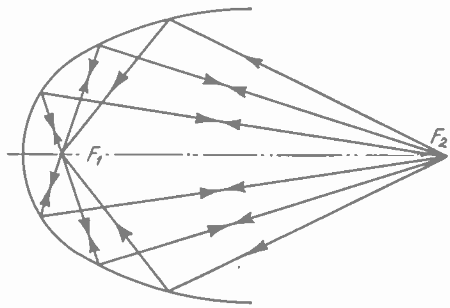


FIG. 10. Cross-section of an elliptical mirror, often used in television apparatus.

REFRACTION

Light rays, as you already know, are bent when passing from one material (medium) to another, provided that the two materials have different optical densities; the amount of bending or *refraction* which a ray undergoes depends upon the relative speed of light in each medium.

For any known substance the velocity of light is a fixed and measurable quantity; the ratio of the velocity of light through two materials is therefore a measure of the amount of bending which a ray will undergo when passing from one of these to the other. This ratio is known as the *relative index of refraction.* It is not necessary, however, to know the exact speed of light through different substances, for in almost every practical case air is one of the substances. Scientists have prepared tables which give relative velocities of light in these substances with respect to air; in each case the ratio, which is known as the *index of refraction,* has been determined from the following equation:

$$\text{Index of refraction} = \frac{\text{Speed of light in air}}{\text{Speed of light in second medium}}$$

* Elliptical mirrors have special shapes (not spherical) which give them the properties described here.

Indexes of refraction for the materials commonly encountered in geometric optics are given in the following table:

INDEXES OF REFRACTION

Air	**1**	**Barium Flint Glass**	**1.568**
Water	**1.33 or 4/3**	**Light Flint Glass**	**1.580**
Alcohol	**1.36**	**Medium Flint Glass**	**1.627 or 8/5**
Ordinary Crown Glass	**1.517 or 3/2**	**Carbon Bisulphide**	**1.64**
Borosilicate Crown Glass	**1.524**	**Diamonds**	**2.47 or 5/2**

Refraction plays an important part in the design of lenses used to correct defects in human vision, lenses for concentrating beams of light in television and photoelectric apparatus, and in many other forms of optical instruments. For this reason it is important that you understand the geometrical method of determining the path of a refracted ray of light. This procedure is given in Fig. *11*, where line *MM* represents the surface of a body of water as well as the plane

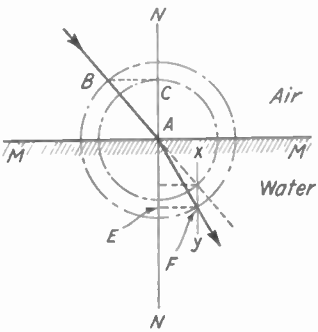


FIG. 11 (above). Refraction of ray of light passing from air to water.

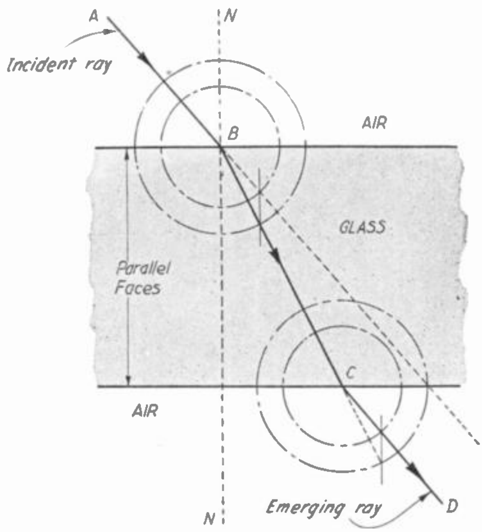


FIG. 12 (right). Refraction of ray of light passing through a pane of glass.

which separates the two materials in question, water and air. Let us assume that a ray of light originating at a source located in air strikes the surface of the water at *A*, along the path *BA*. The table gives the index of refraction for water as 4/3; with these facts at hand, you are ready to locate the path of the light ray through water. The steps are:

1. With point *A* as a center, draw two circles whose radii have the same ratio as the index of refraction for the two materials in question. In this case the circles will have the ratio of 4 to 3; for example, the radii could be 4 inches and 3 inches respectively.

2. Draw the normal line *NN*, which passes through *A* and is perpendicular to the plane (represented by line *MM*) separating the two materials.

3. Draw the projection of the ray *BA* through the water, as shown by the dash-dash line in Fig. *11*.

4. At the point where the projected ray of light in water intersects the smaller of the two circles, draw line *xy* parallel to the normal *NN*.

5. Draw line *AF* from *A* through the point of intersection of line *xy* with the larger circle. This line *AF* then represents the path of the refracted ray through water.

THE PRISM

When light passes from air to another substance such as water or glass, as in the case illustrated in Fig. *11*, the refracted ray is bent *toward the normal;* when passing *from* a substance into air, the refracted ray will be bent *away from* the normal. For example, when a ray of light passes through a pane of glass which has parallel faces, as shown in Fig. *12*, the bending of the ray is such that the entering ray *AB* is parallel to the emerging ray *CD*, but the two rays are not in the same straight line. At point *B*, the upper surface of the glass, the bending is *toward* the normal *NN*, while at *C*, the lower surface of the glass, the bending is *away from* the normal.

If the faces of a glass object are inclined to each other, as in the case of the prism shown in Fig. *13*, instead of being parallel, the ray will be bent toward the *thicker* part of the prism. You can verify this fact by checking the construction shown in Fig. *13*, while remembering that the ray which *enters* the glass is bent *toward* the normal to that surface, while the ray which *leaves* the glass is bent *away from* the normal to that second surface.

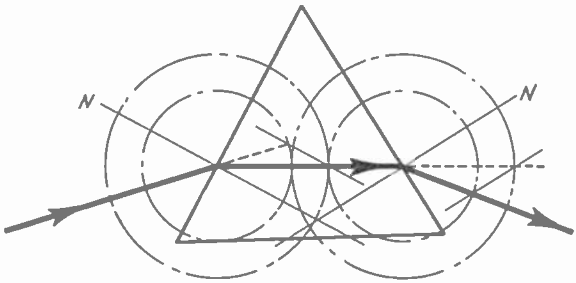


FIG. 13. Refraction of light by a prism.

The amount of bending which a ray of light undergoes in passing through a prism depends upon four things: *1*, the angle which the entering ray makes with the entering surface; *2*, the index of refraction of the glass; *3*, the angle (prism angle) between those two faces of the prism through which the light beam passes; *4*, the color (wavelength) of the light. When a beam of white light, made up of rays of various colors, is directed upon the face of a prism, the entire spectrum of color emerges from the prism, each colored ray at a different angle. The violet rays, the shortest visible wavelengths of light, are bent most, while the red rays, the longest visible wavelengths, are bent the least.

TOTAL REFLECTION

Prisms are often used in place of mirrors to change the direction of a beam of light, for under certain conditions that surface from which the light ordinarily emerges becomes a reflector, blocking the passage of light in that direction but making the light emerge through another face of the prism. The conditions under which total reflection is obtained with glass alone, without silvered surfaces, are important enough to merit careful study. Imagine point *B* in Fig. *14A* to be a source of light inside the glass which is radiating rays of light at various angles. When the angle which a ray makes with the normal *BN* is less than the critical angle shown, the rays are bent away from the normal in the ordinary manner when passing out from the glass to air; rays *P*, *Q*, *R* and *S* are examples of this. A ray passing out from *B* at the critical angle, however, does not emerge into the air, but simply glides along the surface of the glass, as at *T;* the ray is actually bent along the glass surface. Rays having an angle of incidence greater than the critical angle are reflected from the surface of the glass, as at *U*, just as if that surface were a plane mirror. Once the critical angle is exceeded, the rule for reflection for mirrors holds true: the angle of incidence is equal to the angle of reflection.

You can find the critical angle at which total reflection begins for any kind of glass or liquid by means of a geometric procedure which is simply the reverse of the procedure used to determine how much a ray is bent when passing from a rare to a dense medium. The procedure is illustrated in Fig. *14B* for crown glass; *MM* represents one surface of the glass, and point *A* is any point on that surface. The steps to be followed in determining the critical angle are:

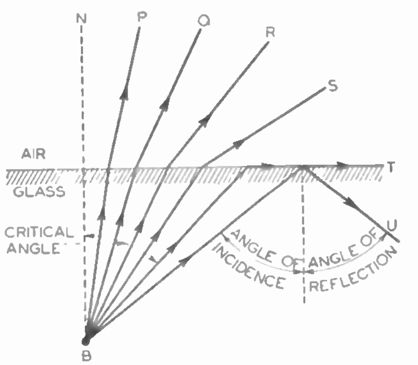


FIG. 14A. Refraction and total reflection of light rays from source B.

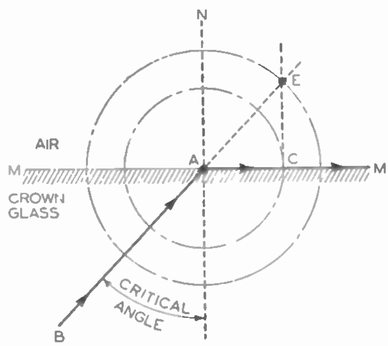


FIG. 14B. Determining the critical angle of total reflection for crown glass.

1. Draw the normal *N* through any point, such as *A*, on the surface of the glass.
2. With *A* as a center draw two circles whose radii have the same ratio as the index of refraction of the glass (here 3/2 for crown glass).
3. At one of the points where the smaller circle intersects the surface of the glass, such as at *C*, draw a line parallel to the normal (*EC*), which intersects the larger circle at *E*.
4. Draw a line from *E* through *A*, projecting it into the glass to *B*. The angle between *AB* and the normal will then be the critical angle, and a ray of light directed from *B* to *A* through the glass will follow the surface of the glass instead of being refracted or reflected.

The critical angle of total reflection for water is found in much the same way as that shown in Fig. *14B*, except that circles whose radii are in the ratio of 4 to 3 are chosen. You can even determine this critical angle for water directly with a tumbler full of water. Hold the glass of water above your head and gradually lower it while looking at the surface of the water from beneath. The surface will take on a brilliant silvery appearance when your eye is on the line which forms the critical angle for water (neglecting refraction through the side walls of the glass).

Total reflection can take place only when a ray of light passes from one material into another which has a *lower* index of refraction; thus, there can be no total reflection for a ray passing from air to another material.

Total reflection from glass is utilized in periscopes, prismatic binoculars, opera glasses and in the optical systems used in some types of sound projection and television equipment. The direction of the emerging beam can be determined accurately beforehand by a geometric procedure and the surfaces of the prisms ground to give exactly the desired reflecting properties to the prisms.

The type of prism shown in Fig. *15A* is most often used in optical systems where light is to be reflected at right angles with minimum losses and without bending the rays. Since rays of light enter and leave the prism at right angles to the surfaces, there is no refraction or bending of the light beams. Practically all light is reflected by a prism of this type, the losses being very low. In addition, the use of mirror surfaces which tarnish with age is avoided. Prisms are as a rule more expensive than mirrors, and cost must therefore be taken into consideration when choosing between mirrors and total reflecting prisms for a given optical system.

Prisms can also be used to invert images; for example, in Fig. *15B* the object *AB* would appear to be inverted if viewed through the prism in the manner shown. Total reflection takes place here at the base of the prism, with minimum loss of light.

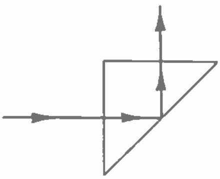


FIG. 15A. Prism used as mirror.

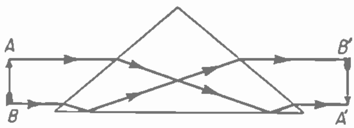


FIG. 15B. Prism used as image-inverter.

LENSES

A lens is a combination of prisms. The laws of refraction just studied, which have heretofore been applied to prisms, apply equally well to lenses of all types. Remember this rule especially: A ray of light, in passing through a prism or lens, is always bent toward the *thicker* part of the glass.

Two-Prism Lenses. When two triangular prisms are placed base to base in the manner shown in Fig. *16A*, you will find, by tracing the rays in the usual manner, that the upper prism bends the emerging ray downward while the lower prism bends its emerging ray upward. The parallel rays of light entering the prisms will, therefore, be refracted to a point at *F*. If the prisms were placed peak to peak, as in Fig. *16B*, the upper prism would bend the emerging ray upward while the lower prism would bend its emerging ray downward, with the result that the two parallel rays entering the prism would be spread apart after refraction and the emerging rays would appear to come from point *F*.

Converging and Diverging Lenses. Instead of using only two prisms, we can arrange a number of prisms (any block of glass having at least two sides which are not parallel to each other is known as a prism) in the manner shown in Figs. *17A* and *17B* to get the same effect as in Figs. *16A* and *16B* for a beam of light. The combination of prisms in Fig. *17A*.

which converges the parallel rays of light to a point, forms a *converging* lens, while the combination shown at Fig. *17B* forms a *diverging lens.* As more and more prisms are combined in this manner and each prism is made smaller and smaller, the outer surfaces come nearer to forming the arcs of circles. That is why we can consider a lens to be built up of a large number of small prisms, even though a prism always has flat surfaces and a lens curved surfaces.

Various types of lenses, some of which are combinations of a plane surface and a spherical surface, others of which are spherical surfaces having either equal or different radii of curvature, are shown in Fig. *18.*

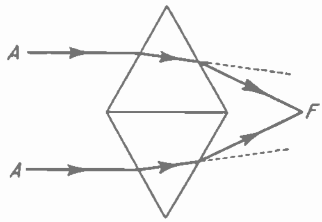


FIG. 16A. A two-prism converging lens.

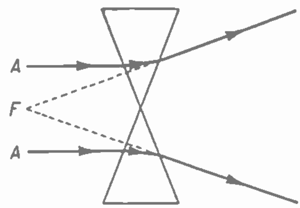


FIG. 16B. A two-prism diverging lens.

The centers of curvature of the surfaces of the lenses are marked by the letter *C*. Remember that a *converging lens* is thickest *at its center,* while a diverging lens is thickest *at its edges.*

The *optical center* of a lens is that point through which a ray of light may pass without suffering a change in direction. In thin lenses the optical center is approximately the center of mass of the lens, which for symmetrical lenses is midway between the two surfaces.

Of the six kinds of spherical lenses, the double-convex, the plano-convex and the concavo-convex lenses in Fig. *18* are known as *positive* or converging lenses, while the double-concave, plano-concave and con-

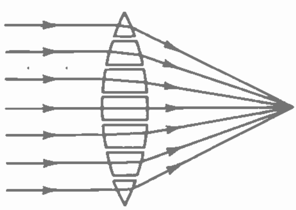


FIG. 17A. Converging lens formed with prisms.

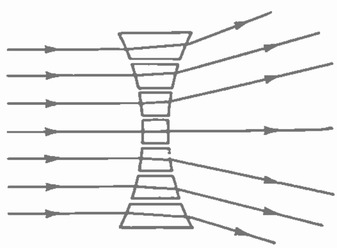


FIG. 17B. Diverging lens formed with prisms.

vexo-concave lenses are known as *negative* or diverging lenses. A study of a few of these lens shapes will show you the reason for these designations.

Tracing Light Rays Through Lenses. Before the path of a ray of light can be traced through a given lens, the centers of curvature and the optical center of that lens must be located (the center of curvature of a lens surface can be located by trial and error with a compass, drawing various curves until one is found which duplicates the lens surface in question). The optical center will then be midway between the surfaces of the lenses on a line passing through the two centers of curvature or, where one lens surface is plane, on a line perpendicular to the plane surface and passing through the center of curvature of the curved surface. The procedure to be followed in tracing a ray of light through a lens is given in Fig. *19;* the steps are:

1. Assuming that line *AB* represents an incident ray, draw normal *NB* through the point of intersection *B* with the lens. (This normal *NB* would, if extended, pass through *C″*, the center of curvature of this surface.)
2. Using point *B* as a center, draw two circles having a radii ratio of 3 to 2 (the index of refraction for crown glass, used in most ordinary lenses, is 3/2).
3. Through point *P*, the intersection of ray *AB* with the smaller of the two circles, draw a line parallel to line *NB*.
4. Where the line just drawn intersects the larger circle (point *H*) draw a line to point *B*, extending this line to the right of *H* until it meets the other surface of the lens. This line, *BD*, now represents the path of the refracted ray through the glass.
5. The ray of light will again be refracted at *D*; draw normal *N′D* through point *D* (this line, if continued, would pass through *C′*, the other center of curvature).
6. Draw two circles as before, with centers at point *D*.

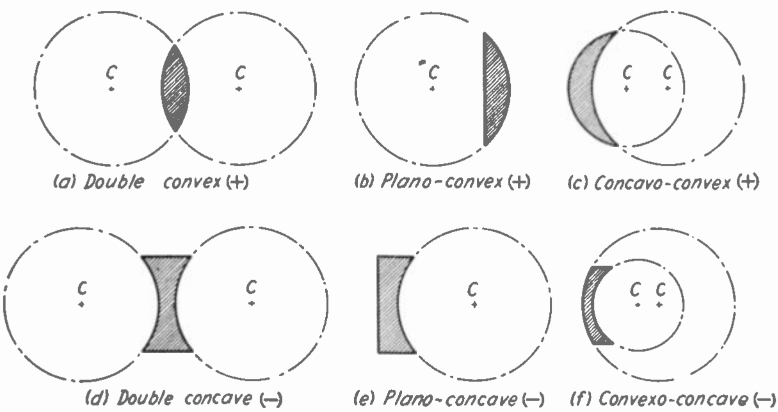


FIG. 18. Six types of lenses; plus sign indicates converging lens, while minus sign indicates diverging lens.

7. Through the intersection of line *BD* (continued) with the larger of the two circles, draw a line parallel to the normal *N′D* and mark the point at which this line intersects the smaller circle *K*.
8. Draw a line from *D* passing through *K;* this line then represents the path of the ray after leaving the lens.

Focal Length. If ray *AB* had been parallel to the principal axis *C′C″* of the lens, as in Fig. *20A*, the emerging ray *DE* would cut the principal axis at point *F*, and the distance from the optical center *OC* to this point *F* would be the focal length of the lens. The method of determining this focal length by geometric methods is shown in Figs. *20A, B* and *C* for three types of lenses; in each case the path of a parallel incident ray of light (parallel to the principal axis) is traced through the lens. The intersection of the refracted emerging ray with the principal axis (or the projection of the emerging ray as in the case of Fig. *20C*) locates the *focal point, F*.

Real and Virtual Focal Points. The focal points of converging lenses, such as are illustrated in Figs. *20A* and *20B*, are said to be *real focal points*, while the focal point of a diverging lens, such as is shown in Fig. *20C*, is *virtual* and must be determined by a continuation of the refracted ray back through the lens.

Locating Focal Points. Every lens has two focal points, one on each side of the lens, at equal distances from the optical center of the lens; the two focal lengths of a lens are therefore always equal. The focal length of a lens can be determined in a number of ways besides the geometric procedure just described; if the two radii of curvature (R_1 and R_2) of the lens and the index of refraction μ are known, the following formula gives the focal length f:

$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} + \frac{1}{R_2}\right).$$

The focal length and the radii must be in the same units of length. This formula applies to all lenses, provided that the radius of curvature of a *concave surface*

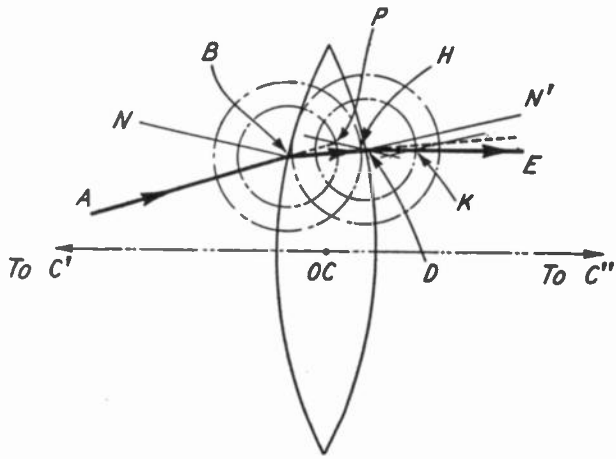


FIG. 19. Tracing a ray of light through a lens.

is considered *negative;* if a negative value is obtained for f, the focal point is *virtual.* (The radius of a plane surface being infinite, the value 1/R will become zero for a plano-convex or plano-concave lens, and only the radius of the curved surface will affect the focal length.) For practical purposes, the index of refrac-

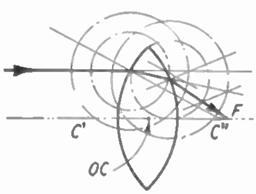


FIG. 20A. Double convex lens; *real* focal point.

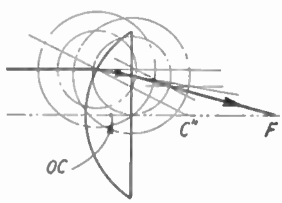


FIG. 20B. Plano-convex lens; *real* focal point.

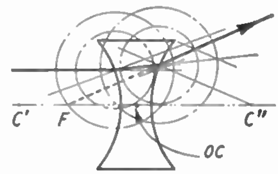


FIG. 20C. Double concave lens; *virtual* focal point.

tion for the glass used in the average lens can be considered as equal to 3/2; using this value for four common types of lenses, the following results are obtained:

For a *plano-convex* or *plano-concave lens* the focal length is approximately equal to *twice* the radius of curvature of the spherical surface.

For a *symmetrical* (either double-concave or double-convex) lens, which has equal radii of curvature, the focal length is approximately *equal to* the radius of curvature.

The focal point of a lens can also be determined by actual measurement. Place the lens between a sheet of white paper and a light source giving parallel rays (such as the sun or the parabolic headlight of an automobile), and vary the distance between paper and lens until the spot of light concentrated on the paper is of minimum diameter. The distance between the optical center of the lens and the paper is then the focal length. Experimenters often check the focal lengths of lenses in this manner before constructing permanent mountings for the lenses.

FORMATION OF IMAGES BY LENSES

The perfect image-forming lens, as designed for use in optical systems, should fulfill the following five requirements:

1. It must receive a large amount of light from the source; this means that it must have a large aperture.

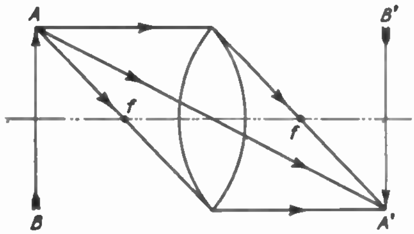


FIG. 21. Three image-locating rays.

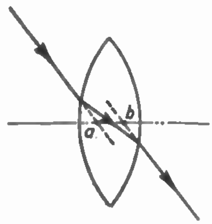


FIG. 22. Nodal points of thick lens.

2. It must condense to a sharp point all of the rays which it receives from each point of the object or source.
3. It must arrange the various points which form the image in proper order and position to correspond with the arrangement of the point sources of light which make up the light source or object.
4. It must make the illumination on all points of the image proportional to the illumination of corresponding points on the object.
5. It must form all points of the image in one plane, even though the object be illuminated by white light (having many different wavelengths).

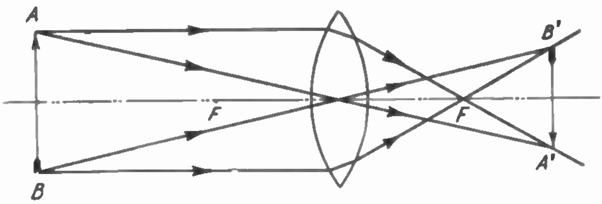


FIG. 23A. Locating image for double convex lens when object is outside focal point.

Unfortunately, no single optical lens can fulfill all five of these requirements, but lenses can be designed to correct particular defects, and two or more lenses can be combined to form a lens which is more perfect than any individual unit in the combination. High quality photographic lenses must, as a rule, be more perfect than those required in photoelectrical applications and in certain types of optical instruments. It is, therefore, important that you should know not only the type of image produced, but also how that image is formed when selecting a lens for a particular job; knowing the defects of various lenses, you can more readily offset these defects by making corrections in other parts of the system.

Locating Lens Images. The image formed by any lens can be located graphically by tracing the rays from extremities of the object through the lens to determine the extremities of the image. If three rays are drawn from one point on the object, such as from point A in Fig. *21*, in certain carefully chosen directions, you will find by construction that one ray, that which passes through the optical center of the lens, is not refracted.* The ray which passes through one of the focal points will be refracted to make it emerge *parallel* to the principal axis. The ray which is parallel to the principal axis will be refracted exactly enough to make it pass through the other focal point. All three rays will meet at the same point, establishing the position of A'. Similarly, if three rays are drawn from B in this manner, point B' on the image would be located. In the particular case shown in Fig. *21*, then, the image is *real* and inverted. Any two of these three rays are sufficient to locate one image point.

The construction of a complete real image for a double-convex lens is given in Fig. *23A*; note that the object is outside of the focal point, giving an image which is real, inverted and outside the other focal point.

The formation of virtual images by two types of lenses is shown in Figs. *23B* and *23C*. In Fig. *23B* the object is inside the focal point and the image obtained is erect, virtual and outside that same focal point.

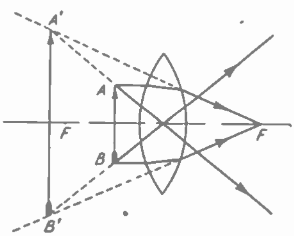


FIG. 23B. Locating image for double convex lens when object is inside *F*.

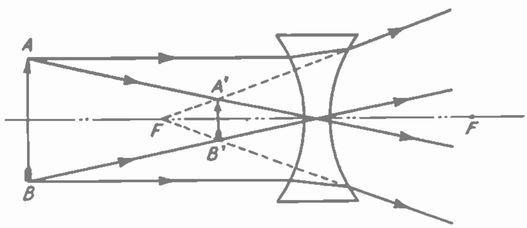


FIG. 23C. Locating image for double concave lens when object is outside focal point.

With converging lenses, a real image is therefore obtained when the object is *outside* the focal length, and a virtual image is obtained when the object is *inside* the focal point. In Fig. *23C*, where the object is outside the focal point of a double-concave lens, the image obtained is erect, virtual and inside the same focal point. A diverging lens *cannot* form a real image except when it is employed in combination with one or more other lenses.

THE LAW OF POSITION

A definite relation exists between the focal length of a lens and the distances of object and image from that lens. This relation, known as the *law of position*, involves the distance P between the object and the optical center of the lens, the distance Q between the image and the optical center of the lens, and the focal length f of the lens, these three distances being shown in Fig. *24*. The relation is:

$$\frac{1}{P} + \frac{1}{Q} = \frac{1}{f}.$$

---

* Thick lenses have two *nodal points*, such as points a and b in Fig. *22*, instead of an optical center. Any ray of light which would, if not refracted, pass close to or through one of these nodal points will be refracted in such a way that it will emerge from the lens as if it had passed through the other nodal point. The emerging ray will be parallel to the entering ray, but shifted a short distance away from it.

We have seen, in Fig. *23B*, that when the object is inside the focal length of a lens, the image is virtual; the value Q must always be given a *negative* sign for a virtual image when making computations with the above formula. Likewise, if you obtain a negative value for Q when solving the above formula, it means that the image is virtual; this rule holds true for all types of lenses.

The formula applies equally well to divergent lenses provided that f, the focal length, is given a negative value. When a divergent lens is combined with one or more other lenses, as in Fig. *25*, the first lens L_1 would, if used alone, form an image at I_1. This image at I_1 becomes the object for the second lens L_2, but is a virtual object rather than a real object. P in the law of position formula must be given a negative value whenever the object is virtual. Calculations are made in steps, one for each lens, when computing by means of the law of position for combinations of lenses.

Summing up these facts, we arrive at the following rules for applying the law of position:

1. The focal length f is always *positive* for a *converging* lens.

2. The focal length f is always *negative* for a *diverging* lens, because the focal point is here virtual rather than real.

3. Q, the image distance, is *positive* when the image is *real*.

4. Q, the image distance, is *negative* when the image is *virtual*.

5. P, the object distance, is *positive* in all cases except that in which a virtual object is used (as in a combination of lenses), when it is negative.

A definite relation exists between the size of the object, the size of the image and the distances of object and image from the optical center of the lens; this relation is:

$$\frac{S_o}{S_i} = \frac{P}{Q}.$$

This formula simply means that the size of the object (S_o) has the same relation to the size of the image (S_i) as the object distance (P) has to the image distance (Q). This rule applies equally well to both real and virtual images.

When two thin lenses are mounted so close together that they are actually in contact, they may be treated as one lens having a focal length f which is determined by the following formula:

$$\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2}.$$

In this formula f_1 and f_2 represent the focal lengths of the individual lenses, while f represents the focal length of the combination of two lenses. Thin lenses are often combined in this way to correct for chromatic aberration, one type of lens defect which is often objectionable.

Ratings of Lenses. Only two values ordinarily need be given in specifying the characteristics of a certain lens—the focal length and the diameter of the lens; * opticians, however, specify their lenses for eyeglasses by the reciprocal of the focal length in meters ($1/f$), and call this value the lens rating in *diopters;* converging lenses are designated as *plus* and diverging lenses as *minus*. For example, a converging lens having a focal length of .5 meters (50 cm.) would be rated as *plus 2 diopters* by an optician $\left(\frac{1}{.5} = 2\right)$, while a *diverging* lens having a focal length of .67 meters would be rated as *minus 1.5 diopters*. The advantage of the diopter rating is that when computing the rating for two lenses in contact, the diopter values can be combined by simple addition and subtraction. In

* Lenses for photographic apparatus are rated as to the speed at which they gather light; the *speed of a lens* is equal to *focal length divided by diameter*. A lens having an f1.5 speed rating is considered quite fast, while the f7.9 lenses found in lower-priced cameras are slower and therefore require longer exposures on the film used.

testing the eyes of a patient, the optician tries various combinations of lenses until he secures one which gives satisfactory vision; he then adds or subtracts the diopter ratings of the lens used in that combination, depending upon whether they are minus or plus lenses, to determine the required single lens.

Two lenses are often placed in combination to obtain a short focal length without using a thick lens to get the required curvature of the lens surfaces. It is customary to use two plano-convex lenses with the curved surfaces facing each other when doing this, for in this way distortional effects due to curvature can be compensated for in a small measure. With high quality lenses which are corrected for distortion, the curved surfaces may be arranged in any position when combining two lenses.

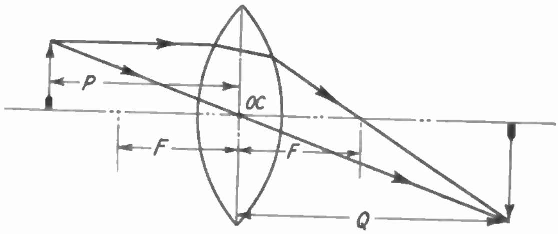


FIG. 24. The law of position: $1/P + 1/Q = 1/f$.

Tabulated Characteristics of Lenses. In the table on page *18* the important characteristics of converging and diverging lenses and mirrors have been tabulated in convenient form for easy reference; use this table when you want to know *what* a certain lens does to a beam of light. If you want to know *how much* the lens affects a ray of light, use either the formulas already discussed or make a sketch of the lens to some convenient scale and go through the geometric construction (already shown in the illustrations) which gives you the desired results.

OTHER CHARACTERISTICS OF LENSES

Chromatic Aberration. You will remember that the index of refraction, which determines the amount by which a ray of light is bent when entering a

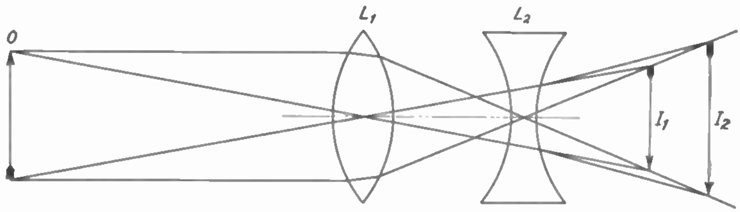


FIG. 25. When lenses are combined like this, image of one serves as object for the other.

certain medium, depends upon the wavelengths or color of the light, and that the bending of the ray is greater for the shorter wavelengths of light. When light coming from a tungsten incandescent lamp, which produces all colors of light, passes through a lens, the violet rays are refracted the most and come to a focus closer to the lens than do the other rays; the focal point for red light is farthest away from the lens. Thus there is a separate focus for each color, and white light cannot be brought to a single focus by a simple lens. This defect in a lens is known as *chromatic aberration.*

Lenses used in the better types of optical instruments are partially corrected for chromatic aberration in the manner shown in Fig. *26A*. The two lenses, one converging and one diverging, have different indexes of refraction and therefore different focal lengths, but are so designed that the dispersions for any two colors (usually red and violet are chosen) counteract each other. The result-

CONVEX (CONVERGING) LENSES AND CONCAVE MIRRORS*

P (Distance of Object from Lens)	Q (Distance of Image from Lens)	Character of Image
Very great (infinity)	focal length (f)	Real, just a point
Between infinity and twice the focal length	greater than (f) but less than (2f)	Real, inverted, smaller than object
Twice the focal length (2f)	twice the focal length (2f)	Real, inverted, same size as object
Between 2f and f	between 2f and infinity	Real, inverted, larger than object
Between f and zero	between infinity and zero	Virtual, erect, larger than object
Whenever object is beyond focal distance	image is beyond focal distance	Image is real and inverted
Whenever object is within focal distance	image distance varies from zero to infinity	Image is virtual, erect and larger than object

CONCAVE (DIVERGING) LENSES AND CONVEX MIRRORS*

P	Q	Character of Image
Infinity	focal length (f)	Virtual, just a point
Between infinity and zero	Between focal length and zero	Virtual, erect, smaller than object
Whenever object is outside focal distance	Image is virtual, erect and smaller than object	

ing lens combination has a definite focal length (a plus focal length in this case, where the convex lens is of crown glass) and rays of the corrected colors are brought to the same focus, even though they travel over different paths. Other rays will still have slightly different focal lengths, but the differences will in most cases be negligible.

Spherical Aberration. Light rays passing through a lens *near its edges* do not have exactly the same focus as rays which pass through the central part of the lens; this is true even for light of a single color. The defect is illustrated in Fig. *26B* and is known as *spherical aberration*. In order to correct for this, the lens must be ground to a different curvature at its outer edges. The final surface of a lens which is corrected for spherical aberration is quite complicated, and the grinding procedure is costly. It is often more advisable to use only the central part of the lens, covering the outer portions with an opaque ring like the adjustable shutter used on many types of cameras, rather than to use a costly corrected lens.

* Occasionally it is necessary to focus light to a line rather than to a point; this can be done with a cylindrical concave mirror or with a cylindrical convex lens, having surfaces which are spherically curved in one direction and are straight in the perpendicular to this direction. The above rules still apply.

TRANSMISSION OF LIGHT

In certain optical applications in television and in electronic control, the important facts are *the amount of light transmitted* and *the way in which light is concentrated.* For example, in television it may be necessary to flood an entire scene with light, direct a powerful but small floodlight on the film being scanned, or direct a small but intensely bright spot of light back and forth over a scene or film in scanning it; in electronic control the photocell must intercept practically all of the light directed toward it. For these purposes it is important to know the *entire* path taken by a beam of light.

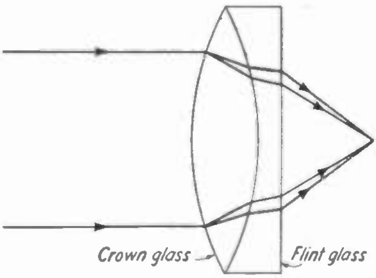


FIG. 26A. Correcting chromatic aberration.

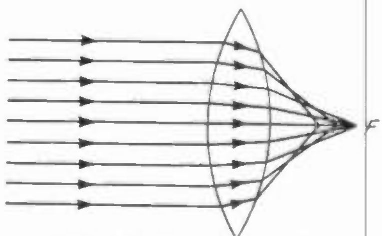


FIG. 26B. Spherical aberration.

Referring to Fig. *27A*, *MN* represents an object, such as the filament of a lamp, while *P* is one of the many specific point sources on this object. By geometry, tracing two rays from *P*, we can locate its image *P′*. All rays from *P* which pass through the lens will therefore pass through *P′*, neglecting spherical and chromatic aberration. The rays from *P* which pass through the lens form what is known as a cone of light (indicated by shaded area between points *1*, *P* and *2*), while the rays from the lens to *P′* form another cone of light, *1P′2*. Neglecting losses in the lens, all light fed into the cone at *P* is transmitted to *P′*. Notice that once the image

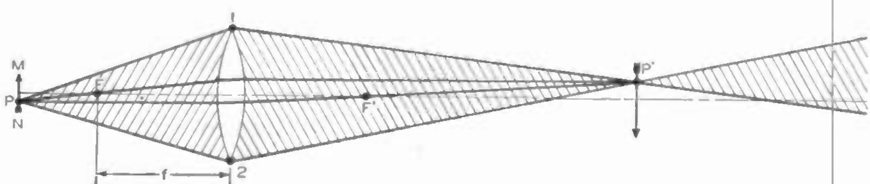


FIG. 27A. Shaded areas indicate cones of light which produce image P′ of point P.

P′ is located, lines drawn from the object and image to the extremities of the lens determine the boundaries of the cones of light.

Turning now to Fig. *27B*, points *M* and *N* are the extremities of the object (a lamp filament). Once the image is located, the entire light path may be found, as shown. Notice these facts, which are true of all lens systems producing a real image: *the cross-section area of the cone of light between the image and the lens is never larger and never smaller than the cross-sectional area of the image or the lens,* and *the cross-sectional area of the beam increases after leaving the image* (at the right of the image in Fig. *27B*). When the object is located between f and

2f, as shown in Fig. 27A, the image will be larger than the object; when the object distance is greater than 2f, the image will be smaller than the object but the rays will diverge rapidly from the image. In practical photoelectric applications, where light is to be focused over long distances, the object distance is generally less than 2f, giving a magnified image. The image is brought to a sharp focus near the desired position, and the position of the object is varied until the desired cross-sectional area of beam is obtained.

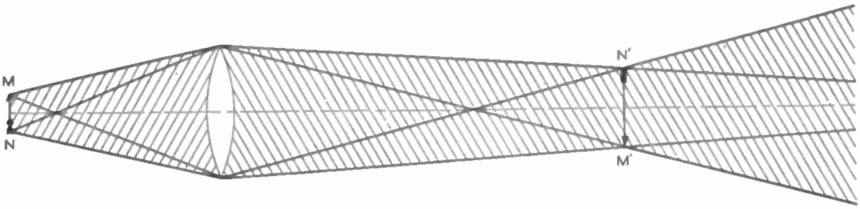


FIG. 27B. Shaded areas indicate beams of light which produce image *M'N'* of object *MN*.

REFLECTION LOSSES

Even though glass is ordinarily thought of as a perfect transmitter of light, actually about five per cent of the light falling on a polished glass surface at zero angle of incidence (perpendicular to the surface) is reflected back. This loss in light by reflection increases rapidly as the angle of incidence is increased; in the following table the percentages of reflection, given for various angles of incidence, can therefore be considered as losses. Notice that the loss increases slowly with the angle and becomes of appreciable importance only when the light beam is directed on the glass at an incident angle greater than about 70 degrees. Keep these reflection losses in mind when directing beams of light obliquely through glass, such as through the plate glass window of a store.

Angle of Incidence in Degrees...	0°	20°	40°	50°	60°	70°	80°	90°
Percentage of Reflected Light....	4.6%	4.7%	5.3%	6.5%	9.7%	18%	39%	100%

THE MANUFACTURE OF OPTICAL GLASS

The glass used for lenses and other optical apparatus is of high quality, made by fusing or melting together in a furnace various mixtures of special sand and certain alkaline chemicals, the proportions and nature of the materials being varied to get different light transmitting and refracting qualities. Various pigments and chemical ingredients are added to give special color transmission characteristics and special properties to the finished glass.

Fused Quartz. Quartz is used extensively in modern optical instruments; it is a clear sand and is found in crystal form in nature. You are already familiar with the crystal form of quartz as used in radio frequency oscillators to generate constant frequencies, but the quartz used for lenses and optical windows is known as fused quartz. The natural crystals of quartz sand are melted in a high-temperature furnace, then slowly cooled. Fused quartz is clear, transparent and has the property of being able to withstand great changes in temperature without cracking. Fused quartz is transparent for a wide band of light frequencies from the infra-red down through the visible and far into the ultra-violet; for this reason photoelectric cells are sometimes made with quartz windows in order to secure maximum response to invisible light rays.

POLARIZED LIGHT

Light, as you know, is a kind of wave motion, much like the waves which pass out along a very long cord when one end of the cord is fastened to the end of a vibrating tuning fork. Any point on the cord moves back and forth at *right angles* to the direction in which the wave

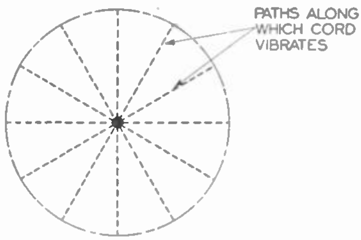


FIG. 28. Looking end-on at a length of cord having one end tied to a fixed object, and the other end tied to a vibrating and rotating tuning fork, you would see the pattern shown here by the dotted lines. Light rays vibrate in much the same way. The black dot in the center represents the cord at rest (when the tuning fork is stopped).

is moving, whereas with sound waves the vibrating particles (such as air molecules) move to and fro in the *same direction* as the *sound energy* is traveling.

Figure *28* represents a cross-section of such a cord in vibration when one end of the cord is attached to a small revolving disc, and the other end is tied to a fixed object. The cord oscillates back and forth, first along one diameter and then along another of a circle whose center is the "at-rest" position of the cord. If you were able to look at a ray of light end-on and could observe the paths of vibratory motion, you would see much the same pattern as that shown in Fig. *28*; light waves would be

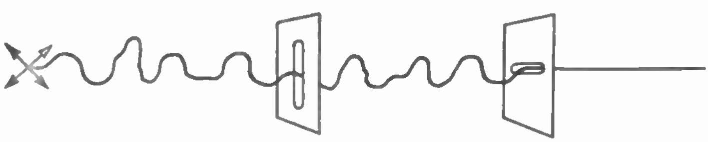


FIG. 29. Vibrating string analogy of the action of polarizing devices.

traveling directly away from you (in a direction perpendicular to the page) but the rays would be vibrating in all directions perpendicular to this motion (in the plane of the page as indicated by the dotted lines).

When a very long string is tied to a support and the free end moved *up and down* (as it would be moved if tied to a tuning fork), wave motion is produced along the string in the *vertical* plane. If the string is now shaken in a *horizontal* direction while it is still moving in a vertical plane, the wave motion will take place in many planes; in other words, the string will be vibrating in all directions, as indicated at the left in Fig. *29*. The insertion of a slotted card or diaphragm like that shown in Fig. *29* will remove all oscillations traveling along the string except those in the plane of the slot; the cord is thus made to vibrate in only one plane, and is said to be *plane polarized.* The addition of a second slotted diaphragm, with its slot at right angles to the first, will remove the remaining oscillatory motion.

Polarizing Crystals. Light, which vibrates in various planes in much the same manner as did the cord just described, may be polarized (made to vibrate in only one plane) by passing it through certain crystals, such as tourmaline, quartz and Rochelle salt crystals, all of which have the peculiar property, when cut in a special manner, of transmitting only that light which is vibrating in one particular plane. Proof that light can be polarized in this way is given by the fact that a second crystal, with its polarizing axis at right angles to that of the first, will cut off the light altogether. Light which has passed through a single crystal is said to be *plane polarized;* it is vibrating in only a single plane or direction.

When light is passed through two crystals or polarizing devices, the first device, which causes polarization, is called the *polarizer*, and the second device is called the *analyzer*.

Nicol Prisms. Crystals of tourmaline are not very efficient polarizers of light, and light passing through these crystals undergoes considerable loss in intensity. In television systems and in certain other services where economy of light is vital, another method of polarizing light rays has until

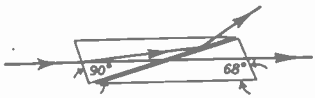


FIG. 30A. Cross-section of a Nicol prism, showing how the incident beam is split into two beams by refraction, one beam being reflected at the Canada balsam layer which separates the two sections of the prism, and the other beam being transmitted through this layer.

FIG. 30B. When two Nicol prisms are arranged like this, no light can pass through the combination. The polarized light coming out of the first prism is totally reflected by the second prism. If the second prism is rotated 90°, polarized light will pass through.

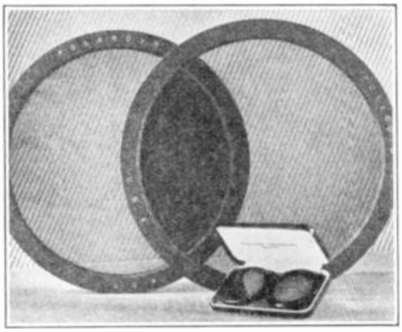
recently been widely used. This method involves the use of a *Nicol prism,* made from a crystal of Iceland Spar (a mineral) which has been cut along a diagonal in a particular manner, polished and recemented with Canada balsam (a transparent liquid cement).

The principle of operation of a Nicol prism is as follows: Light entering the prism is split into two beams, as indicated in Fig. *30A.* Because the prism material offers a different index of refraction to the two rays, the two rays strike the layer of Canada balsam at different angles of incidence and one ray is reflected, while the other is transmitted. The transmitted ray, which passes through the balsam layer, is found to be plane polarized; if a second Nicol prism is arranged in the manner shown in Fig. *30B,* the polarized ray will be totally reflected by the balsam layer of the second prism and light transmission through the system will be zero.

A New Polarizing Device. Although Nicol prisms are quite efficient as polarizers of light, they are not entirely practical for commercial television applications, principally because they are rare, expensive, cause loss in light and are not readily obtainable with large, clear apertures. There is now on the market, however, a very promising substitute for the Nicol prism, in the form of sheets of film which are easily mounted in any optical system. Perhaps the best known of these polarizing films is "Polaroid," made by depositing on a sheet of transparent celluloid or glass a solution consisting of certain chemical substances which have light polarizing properties. The layers deposited are in the form of large numbers of tiny crystals. While the optical properties of "Polaroid" are not quite as good as those of Iceland Spar (the material from which Nicol prisms are made), "Polaroid" sheets are available in sizes far exceeding the dimensions of the largest known Nicol prisms; experimental discs mounted in molded rims are shown in Fig. *31.**

THE KERR CELL ROTATES POLARIZED LIGHT

An English physicist named Kerr discovered that a dielectric material under an electric strain would rotate the plane of polarization of a beam of plane polarized light. The Kerr cell, which he developed, consists simply of two small metal plates suspended in a solution of carbon bisulphide or nitro benzine. This cell has been used in many sound recording and facsimile transmission systems, for when used in con-



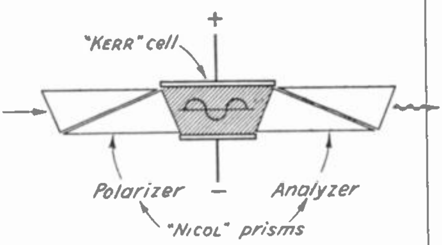


FIG. 32 (above). Complete Nicol prism-Kerr cell system as used in some television sets.

FIG. 31. When two discs of "Polaroid," new light polarizing material, are placed as shown here, the illuminated object in the background (a flat, metal-cutting file) can be seen through the individual discs but not where the discs overlap.

junction with a pair of Nicol prisms it makes a very efficient electrically controlled light valve.

The Kerr cell and Nicol prism system is now used extensively in mechanical television systems. Baird in Great Britain and Peck in this country use it in connection with a mirror wheel, while Priess, another American experimenter, uses it with a vibrating mirror.

The over-all efficiency of a system utilizing a Kerr cell is ordinarily not more than about 2%, making it necessary to use a very large light source in order to obtain a sufficiently bright image. On the other hand, the Kerr cell has very little electrical inertia, and consequently is capable of responding to high frequency electrical variations such as are encountered in television.

* Although of no practical importance, the fact that light can be partially polarized by reflecting it from a non-metallic surface is of experimental interest. Each non-metallic material has a certain angle of incidence, called the *polarizing angle*, at which polarization of the reflected beam is most complete; for glass this polarizing angle is 57 degrees. By using many panes of glass face to face in the polarizer and a large number of panes in the analyzer, polarization effects can be made more perfect.

A complete Kerr cell-Nicol prism system is shown in Fig. 32; if a television signal is applied to the plus and minus terminals (plates) of the cell, the plane of polarization of the light passing through the cell will be rotated by an amount which is directly proportional to the voltage of the applied signal. With the Nicol prisms arranged as shown (Polaroid discs can be used in place of these), conditions will be such that *increases* in signal voltage *reduce* the light transmitted by the analyzer; by rotating one prism 90°, increases in voltage can be made to increase the amount of light transmitted. A Kerr cell system as used in television serves only to modulate the light beam; a scanning disc must be used to re-form the image. If the light coming from the scanning disc is thrown on a screen, a television image in black and white will be obtained.

ELECTRONIC OPTICS

Introduction. In the cathode ray tube used in the electronic methods of television scanning and image reconstruction, and in the cathode ray oscillograph used in radio servicing, it is important that an intense, small diameter electron beam be directed on the fluorescent screen. To get enough electrons from the emitter, a large cathode surface must be used

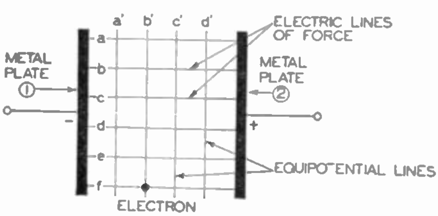


FIG. 33A. Cross-section view of two metal plates, charged with indicated polarity.

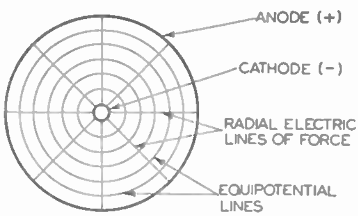


FIG. 33B. Cross-section view of a diode tube having cylindrical electrodes.

in the electron gun, but this naturally gives a beam of large cross-section, with electrons taking many paths besides those in the desired direction.

By making use of the electronic optics principle of electrostatic focusing, it is possible to bundle these emitted electrons into a small-diameter stream and make them form a small, bright spot on the screen. Only the cathode ray tube designer is interested in the actual shapes of the electrodes, in the arrangement of the electrodes and in the voltages applied to each electrode, but the serviceman who understands the problems of cathode ray tube design and knows how the desired effects are accomplished is in a better position to service, install and adjust cathode ray tube equipment.

Electronic optics also plays an important part in the design of regular grid-controlled tubes, and makes possible such special tubes as the beam amplifier tube and the impactor tube.

Basic Facts. The underlying principles of electronic optics are not difficult to understand. An electron is always attracted to a positively charged electrode; it is the path the electron takes in getting there which is quite important. Electric lines of force exist between any two differently charged bodies, such as between the emitter (source of electrons) and the anode of a cathode ray tube; it is along these lines of force that electrons travel. It is easier, however, to predict how an electron will move by referring to what are called *equipotential surfaces,* for these are simpler to locate in actual practice than electric lines of force, and electrons moving from one equipotential surface to another always behave in a definite known manner. The first electronic optics principle to be taken up is, then, the relation between electric lines of force and equipotential surfaces.

Figure *33A* represents a cross-sectional view of two parallel metallic surfaces, with surface *2* being positively charged with respect to surface *1* (which can be a cathode). Electrons are urged from *1* to *2* along lines *a, b, c,* etc., which represent electric lines of force. An electron moving from surface *1* to *2* starts from rest (zero speed) at surface *1*, gaining speed as it moves. All along the path it gains energy, because the energy of a moving body of constant mass increases with its speed. Other electrons starting from rest at various points on plate *1* gain speed at the same rate, so that all electrons moving between the plates possess the *same* energy *at any given distance* from plate *1*. We can indicate this on the drawing in Fig. *33A* by putting in lines *a′, b′, c′* and *d′*, drawn at *right angles* to the electric lines of force; these lines represent positions of

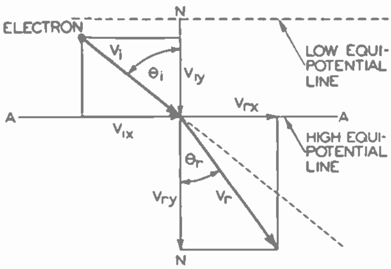


FIG. 34. This is what happens when a moving electron hits an equipotential line at an angle.

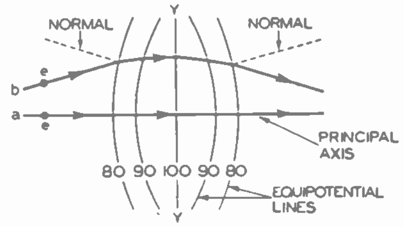


FIG. 35. This field of equipotential lines forms an electronic lens which bends electron rays.

equal potential or equal energy level, and are commonly called *equipotential lines or surfaces.* (Equipotential lines on a cross-sectional view actually represent equipotential surfaces, just as the heavy lines *1* and *2* in Fig. *33A* represent plates.)

Figure *33B* illustrated the electric lines of force (radial) and the equipotential lines (concentric) as you would find them in a simple electronic tube having a cylindrical cathode inside a cylindrical plate; although the drawing gives only one cross-section view of the tube, all other cross-sections are alike. Electrons going from the cathode to the anode will travel along the radial electric lines of force, and will therefore move at right angles to the equipotential lines shown.

When an electron moves from one equipotential surface to another having a *greater* potential, the velocity (speed) of the electron is increased. The opposite of this statement also holds true; if an electron moving at high speed happens to "coast" toward a surface of *lower* potential, its speed will be reduced.

Now let us see what happens when an electron having a definite velocity (definite speed and direction) meets an equipotential surface at some angle other than a right angle. Suppose that an electron starting from rest travels through various equipotential surfaces and arrives at one such surface with the speed and direction indicated by V_1 in Fig. *34*, the direction being such that the electron path makes the angle θ_1 with the normal to equipotential surface represented by line *AA*. The velocity of this electron can be divided into two parts: V_{1x}, the component *along* equipotential surface *AA*, and V_{1y}, the component along the normal *NN*. Note that the electron left a low potential surface; in moving through an equipotential surface of higher energy level, the electron is therefore speeded up. Component V_{1x} of the electron velocity is not affected, for it is directed along a surface of constant energy level; the resultant velocity component along the surface, V_{rx}, is therefore exactly the same as V_{1x}. The normal component of velocity, V_{1y}, is increased to the new value V_{ry} on passing through the equipotential surface, and the new direction and speed of the electron are represented by V_r. Notice that the electron path has been bent closer to the normal *NN*, making angle θ_r less than θ_1; if the electron had been traveling in the opposite direction, from a high to a low equipotential surface, all arrows in Fig. *34* would be reversed, and the electron path would be bent *away from* the normal to the surface. Thus an electron stream can be bent towards or away from the normal to an equipotential surface, just as a light ray can be bent towards or

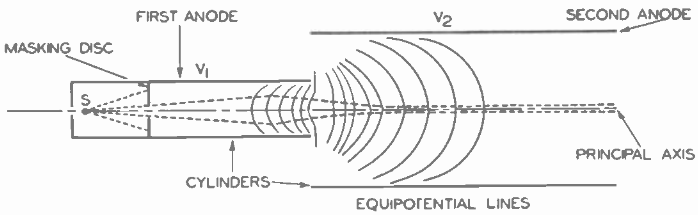


FIG. 36. Two cylinders of different diameters, charged with different voltages, form a converging electronic lens such as is used in an electron gun.

away from the surface which divides materials of different optical densities.

These facts about electrons and equipotential surfaces can be summarized as follows: *1*, An electron meeting an equipotential surface at right angles is not changed in direction, but is speeded up if it enters a zone of higher equipotential and slowed down if it enters a zone of lower equipotential; *2*, if an electron enters a *higher* equipotential surface at an angle, the electron path will be bent *towards* the normal; if the electron enters a *lower* equipotential surface at an angle, the electron path will be bent *away from* the normal.

Now let us consider the path of an electron entering an electrostatic field like that shown in Fig. *35*, which represents an *electronic lens*. The equipotential surfaces are assumed to be spherical in shape, making their cross-sections the arcs of circles, as shown. Electrons following path *a* meet each equipotential surface on a normal (at right angles) and hence their direction is not changed; the line through path *a* is known as the *principal axis* of this electronic optics system. An electron taking path *b*, however, will be hitting equipotential surfaces at various angles; now we must consider the potential (energy level) of each surface, indicated by the numbers in Fig. 35, in order to determine the electron path. The electron is entering surfaces of higher energy level up to the time it reaches YY, and is therefore bent towards the normal at each intersection; after passing through YY, however, the energy levels decrease in magnitude and the electron path is bent away from the normal to each surface at the point of intersection, as shown. Note that in each case the electron path has been bent *towards* the principal axis. This means that if a diverging cone of moving electrons originating at some point to the left of YY on the principal axis enters the lens, the electrons will all be progressively bent towards the principal axis, and will either meet at a point to the right of YY on the principal axis or will, if the electron source is at a definite point called the *focal point of the electronic lens,* emerge as a parallel beam of electrons. Thus we have a beam-controlling system much like the glass lens used in bending light; in the electronic lens the bending is continuous throughout the electric field which forms the lens (since there is an infinite number of equipotential lines at which bending can occur).

Electronic Lenses Used in Cathode Ray Tubes. It is comparatively simple to trace the path of an electron through an electric field produced by symmetrical electrodes when the positions of the equipotential sur-

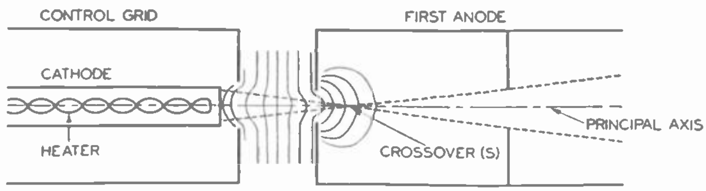


FIG. 37. An electronic lens here focuses electrons emitted by the cathode; the control grid or control electrode controls the number of electrons leaving the cathode.

faces are known. Expert mathematicians can calculate the positions of these surfaces by a long and tedious process, but only for simple electrode shapes. The usual and quite practical procedure involves making a large, accurately scaled model of the electrodes, immersing this model in a conducting liquid, and applying voltages to the electrodes. A test probe which is completely insulated except for a tiny metal ball point at its tip is connected to a vacuum tube voltmeter; this probe is then moved around in the liquid between the electrodes to search out points of equal potential. These points are plotted on a cross-section diagram of the electrodes and connected together by smooth curves to give the equipotential lines for that electrode arrangement.

The electronic lens shown in Fig. 35 can be approximately reproduced by using two open cylinders, one larger than the other, placed end to end as shown in Fig. 36, and applying a higher positive voltage to the larger cylinder than to the small one. The electronic lens formed by the equipotential surfaces near the junction of the two cylinders progressively bends the electron paths toward the principal axis. If point S is the focal point of the electronic lens, the final beam will be a bundle of electron rays parallel to the principal axis; if S is to the left of the focal point, the emerging beam will be coned or converged to a point. These effects can be attained by varying the ratio between the electrode voltages V_1 and V_2.

Electrons passing through an electronic lens are subjected to the effects of chromatic and spherical aberration, just as in the case of glass lenses. Chromatic aberration in an electrostatic lens is due to the different velocities of the electrons in the stream, just as chromatic aberration in a glass lens occurs because light of different colors (different wavelengths) travels through the lens at different velocities. In electronic optics, the effects of chromatic aberration are reduced by making the electrons leave source S with as nearly the same speed as possible. Spherical aberration results because the shapes of the equipotential surfaces depart from the true spherical form in actual practice; this defect is more apparent at points farther away from the principal axis, and is quite evident in Fig. *36*. Spherical aberration in an electronic lens is corrected by making the cone of electrons leaving S as small as possible and by placing a mask near S, to block electrons which are too far away from the principal axis.

A cathode of large area must be used in a cathode ray tube in order to secure the necessary number of electrons; these electrons must then be focused to a point from which they will emerge as a small cone, as at S in Fig. *36*. A cylindrical electrode surrounding the cathode, with a masking disc located as shown in Fig. *37*, has by theory and experiment been

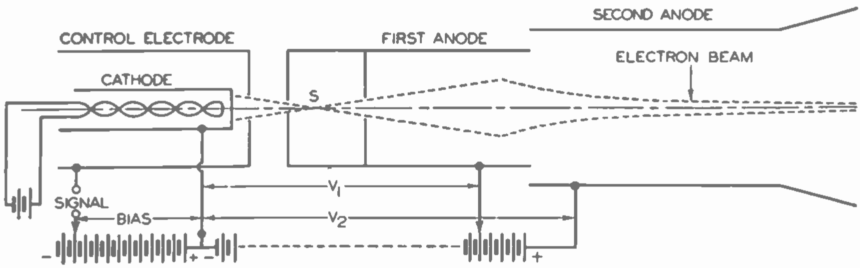


FIG. 38. Cross-section view of a complete electron gun, with simplified schematic diagram of power supply circuits.

shown to give the desired focusing effect; this electrode, known as the *control electrode*, is placed at a negative potential (bias) with respect to the cathode. The resulting electrical field produces equipotential lines of the shape shown, which progressively bend the emitted electrons into a cone-shaped beam which has a minimum diameter at point S, sometimes called the *cross-over point*. The electrons continue on to the right of S in a gradually diverging beam; part of this beam is blocked by the second masking disc, while the remainder passes into the second cylinder, which is like that shown at the left in Fig. *36*.

The control electrode provides a means of varying the number of electrons which leave the cathode; the more negative the potential on this electrode, the fewer electrons there will be in the beam. Large negative potentials result in greater chromatic aberration, however, for electrons emitted near the edges of the cathode will then be slowed up more by the control grid than the electrons emitted from the center of the cathode. With small values of negative bias, the electrical field is positive near the greater part of the cathode, and all electrons enter the beam at practically the same speed. The effects of chromatic aberration are further reduced by the masks at the end of the control electrode and in the first anode. Since the number of electrons reaching S can be varied by changing the potential on the control electrode, it is customary to apply the beam-modulating voltage (such as a television signal) to this electrode.

The typical electron gun for a cathode ray tube, shown in Fig. *38*, contains the electronic lens systems given in Figs. *36* and *37*. The signal voltage applied to the control electrode determines the intensity of the electron beam and therefore the brightness of the spot formed on the fluorescent screen, while the ratio of voltages V_2 and V_1 controls the focusing and therefore the diameter of the spot on the screen. Deflecting plates or magnetic fields located to the right of the second anode are used to control the position of the spot on the screen; since these beam-deflection methods are already familiar to you, they need not be discussed here.

TEST QUESTIONS

Be sure to number your Answer Sheet with the *number* appearing on the front cover underneath the title of this text.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your Course, and you will receive the best possible lesson service.

1. In a plane mirror, where does the image appear to exist?
2. Name the two kinds of spherical mirrors.
3. What type of mirror is used to concentrate light from one *point* to another *point?*
4. In which direction will a ray of light be bent when sent through a prism?
5. Name the six kinds of spherical lenses.
6. Can a double-concave (diverging) lens give a real image when used alone?
7. If you directed a beam of light obliquely through the plate glass window of a store, would there be any loss in light?
8. What is meant by plane polarized light?
9. What is the purpose of the Kerr cell system in a television system?
10. How will the path of electrons which are entering a *higher* equipotential surface be bent?

1. Behind the mirror. (It will be virtual, erect and as far behind the mirror as the object is in front of the mirror.)

2. Convex and concave spherical mirrors.

3. An elliptical mirror.

4. It will be bent toward the thicker part of the prism.

5. Double-convex, plano-convex, concavo-convex, double-concave, plano-concave, and convexo-concave.

6. No.

7. Yes.

8. Light vibrating in only a single plane or direction.

9. To modulate the light beam.

10. Towards the normal.

USES FOR OPTICS IN ELECTRONICS AND TELEVISION

58RH-1

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

PUTTING PRINCIPLES TO WORK

You are now familiar with the important fundamental principles of geometric optics—but these principles are of little use unless you know how to put them to work. This lesson, therefore, gives you examples of uses for the fundamentals of geometric optics in actual photoelectric control and television systems.

Although it is clearly impossible to cover each of the thousands of possible applications of optics in these fields, enough of them have been taken up to give you the knowledge needed to handle any ordinary job which may be encountered.

Heretofore you have studied optical systems in terms of mirrors and lenses; now you will take up ways of making light beams travel in certain definite ways for specific purposes, and learn how to design the systems of mirrors and lenses which are required.

J. E. Smith.

NATIONAL RADIO INSTITUTE

WASHINGTON, D. C.

1942 Edition

A LESSON TEXT OF THE N. R. I. COURSE
WHICH TRAINS YOU TO BECOME A
RADIOTRICIAN & TELETRICIAN
(REGISTERED U. S. PATENT OFFICE) (REGISTERED U. S. PATENT OFFICE)

NCP17C642 Printed in U. S. A.

Uses for Optics in Electronics

INTRODUCTION

SINCE optical systems involving the transmission and control of light play an important part in electronic control and television apparatus, it is quite essential that those dealing with this equipment should thoroughly understand the problems involved in designing, installing, repairing and maintaining the different types of optical systems which may be encountered. Basic optical arrangements will be stressed in this lesson, but details of specific optical apparatus will be given when of value in illustrating important principles. The optical requirements for photoelectric control, an important branch of electronics, will be considered first.

SECURING A PARALLEL BEAM OF LIGHT

In the commonest type of photoelectric control system, where interruption of a beam of light by a moving object actuates a control relay, an optical system furnishing a parallel beam of light is widely used. From your study of geometric optics, you know that a point source of light located at the focal point of a parabolic mirror or a thin convex lens will *theoretically* give the desired parallel beam. In general, the light-sensitive cell used in a photoelectric control system is concerned only with the color quality and the total amount of light directed on it; the formation of an accurate image on the cathode of the cell is therefore unimportant.

Immediately, in considering the practical optical systems available for producing a parallel beam, a problem is encountered: Actual light sources, such as the incandescent lamps used in automobile headlights, are not pure point sources of light; their filaments have a definite size, and light rays emerging from various points of the source will either diverge or converge, depending upon the position of each point with relation to the focusing mirror or lens. The crater of a high intensity electric arc is about the closest practical approach to a high intensity point source of light it is possible to produce; with this light source, a beam which diverges from a perfectly parallel characteristic by only a few minutes (a small fraction of a degree) can be secured. This arc light is obviously impractical for ordinary photoelectric control systems, but it is possible to secure sufficiently parallel beam conditions for ordinary use with incandescent lamp sources.

Consider the case illustrated in Fig. *1*. The object or source of light is here a headlight bulb or projection lamp whose filament has a definite size and is therefore not a true point source of light. Assuming that the center of the filament is placed at the focal point of the lens, some idea of the nature of the beam transmitted by the lens can be secured by tracing the cones of light formed by points located at the top, at the center and at the bottom of the filament. As you can see, light from point *F* is transmitted in the form of a perfectly parallel beam, while light from points *A* and *B*, at the extreme limits of the filament, emerges from the lens in the form of beams which diverge slightly from each other and from the parallel beam.

Those points on the filament which are ahead of or behind the plane of the principal focus will likewise produce deviations from a true parallel beam; point sources between the focal point and the lens will give a diverging beam, while point sources behind the focal point will produce

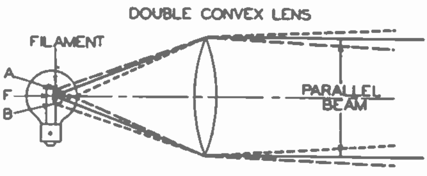


FIG. 1. Using a lens and practical light source (an automobile headlight bulb) to produce a nearly parallel beam of light.

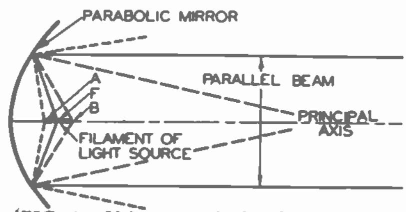


FIG. 2. Using a parabolic mirror and practical light source to produce a nearly parallel beam for television or electronic control apparatus.

converging beams which diverge after passing through a cross-over point. The final cone of light transmitted by the lens, therefore, consists of an infinite number of individual cones, each formed by a point source on the filament of the lamp. Thus, if an automobile headlight lamp placed near the focal point of a double convex lens gives a diverging beam (the light spreads out after leaving the lens), we can make the beam converge by moving the lamp slightly *away from the lens.* The best lamp position for a desired size of beam can readily be determined by experiment.

Parabolic Mirrors. The principles just discussed apply in much the same way to parabolic mirrors used in producing parallel beams. In Fig. 2, light rays from *F*, the focal point of the parabolic mirror, are reflected from all parts of the mirror's surface perfectly parallel to each other, forming a parallel beam. An actual filament, however, has a definite size, as shown, and rays from its extremities, *A* and *B*, will not emerge parallel to the principal axis. For example, rays from points between the focus and the mirror, such as from point *A*, will be reflected in a diverging cone, while rays on the other side of the focal point, at point *B*, will be reflected as a converging cone which diverges after passing through the cross-over point.

In Fig. 2, the three point sources considered are on the principal axis of the mirror; just as in the case of a lens, deviations from a parallel reflected beam are obtained for all points on the filament which do not lie on the principal axis. Again in the practical case it is necessary to adjust the position of the light source slightly, to secure a beam which most nearly meets the requirements of a particular job. For example, the adjusting of automobile headlights to prevent glare consists simply of moving the light source away from the focal point (away from the mirror) until a position is found where there is a minimum amount of diverging rays.

Elliptical Mirrors. Even in the ordinary parabolic reflector a great deal of the light emitted by the lamp is lost in the form of diverging rays which travel out without being reflected from the sides of the mirror.

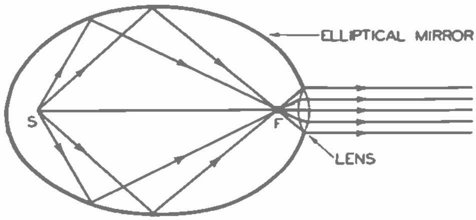


FIG. 3. Producing a nearly parallel beam with an elliptical mirror and a double-convex lens. A perfect point source of light is assumed here; an actual light source would produce rays deviating from a parallel beam.

Recognizing this defect, engineers have in many cases adopted for automobile headlights the *elliptical mirror and lens* arrangement shown in Fig. *3*, which produces a parallel beam of higher intensity than can be secured with a lens or with a parabolic mirror. An elliptical mirror, as you know, has two focal points, at *S* and at *F* in Fig. *3*, and all light coming from one focal point will be reflected by the mirror to pass through the other focal point. If an automobile headlight bulb is placed at *S*, practically all of the emitted rays of light will be reflected by the mirror to pass through the other focal point *F*. Now, if the lens is so chosen that its focal point is at point *F*, this point will act as a secondary source of light from which the lens can produce a practically parallel beam. Adjusting the position of the lamp slightly gives any desired form of beam.

Elliptical mirrors, where available, can be very readily adapted to use in television and electronic control systems where a high efficiency parallel beam is required. These mirrors are widely used as light sources in the scanning of movie films for television transmission purposes; the light source is placed at one focus of the mirror and the movie film is located sufficiently close to the other focus to give intensely bright illumination of one frame of the film at a time, or a lens is used to focus a parallel beam on the film.

CONTROL OF LIGHT BEAM BY FOCUSING

For transmission of light over long paths, it is obvious that the parallel beam optical system is less efficient than a system which focuses the light into a converging cone which can be totally intercepted by the light-sensitive cell. Suppose we have a problem like that illustrated in Fig. *4*, where a photovoltaic cell having an effective light-sensitive surface 2 inches in diameter is to be located 30 feet from the lens of the light source, and the incandescent lamp used as a light source has a filament whose height (or diameter) is 1/16 inch. The problem is to determine the proper values for P and f in this system. We know definitely that the object distance P divided by the image distance Q will

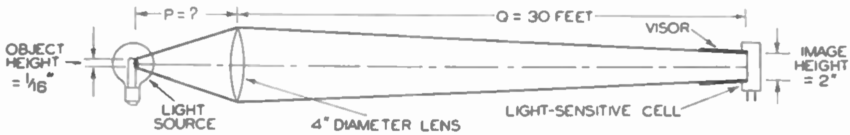


FIG. 4. System using a 4" diameter double-convex lens for projecting a light beam over a 30-foot path to a 2" diameter light-sensitive cell.

always be equal to the object height (1/16") divided by the image height (2"). By simple arithmetic, then, $P \div 30$ is equal to $1/16'' \div 2''$ and P is equal to about .94 foot. Note that distances are here given in feet and height in inches; this is quite all right as long as both distances are in the same units and both heights are in similar units. Knowing that P is .94 foot and Q is 30 feet, the focal length required for the lens can be determined from the formula $1/P + 1/Q = 1/f$. Placing known values in this formula, we have $1/.94 + 1/30 = 1/f$. This gives for f a value of about .91 foot, or 11 inches; a lens having about this focal length would therefore be selected for this particular job.

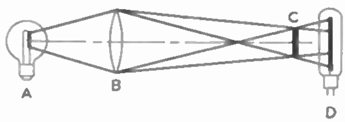
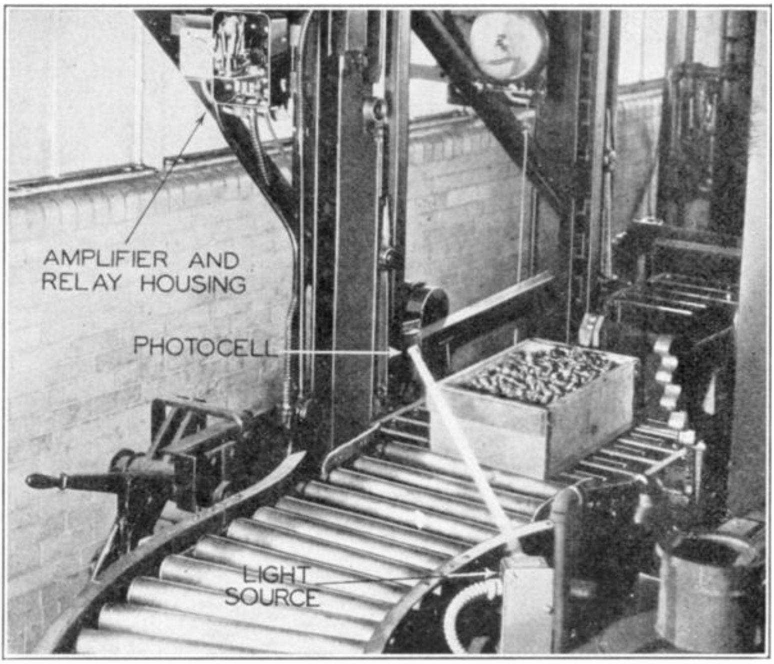


FIG. 5A. System for coning light to a definite area at C. Photocell D intercepts all of the light which passes through C, the cross-over.

Any diameter of lens may be used in this system, provided that it has a 11 inch focal length, but remember that the larger the lens the more light it will intercept and concentrate into the transmitted conical beam. Increasing the diameter of the lens without changing the focal length gives more light without affecting the image size. Ordinarily a visor is placed over the light-sensitive cell, as shown in Fig. *4*, to keep out undesirable light from other sources. Incidentally, the image height in this example is equal to the diameter of the beam at the light-sensitive cell. Further study of this example will show that for image distances greater than about 30 feet, the object distance P will practically be equal to the focal length of the lens, making the focal length for a given image size and image distance dependent only upon the size of the object (lamp filament).

HIGH-INTENSITY, SMALL-SIZE LIGHT BEAMS

In some types of photoelectric control systems a very small object or device passing through a part or all of the light beam must make



Courtesy General Electric Co

In this representative industrial photoelectric control system the light source, mounted behind a focusing lens, directs a high-intensity parallel beam upon the photocell. Flexible BX cable protects the wires which connect the photocell housing to the amplifier and relay housing. Interruption of the beam of light by a box moving along the conveyor system serves to give the desired control of the conveyor machinery.

large changes in the transmitted light; for example, the movement of beans being sorted, the expansion of a column of mercury in a thermometer or the swinging of a meter pointer over a small hole in the meter scale must produce sufficient change in the light falling on the light-sensitive cell to give the desired control. The required optical system is shown in Fig. *5A;* you will note that the part to the left of cross-over *C* is identical with the optical system of Fig. *4*.

Lens *B* in Fig. *5A* concentrates the light from source *A* into a converging beam whose minimum diameter is at *C*, the position of the controlling shutter or gap. Light diverges on the other side of this opening until it reaches photocell *D*, which intercepts all of the emerging cone of light. Calculations for this optical system are identical with those given in the preceding example, but if *C* is to be small in size, the object and image distances must be very nearly alike.

Curved mirrors can, of course, be used in much the same way as lenses to produce parallel beams and to cone light in any optical system; the methods of calculating the various distances and the image height are the same as for lenses. Being considerably lower in cost, however, lenses are preferable for most practical applications.

Right—Photoelectric light source suitable for projecting a light beam to a light-sensitive cell located up to 15 feet away. Adjustable lens tube contains 1⅛" diameter, 3" focal length lens. The beam produced is very nearly parallel.

Left — This mirror, designed especially for photoelectric work, is mounted in a sturdy cast aluminum housing which can be fastened rigidly to a wall or post. Two screws with lock nuts control angle of mirror, permitting fine adjustments.

Courtesy G-M Labs. Inc.

PRODUCING RIBBONS OF LIGHT

In many industrial inspection processes, such as the testing of the edges of razor blades or the checking of the thickness of long, thin objects, a narrow slit or ribbon of light must be produced. A parallel beam could be directed through a slotted mask to block unwanted rays, but this would be a great waste of light energy. Another possible solution of the problem is placing a point source of light slightly beyond the focus of a cylindrical lens which will concentrate the light to a sharp cross-over *line;* the disadvantage here is that light will be strongest in the center of the line and weakest at the ends. A practical method for producing a ribbon of light involves using a long flat ribbon filament lamp placed with the filament parallel to the straight side of a cylindrical lens. Adjust the distance between filament and lens so the emerging wedge-shaped beam will focus to a line at the desired position. Even greater efficiency can be obtained by backing up the filament with a cylindrical mirror which will reflect light back to the filament.

COLLECTING LIGHT

If the beam of light at the location of the light-sensitive cell has a cross-section area which is much greater than the area of the cathode of the cell, it is obvious that there will be considerable loss in useful light. To avoid this, a light-collecting lens can be mounted close to the light-sensitive cell and used to condense the incident light into a beam of smaller cross-section area; the cathode of the cell is then located at a point where it intercepts all of the light in the new beam.

When the cone of light diverges rapidly after passing through its cross-over point, as in Fig. *5B*, and mechanical limitations prevent placing the photocell close enough to the cross-over point so it can intercept the entire beam, a light-collecting lens must be used. A simple graphical procedure is used to find the correct focal length of lens for a particular system. The distance *P* (Fig. *5B*) will always be known (obviously you want to place the light-collecting lens as close as possible to *C*, so a reasonable diameter of lens will intercept the greatest amount of light). The diameter of the lens is generally fixed, and the effective diameter of the photocell cathode will likewise be fixed, both

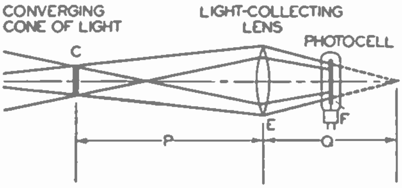


FIG. 5B. Use of a double-convex lens to concentrate a diverging beam on a photocell. The focal length required for the lens can be determined with the aid of this diagram.

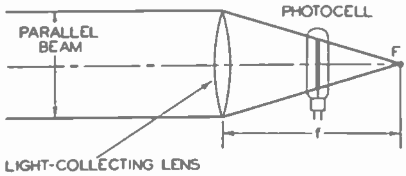


FIG. 5C. Graphical method of determining the focal length of a light-collecting lens when the source produces a parallel beam. If all of the light in the beam is to fall on the photocell, the minimum dimension of the cathode (usually the width) must be used.

depending upon economical limitations as to cost. The distance between the light-collecting lens and the photocell will be determined by the size of the housing used for these; this distance is therefore ascertained beforehand.

First, then, lay out the lens diameter, as shown, at the known distance *P* from *C*, and draw the photocell at its required distance from the lens. Now draw lines through the extremities of *E* and *F;* the intersection of these lines determines *Q*, the distance which the image of *C* must be from the lens. Knowing *P* and *Q*, the focal length can now be determined with the lens formula or the Easy Calculating Chart for lenses (given on page 15).

When light reaches the light-collecting lens in a parallel beam, a slightly different graphical procedure, illustrated in Fig. *5C*, is used. Photocell and light-collecting lines are drawn to scale as before, but now the lines drawn through the extremities of these parts intersect at the focal point, and the focal length can be measured directly from the drawing.

Practically all photoelectric control units which are designed to operate over distances greater than 30 feet contain light-collecting lenses; as a rule these lenses are built into the unit which houses the photocell and associated equipment.

CHANGING THE DIRECTION OF A LIGHT BEAM

Silvered glass mirrors or polished flat metal surfaces are generally used when it is necessary to change the direction of a beam of light; high cost prohibits the use of prisms for practical industrial applications. In a plane mirror the converging, diverging or parallel characteristic of a beam striking a mirror is not changed; this means that a plane mirror may be located anywhere in a beam as long as the mirror intercepts all of the light. In the interests of economy, however, the mirror is generally placed at a point where the beam is of small cross-section area, to keep down the size of the mirror.

You know that various substances differ greatly in reflecting power; sheets of metallic silver reflect light much better than do sheets of aluminum. It is also true that the amount of light reflected by a substance depends upon the color of the light; the table below gives the per cent of incident light which is reflected from different materials at normal incidence for *different colors* of incident light.

Color of Light	*Wave Length*	*Per Cent Reflection*			
		*Silver**	*Monel Metal*	*Stellite*	*Zinc*
Deep Blue	0.45 microns	88.0	56.5	63.5	54.0
Yellow Green	0.55 microns	91.5	59.0	68.3	56.0
Orange	0.60 microns	92.7	60.2	70.1	57.3
Light Red	0.65 microns	93.5	61.8	71.0	60.0
Deep Red	0.70 microns	94.1	63.7	71.8	61.0

*On thin plate glass.

The selection of the best material for a particular mirror will depend upon the nature of the job and atmospheric conditions existing at the location of the mirror. For example, silvered mirrors should not be used in locations where acid fumes or smoke exists unless the silvered surfaces are well protected. In these cases it is best to use for the mirror a material which will resist the type of acid present; the intensity of the light source must then be increased sufficiently to offset the reflection losses at the mirror.

Where the mirror or any other part of the optical system is likely to suffer mechanical vibration, the mirror used should be considerably larger than the area of the cone of light at the mirror location. Remember that vibrations shift the final beam reflected from a mirror through twice the angle of mirror shift.

SECURING EQUAL-INTENSITY LIGHT BEAMS

In certain photoelectric applications it is necessary to secure two identical beams of light from a common source; the method of solving this problem is shown in Fig. *6*. Source *A* is located equidistant between two double convex lenses, *B* and *B'*. Plane mirrors *C* and *C'* make the two beams of light travel parallel to each other, while converging lenses *D* and *D'* condense the beams onto the light-sensitive cells *E* and *E'*.

Arrangements like this are widely used for matching the transparency, opacity, or color of a material or solution.

COLOR FILTERS

In the automatic sorting of objects as to color or shade and in many other photoelectric applications, the color of the light beam is very important. An ordinary incandescent lamp supplies all wavelengths of light except ultra-violet (this color can be secured by using quartz or Corex [a trade-name for a special glass] envelopes for the lamps). With light sources capable of supplying all colors of light, the problems remaining therefore involve the color response of the light-sensitive cell and the types of glass filters to block out or absorb undesirable colors. It is obviously useless to filter out all but the invisible infra-red light and then use a light-sensitive cell which has little or no response in this region of the light spectrum. Where a beam of light is to have a particular color, it is necessary that the source provide that color, the light-sensitive cell respond to that color, and the filter allow transmission of that color. The common caesium cells have a maximum response in the longer wavelength regions, such as yellow, red and infra-red, while selenium-on-iron photovoltaic cells have a maximum response in the yellow-green region just as has the human eye.

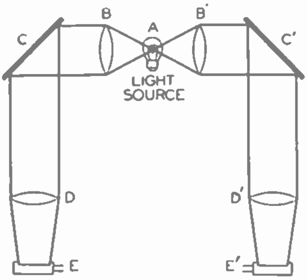


FIG. 6. Securing two parallel beams of light from one source, with the aid of lenses and mirrors. With this arrangement, the two light-sensitive cells, E and E', can be placed side by side.

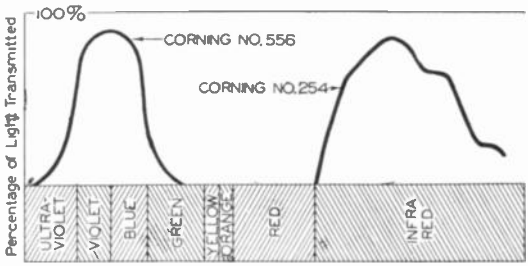


FIG. 7. Light transmission characteristics of two kinds of filter glass made by the Corning Glass Works. No. 556 transmits blue, violet and some green and ultra-violet, while No. 254 transmits only infra-red or heat rays. These curves are for 1-millimeter thick panes of glass; the thicker the glass, the lower is the percentage of light transmitted. Two or more filters can be used together to give combination filtering characteristics.

In order to filter light successfully, the optical transmission properties of the substances being considered for filters must be known. Glass filters which have almost any desired optical transmission characteristics are now commercially available; in selecting a filter for a particular job and photoelectric cell, then, the glass filter selected should transmit the desired color of light while absorbing any undesired colors, and the photocell must have an appreciable response to the color of light transmitted. Transmission characteristics of two types of filters are given in Fig. 7; curves like these are supplied by glass manufacturers for each type of filter offered.

Photoelectric equipment is today capable of sorting objects steadily and automatically into many different shades. For example, cigars are being sorted into thirty or more shades of brown by using batteries of photocells which can detect slight differences in the amounts of light reflected by different cigars.

THE LENS TEST BENCH

After the design of an optical system has been completed and all necessary parts secured, it is always best to assemble the system temporarily and make final tests before mounting the parts permanently. Most lens systems are worked out on the basis of point sources of light, thin lenses and low optical losses, whereas practical set-ups may give quite different results. The practical man, therefore, sets up a sort of breadboard assembly of his lenses, making adjustments as required until the correct positions for each part have been determined. Preliminary

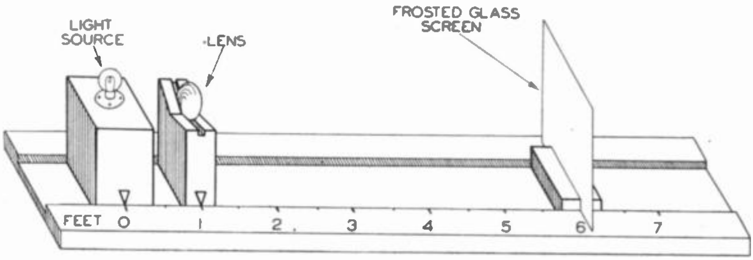


FIG. 8. Practical optical systems are usually tested on a lens bench similar to this before being mounted permanently in photoelectric or television apparatus.

tests on mirrors and lenses can be most easily made on a simple optical bench consisting of a long board having a yardstick or a scale of inches along one side. The optical devices can be mounted temporarily on upright blocks of wood which are notched at the top, and which slide in a groove in the board, as illustrated in Fig. *8*. The source of light and a white screen are likewise mounted on supports which can be moved along the bench. Light source, lenses and screen are slid back and forth along the bench until the best positions are found for the desired results. It is best to use the bench in a dark or semi-dark room, to permit a study of the light paths. The outlines of the different beams can be seen more clearly if smoke (such as tobacco smoke) is blown across the light paths.

Uses for Optics in Television

As far as the optical system is concerned, the lenses used in modern television cameras (such as the iconoscope and the kinescope) are exactly the same as the lenses used in high-grade cameras, and are therefore corrected for both spherical and chromatic aberrations. In each case the lenses form a sharp optical image on a surface which is sensitive to light.

THE CAMERA

The ordinary camera is perhaps one of the best known examples of the use of lenses. One or more convex lenses produce in an inverted position on the sensitized film a small, real image of the object or scene being photographed. In focusing a camera, the position of the lens is adjusted until the desired sharp image is formed on the film. For distant objects, the film should be located at the focal point of the lens, but should be beyond the focal point for objects relatively near to the camera. In inexpensive cameras, such as box cameras, the distance between the lens and the film is fixed at a value about half-way between that required for very close and for distant objects.

The focal length of the lens used in a camera is determined by the size of the picture desired on the film and by the minimum distance from the camera at which objects are to be photographed. If a lens having a short focal length (called a *wide angle lens*) is used, the image on the film will be small but a wide field of view will be covered. A

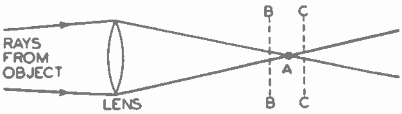


FIG. 9A. With the camera lens focused to produce an image on a screen placed at point A, a satisfactory image (as far as focusing is concerned) is obtained with the screen at any position between the two dotted lines.

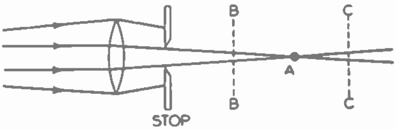


FIG. 9B. When a stop is used to cut down the effective area of a camera lens, the decreased angle of the image-forming rays permits a wider range of screen (film) positions for a given deviation from perfect focusing. Film may be anywhere between dotted lines BB and CC.

longer focal length lens produces a larger image but with a smaller field of view.

The use of a single lens having a short focal length results in a distortion of the perspective of the picture, producing the peculiar effect of enlarging objects which are close to the camera and diminishing the size of objects farther in the background. In other words, the relative sizes of near and distant objects appear distorted on the film. To overcome this to some extent, the camera lens may be *stopped down* by reducing its effective area with a diaphragm, as shown in Figs. *9A* and *B;* this gives a greater *depth of focus* (a greater distance between the nearest and farthest objects which are in satisfactory focus on the film). With the lens stopped down, errors in focusing have less effect upon the sharpness of the image, but of course considerable loss in light is encountered.

Spherical aberration, if found to be excessive in a lens, can be reduced by stopping down the lens. By using two lenses and placing the stop or mask between them, spherical aberration is kept at a minimum; this is the construction employed in all better quality cameras.

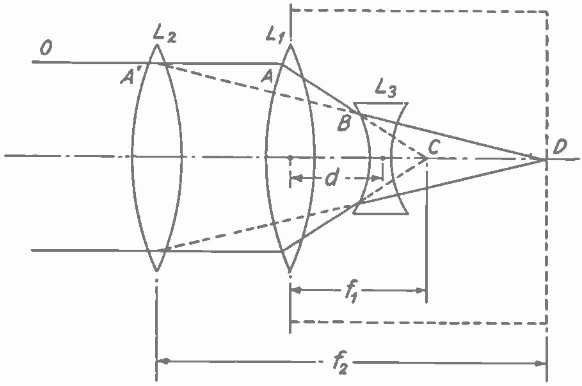
When two identical thin convex lenses are placed close together, their combined focal length is only half that of a single lens; such a combination is called a doublet, and is usually mounted inside a metallic tube referred to as the *lens barrel.*

Camera lenses are rated not only as to focal length but also by their ability to gather light, the latter characteristic being called the *speed* of the lens. The rating for a particular lens is obtained by dividing the focal length of the lens or lens combination by the diameter of the lens. For example, a 1-inch diameter lens having a focal length of 8 inches would have a speed of 8, and the rating would be written as *f8*. A lens ½ inch in diameter with a focal length of 4 inches would have the same rating; the two lenses just described would form images which differ in size (and usually in quality) but which are alike in intensity of illumination.

FIG. 10. This diagram illustrates how a telephoto lens combination made up of double-convex lens L_1 and double-concave lens L_3 gives the equivalent focal length of an imaginary lens at L_2. The formula for determining the equivalent focal length f_2 of a combination of any two lenses such as this is:

$$\frac{1}{f_2} = \frac{1}{f_1} + \frac{1}{f_3} - \frac{d}{f_1 \times f_3}$$

where f_2 = equivalent focal length.
f_1 = focal length of L_1.
f_3 = focal length of L_3.
d = distance between L_1 and L_3.



Two lenses are sometimes mounted in such a way that the difference between their optical centers can be varied. For two double convex lenses, the focal length of the combination increases as the distance between the lenses is increased. A lens combination of this type is sometimes desirable in that it gives a variable focal length. Double lenses are further controlled as to speed by using a variable iris diaphragm between the two lenses or between the lenses and the object. Decreasing the iris opening decreases the lens speed and increases the depth of focus.

THE TELEPHOTO LENS

It is sometimes difficult or even impossible, with the cameras used in television and photography work, to get close enough to the object to use an ordinary camera lens and still get a sufficiently large image. Special double lens systems have been designed for "long shots"; these lenses, known as *telephoto lenses,* consist of a combination of a double convex lens of normal focal length and a double concave lens which together give a lens doublet of long focal length, with the apparent position of the doublet much closer to the object than it actually is. Thus the image on the light-sensitive film is made large without increasing the length of the camera.

The principle of the telephoto lens can be understood by studying Fig. *10* carefully. Lenses L_1 and L_3 form the telephoto lens doublet which fits inside the camera housing (shown by dotted lines) and gives the same results as a single imaginary lens L_2 located some distance in front of the camera. When a ray of light from a distant object passes through L_1, it will be bent to pass through the focal point of this lens, C, along the path O - A - B - C. Double concave lens L_3 is placed between C and lens L_1, however, and bends the rays outward to intersect the principal axis at point D. Now, by projecting the rays backward from D until they intersect the direct rays from the object, the position of imaginary lens L_2, whose focal length is f_2, is determined.

A very long camera box would be required if only a single lens of focal length f_2 were used; a telephoto lens therefore provides the advantage of long focal length in ordinary cameras. Television cameras designed for outdoor work are usually built with several telephoto lenses

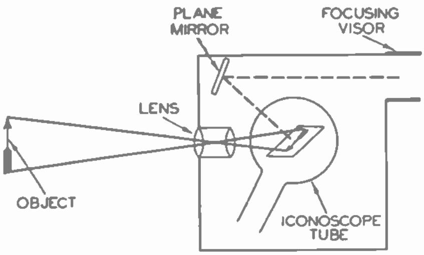


FIG. 11. Simplified diagram of the optical system of a modern television camera. In some television cameras a separate lens system is used for focusing instead of the plane mirror.

arranged on a turret so lenses can be changed instantly by rotating the turret.

Focusing a Television Camera. A cross-section view showing the arrangement of the essential parts in a simple television camera is given in Fig. *11.* Notice how a plane mirror is used to allow the operator to see the image being formed on the light-sensitive screen of the iconoscope; with the image always visible, the operator can adjust the position of the lens combination to keep the object in focus at all times.

INTRODUCTION TO MECHANICAL TELEVISION

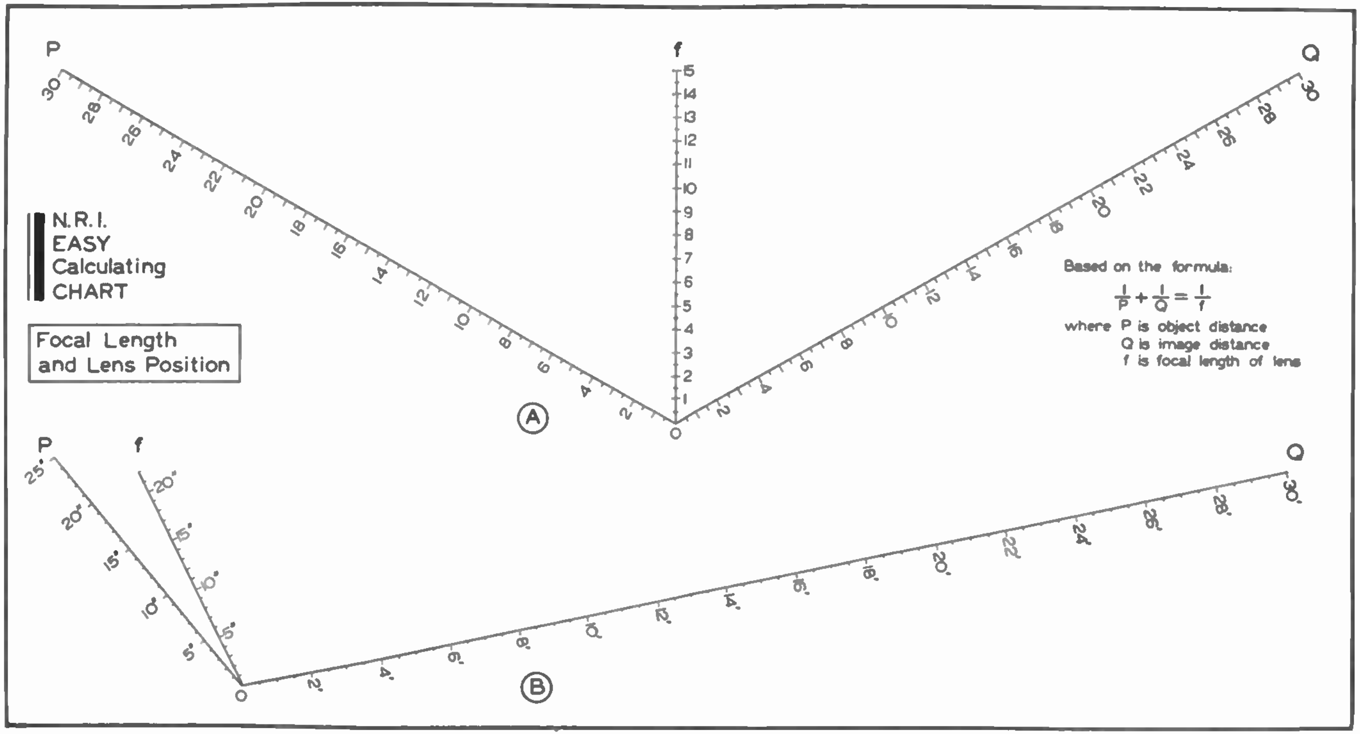
Television originated as a mechanical system of scanning the object and reconstructing the image. Although a great many experts are today forecasting the complete adoption of electronic television methods, there is an equally well-informed group of scientists which feels that mechanical systems, at least at the receiving points, are better suited for the general needs of the public. This latter group points out that a mechanical system will give large and bright images, whereas the image on a cathode ray tube in the electronic system is limited to the size of the tube, which in turn is limited by factors of economy and convenience. The sponsors of electronic television methods claim that large pictures can be obtained by projecting onto a screen the image formed by a small cathode ray tube, but such a system requires that there be an intensely bright image on the screen of the tube, and involves the use of an expensive projecting lens. Any study of television would, therefore, be incomplete without a serious consideration of the various mechanical television schemes used in the past and now under development. In this text only those systems which help illustrate the application of optics to television will be considered.

Basic Principles of Scanning and Image Reconstruction in Mechanical Television Systems. There are two fundamental methods of scanning an object; one involves flooding the object with light and using a mechanical-optical system which will allow a photoelectric cell to view only a limited area on that object at any one instant, and the other method involves using a mechanical-optical system which progressively illuminates small areas of the object in a definite order, the reflected light being picked up by a light-sensitive cell. Image reconstruction is simply the reverse of these processes, as you shall soon see.

THE DISC PIN-HOLE SCANNER

In the disc pin-hole scanner, the simplest of all mechanical television cameras, a clear image of the object being televized is focused on a rotating disc by a high quality camera lens. A series of holes is arranged in the form of a spiral on this disc, the holes being located in such a way that one line after another of the image is scanned through the holes. Light passing through the holes acts as a source for a second lens, which collects the light transmitted and concentrates it on the cathode of the photoelectric cell. By separating the holes a distance corresponding to the width of the image desired and arranging the holes in a spiral whose greatest deviation from a circle corresponds to the desired height of image, the entire object can be scanned in one revolution of the disc. Although this mechanical scanner, whose optical system is shown in Fig. *12*, is one of the very oldest, it is still considered one of the finest. With it, television images of good quality can be picked up if a good image-producing lens is used and the scanning disc is very thin (or the holes have been countersunk to give the effect of a thin disc).

Flying Spot System. By replacing the light-sensitive cell with a powerful light source which is directed upon the scanning disc, the light passing through each hole in the disc is focused on the object by the lens located between the disc and the object, and the flying spot of light passes over every part of the object once for each revolution of the disc. Photocells mounted to face the object collect the pin points of light reflected from it. The action is such that the photocell sees only one illuminated spot on the object at any instant. Although this scheme was used in early demonstrations of mechanical television, it is unfortunately not practical in meeting the requirements of modern day television. The



N.R.I. EASY CALCULATING CHART. These charts were designed for practical electronic and television problems in which a real image is produced by a positive lens (double convex or plano-convex). When any two of the following values—Object Distance P, Image Distance Q and Focal Length f—are known, the third can be quickly found by laying a ruler across one of the above charts. Chart A covers a wide range of values with fair accuracy and gives most accurate results when P and Q are nearly the same; chart B is best to use where Q is many times greater than P.

HOW TO USE CHART A: The two known values must be in the same units (both in inches or both in feet). Locate these known values on their respective scales, and place a ruler or straight edge so it passes through both points; the intersection of the ruler with the third scale gives the unknown value in the same units as the other values. Examples: If P = 10 inches and Q = 28 inches, f = 7.3 inches; if f = 3" and Q = 20", P = 3.5".

HOW TO USE CHART B: P and f must be in inches and Q in feet for this chart. Locate the known values on their scales and place a ruler through them; the intersection of the ruler with the third scale gives the unknown value. Examples: If P = 10 inches and Q = 25 feet, f = 9.7 inches; if f = 15" and Q = 30', P = 15.4".

chief drawback is that very little light sweeps over the object, and even the effect of this light is reduced if there are other sources of illumination in the studio.

LENS DISC IMAGE RECONSTRUCTOR

A pin-hole disc can be used to reconstruct an image on a screen by replacing the light-sensitive cell in Fig. *12* with a glow lamp having flat electrodes which produce a strong glow of light whose intensity varies in accordance with the picture signal. Since the area of the pin-hole in the disc is quite small in comparison with the area of the entire surface of the glow lamp, it is clear that only a small part of the available light can reach the screen.

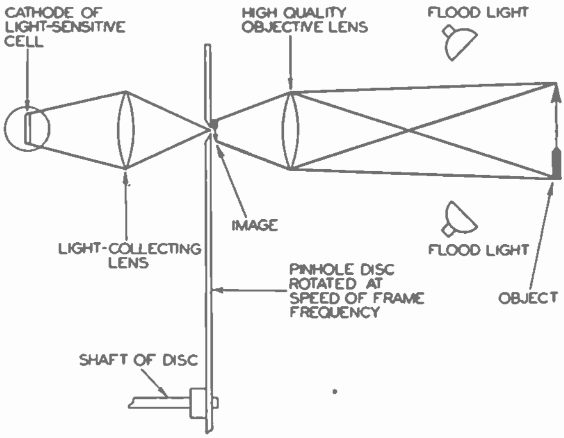


FIG. 12. Cross-section diagram of the simplest of all mechanical television cameras, the disc pin-hole scanner.

To increase the efficiency of the system, the glow lamp was redesigned to have an intensely bright spot of light; in this form it is known as a *crater type glow lamp*. The next problem, that of producing an image of this crater on a screen, is optical in nature. A projecting lens (double convex or plano convex) set into each pin-hole opening in the scanning disc focuses the light from the crater lamp on to the screen (which would be located at the object position in Fig. *12*). As the lens disc makes one complete revolution, the spot of light sweeps once over the entire screen, its intensity varying rapidly to recreate the image of the object.

The optical system of the image reconstructor is shown in Fig. *13*. The lens shown at *a* is one of those mounted on the scanning disc; the distance *P* is that from the lens to the object (here a crater glow lamp which is continually varying in intensity), while *Q* is the distance from the image on the screen to the lens. Fig. *13b* illustrates how, as the lens closest to the center of the disc forms the last line of the image, the outermost lens begins forming the top line of the image over again. The distance between the innermost and outermost lenses on the disc, illustrated in Fig. *13c,* therefore determines the maximum height of the image on the screen. The larger the lenses used in the scanning disc, the larger will be the cone of light intercepted from the crater lamp by these lenses, and the more light will be transmitted to the image.

It is quite a simple matter to figure the correct focal length for the lenses used in a lens disc. Suppose that the source of light is a crater lamp whose spot size is .020 inch, and an image 18 inches high

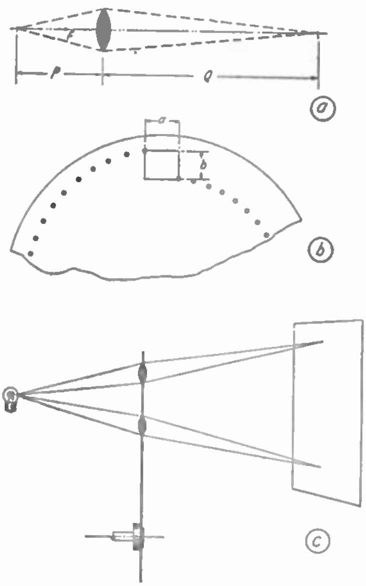


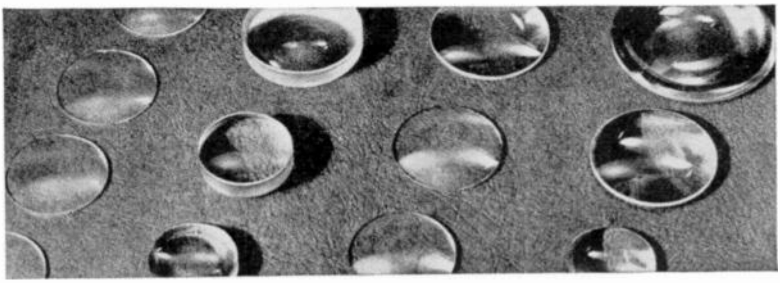
FIG. 13. Optical system of the lens disc image reconstructor. In *b* the small circles are the centers of lenses which are made as large as possible without lowering the mechanical strength of the disc too much.

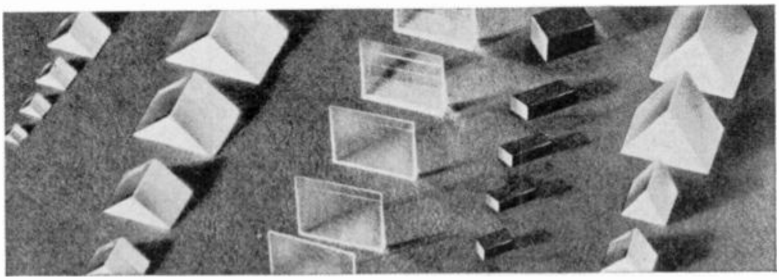
is desired on the screen. If a 180-line picture is to be formed, 180 lenses must be used on the disc. The spot of light formed on the screen should therefore have a diameter of 18 ÷ 180 or about .100 inch. With an object height of .020 inch and an image height of .1 inch, the image is 5 times the height of the object; immediately you know that the image distance must be 5 times the object distance. If the screen is placed 5 feet away from the disc, the crater lamp must then be 1 foot away from the disc on the other side. The focal length of the lens can now be determined:

$$\frac{1}{P}+\frac{1}{Q}=\frac{1}{f} \qquad \frac{1}{1}+\frac{1}{5}=\frac{1}{f} \qquad f=\frac{5}{6}= .83 \text{ feet.}$$

Each lens should therefore have a focal length of .83 feet (10 inches). The radial distance between the centers of the outermost and innermost lenses on the disc is determined as follows:

Radial distance in inches equals image height in inches multiplied by the ratio $\frac{P}{P + Q}$. In the preceding example the maximum radial separation between lens centers is therefore 18 times 1/6, or 3 inches. For a given size of disc, the lenses should be of the greatest diameter which will just make adjacent lenses touch.





Courtesy Bausch & Lomb Optical Co.

These converging and diverging lenses (above) and prisms of various sizes (below) are used in many types of mechanical and electronic television systems and in the optical systems of electronic control apparatus.

If the crater lamp is replaced by an intensely bright constant point source of light, such as that produced by an elliptical mirror, the lens disc image reconstructing system can be used to produce a flying spot of light for scanning the object. Light reflected from the object would then be picked up by photoelectric cells.

KERR CELL RECONSTRUCTORS

Although lens discs and crater lamps, used extensively in the early days of television, gave bright and large images, it was soon realized that the system had many practical disadvantages. It was by no means a simple task to produce crater glow lamps having small but intensely bright and efficient light sources whose intensity could be easily controlled, even though much progress had been made in this direction by lamp experts. The light produced by these glow lamps was either red or blue in color, and therefore produced a colored image rather than the desired black and white image. The lens disc itself proved another drawback, for at the rotational speeds required to produce from 24 to 60 pictures per second, vibration of the disc became quite a problem. A large number of lenses, each of which must be of the best quality available, was required, and the position of each lens on the disc with relation to the others had to be determined with great accuracy to prevent streaks on

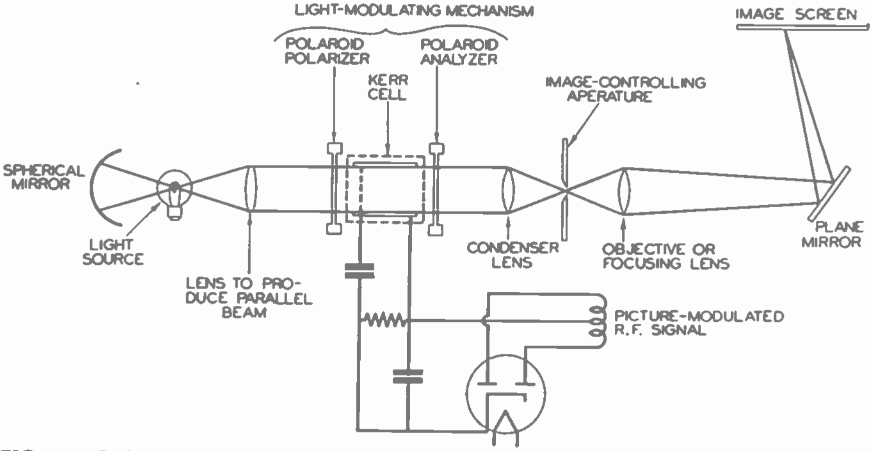


FIG. 14. Optical arrangement of a television image reconstructor system using a Kerr cell and two Polaroid light-polarizing discs to modulate the light beam. Schematic circuit diagram of the full-wave detector used in the television receiver to feed signal voltages to the plates of the Kerr cell is also shown.

the image and to keep the image in focus. The high cost and the tedious adjustments required therefore compelled the sponsors of the mechanical system to turn to other schemes of image reconstruction.

The demand for a black and white image was met by means of a Kerr light cell using Nicol prisms or the more recently developed polarizer and analyzer devices such as Polaroid. The Kerr cell is essentially an electrostatic device whose frequency response is limited by its own electrostatic capacity and whose light transmission characteristic is controlled by the voltage applied to the plates of the cell by the picture frequency amplifier of the television-radio receiver. A linear detector capable of supplying from 30 to 50 volts on peaks is sufficient to operate the Kerr cell; for most efficient operation, the light directed through a Kerr cell system should be in the form of a parallel beam. The light source may be an ordinary automobile headlight lamp, a projection lamp or an arc lamp whose crater is focused into a parallel beam which is directed through the light-modulating mechanism and then focused to a point near an aperture. Light passing through the aperture reaches a projection lens which projects the final image on the viewing screen. Of course, some device must be inserted in the path of the beam to cause it to sweep over the screen, line after line. Two methods are now being used, one involving a rotating mirror wheel and the other a vibrating mirror.

One possible optical arrangement for the Kerr cell system is shown in Fig. *14*. A double convex lens and a spherical mirror together project light from the source in the form of a parallel beam (an elliptical mirror and lens or a parabolic mirror system can just as well be used to produce this parallel beam). In passing through the first Polaroid analyzer, the light is polarized; the polarized beam is rotated an amount determined by the picture signal voltage, then analyzed by the second Polaroid disc, the action of the entire light-modulating mechanism being such that the amount of light transmitted is proportional to the picture signal voltage. The emerging beam is condensed to a point by a second lens, an aperture being placed very close to the cross-over point. The light emerging from this aperture serves as the object for the third lens in the system, a high quality lens which projects the image on the screen. The shape of this image is controlled by the shape of the aperture. The mirror shown in Fig. *14* is quite an important part of this optical arrangement, for it controls the scanning of the image. The two methods of mounting the mirror—the mirror wheel system and the vibrating mirror system, will be discussed next.

VIBRATING MIRRORS

A single mirror, if made to vibrate properly, is sufficient to sweep a spot of light across the screen, line after line, to reconstruct the image. This mirror must of course vibrate in step with the scanning mechanism at the transmitter; it is possible to introduce synchronizing signals into the picture signal for this purpose. At the present time we are concerned only with the optical system required; this system must sweep the spot *horizontally* across the screen, and at the same time move each line down in sequence to give what is known as *vertical sweeping*.

When the beam of light emerging from the objective lens is reflected from a mirror which is vibrating from side to side in the manner shown in Fig. *15A,* the spot of light on the screen will be swept horizontally, and will be moved through twice the angle of the mirror displacement. When the mirror is caused to swing forward and backward, as shown in Fig. *15B,* the spots on the screen will be swept up and down the screen in a vertical manner. To accomplish a horizontal and a vertical sweep simultaneously, a mechanism similar to that shown in Fig. *15C* is employed. A polished steel mirror is mounted on a stretched length of non-magnetic wire whose ends are attached to a steel frame; the mirror faces the two poles of an electromagnet which is fed with line frequency current. The mirror system is mechanically tuned to the line frequency, and the mirror therefore vibrates horizontally to give horizontal sweeping of the spot. The steel frame which supports the mirror is likewise attached to another wire stretched at right angles to the first, the frame and its suspension being mechanically tuned to the frame frequency. A second and larger electromagnet, fed with frame frequency current, swings the entire frame and mirror vertically to give vertical sweeping. In each case the systems are off center when current is zero, and current through the electromagnet coils tends to equalize the air gaps in the magnetic paths.

The distance between the mirror and the screen, together with the angles through which the mirror vibrates in the horizontal and vertical planes, determine the amplitude of the sweep on the screen and therefore the size of the picture. To secure a square image, the angle of sweep of the mirror must be the same for both horizontal and vertical movements;

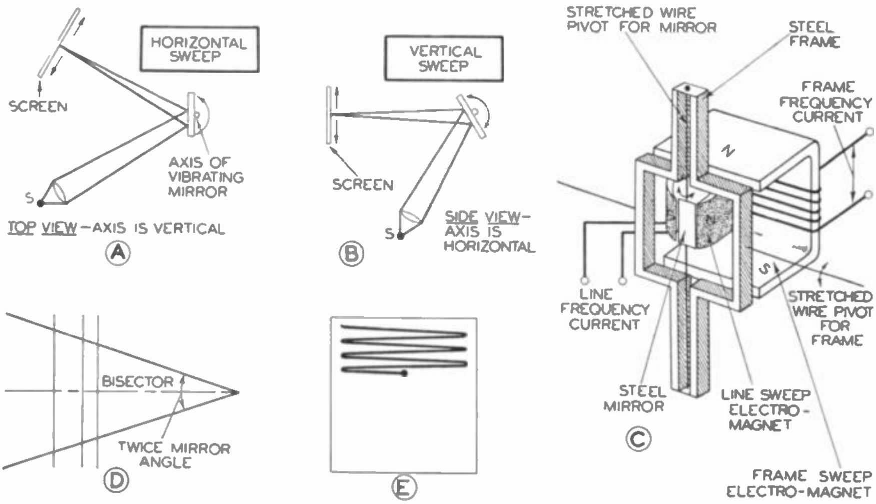


FIG. 15. Illustrations showing principles of the vibrating mirror type of television scanning system.

if the image is to be wider than it is high, then the horizontal angular movement of the mirror must be proportionally increased. For example, if a picture 12 inches wide and 9 inches high is desired, and the vertical mirror shift is 3 degrees, then the horizontal mirror shift must be 4 degrees. (Picture width divided by picture height equals horizontal mirror angle divided by vertical mirror angle; in this case, $12 \div 9 = 4 \div 3$.) The mirror swing angles, which determine the picture size and the aspect ratio, can be controlled by varying the magnitudes of the electromagnet coil currents.

To locate the correct position of the screen with relation to the mirror, draw a diagram like that shown in Fig. *15D*, either to scale or exact size. The mirror angle being known, draw two lines at an angle which is twice that of mirror movement, then draw various lines perpendicular to the bisector of this angle and select the one whose length corresponds to the desired image width or height. The distance from this line (which represents the screen) to the mirror may now be measured directly.

The mirror should be located at a sufficient distance from the projection lens to make the entire cone of light fall on the mirror. Furthermore, the total length of the light path between the projection lens and the screen must be great, to give sufficient depth of focus to the image of the aperture on the screen (this is necessary because as the spot crosses the screen, the distance between the image and the mirror is continually varying, becoming greatest when the spot is at the edges of the screen). Bear in mind that the two sets of coils are fed with sine wave currents which sweep the spot to the right, then to the left, and at the same time from the top to the bottom and the bottom to the top continuously, in

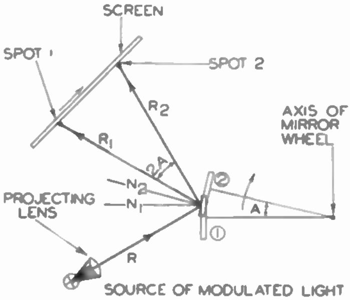


FIG. 16. Illustrating the principle of sweeping the spot of light over the screen in the mirror wheel television scanning system.

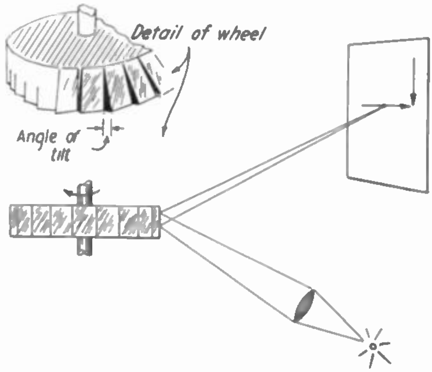


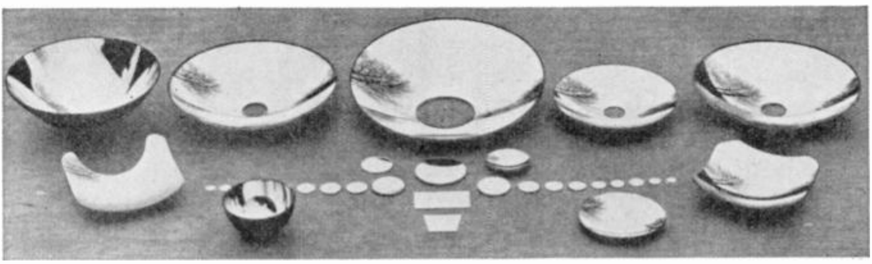
FIG. 17. Simplified sketch of mirror wheel scanning system, with detail of mirror wheel.

the manner shown in Fig. *15E*. This is quite different from the usual scanning disc method, where the spot is always swept in one direction horizontally and in one direction vertically. The scanning mechanism used in the television studio must, of course, be identical with that used in the receiver if there is to be synchronism between the two systems.

Advantages of the vibrating mirror include compactness, comparatively low cost of construction and the low operating power required in the sweep coil circuits (due inherently to the mechanical resonance of the system). It is more desirable, however, to make the mechanical resonant frequency of the two vibrating mirror systems much higher than the line and frame frequencies, and supply sufficient power to drive the two systems as linear devices; this overcomes the problem of trying to get stabilized results from undamped resonant circuits. It is perfectly possible to drive mirror vibrating systems linearly at frequencies up to *2,000 cycles;* a 240 line, 30 picture per second square image, however, would require 240 times 30 divided by 2 or *3,600 cycles*—a frequency which would tax mechanical ingenuity. Mirror wheels driven by synchronous motors are therefore preferred by some television experts for mechanical systems; in small sizes these wheels can be made to rotate steadily at speeds up to 20,000 and 30,000 revolutions per minute.

MIRROR WHEELS

When a plane reflecting mirror is mounted on a rotating wheel, a ray of light directed on the wheel will be reflected in the form of a line extending across the screen. The emerging ray, represented by R_1 and R_2 in Fig. *16,* will be moved through twice the angle A of mirror movement. The geometry of the system is completely shown in this diagram; R is the incident ray coming from the projection lens. With the mirror in position *1*, N_1 is the normal to the mirror, and R_1 is the reflected ray; with the mirror in position *2* the mirror normal is N_2 and the reflected ray is R_2. The angle of mirror rotation and the distance from the mirror to the screen together determine the spread of the two extreme positions of the spot on the screen.



Courtesy Bausch & Lomb Optical Co.

Examples of mirrors of various sizes, with parabolic, spherical and plane surfaces. The silvering on the carefully ground and polished glass surfaces consists of a heavy chemical deposit of silver, covered and protected with electroplated copper and a backing consisting of black enamel, of heat-resisting refractory materials or of a wire mesh embedded in binding material.

A single mirror wheel having as many mirrors as there are lines in the picture may be used in a mechanical image reconstruction system. Vertical displacement can be obtained by increasing the tilt of successive mirrors to the mirror wheel axis, as shown in Fig. *17*. The mirror wheel is rotated at frame speed; that is, if there are to be 24 frames per second, the mirror wheel speed is 24 revolutions per second. Each mirror sweeps the spot horizontally across the screen, and because of the gradually increasing tilt, a succeeding mirror sweeps the spot over the next lower line.

Each mirror swings through an angle A equal to 360 divided by M_H, where M_H is the number of mirrors on the wheel. For a square picture the total axial tilt of all mirrors (the angle between mirrors forming the top line and the bottom line of the image) must equal angle A; to distribute this tilt equally, each mirror must be tilted from an adjacent mirror by an angle equal to $A \div M_H$, or 360 divided by M_H divided by M_H ($360 \div M_H \div M_H$). For example, if 60 mirrors are being used and a square picture is desired, each mirror must tilt an angle equal to 360 ÷

60 ÷ 60 or .1 degree. Obviously, if the picture is to be higher than it is wide, this angle of tilt must be increased; to secure an image which is wider than it is high, the angle of tilt would be decreased. To get the correct mirror tilt angle, divide the tilt of each mirror for a *square* picture by the ratio of the picture width to picture height (often called the *aspect ratio*). An aspect ratio of 1.33 is quite standard, and the tilt of each mirror in this case will be .1 divided by 1.33, or .075 degree, making a picture which is 1.33 times as wide as it is high.

Each mirror must be sufficiently wide to reflect the entire cone of light directed upon it; this means that if many mirrors are needed to secure high definition, the diameter of the wheel will be quite large. It is, of course, possible to use a small wheel with many mirrors by narrowing the beam, but this results in a loss in light efficiency. Cutting perfectly flat mirrors, each tilted from the other by .075 degree or even less and mounting them with any degree of perfection is a task which will tax the ingenuity of the best tool makers—a task which production engineers would hesitate to assume. Driving such a large wheel at a constant speed presents another problem; for this reason, Peck and other television experimenters have adopted the two-mirror wheel system.

In the double mirror-wheel system each wheel uses only mirrors which are parallel to the axis of rotation. One wheel provides the *horizontal spot displacement*, determining the number of *lines* per second, while the other gives *vertical spot displacement*, determining the number of *frames* per second, as illustrated in Fig. *18*. In either case, the number of mirrors presented per minute must be equal to the number of lines or frames desired per minute. For example, if a 180 line, 30 picture per second image is to be formed, the total number of lines per minute will be 180 times 30 times 60, or 324,000 lines. If the line wheel has 24 mirrors, the speed of this wheel must be 324,000 divided by 24, or 13,500 r.p.m. Small synchronous motors can be designed for this speed if the wheel is not too bulky.

Having determined the speed required for the line (horizontal sweep) wheel, the frame (vertical sweep) mirror wheel speed is figured next. There will be 30 times 60 or 1,800 mirrors required per minute; if this wheel has 12 mirrors the mirror wheel speed must be 1,800 divided by 12, or 150 r.p.m.; the design of a motor for this mirror wheel is therefore a much simpler task.

If the synchronous motors used are of the two-pole type, the power supply for each must have a frequency equal to the speed of rotation of the mirror wheel which it drives. For 13,500 r.p.m., the power will therefore have a frequency of 13,500 divided by 60 or 225 cycles; the frame mirror wheel power will be 150 divided by 60, or 2.5 cycles per second. By using Thyratron-controlled power supplies which are in turn controlled by the inherent line and frame frequencies in the picture signal, synchronism may be accomplished and the frame and line frequencies controlled by the transmitter, as they should be. The facts just given in connection with mirror wheels can be summarized as follows: *The number of mirrors* *in the line wheel multiplied by the speed of the line wheel in revolutions per second must equal the line frequency in the picture; the number of mirrors on the frame wheel multiplied by the speed of the frame wheel in revolutions per second must equal the frame frequency.*

The question of controlling the final picture width and height (the aspect ratio) must next be considered. By studying Fig. *18* closely, you can see that as the line wheel is moved farther away from the frame wheel, the height of the picture is increased; as the screen is moved farther away from the frame mirror, the frame sweep and therefore the

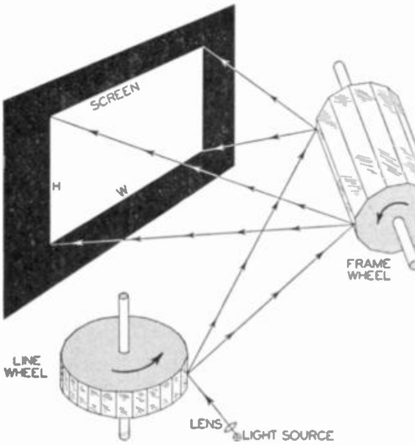


FIG. 18. Simplified sketch of a double mirror wheel scanning system.

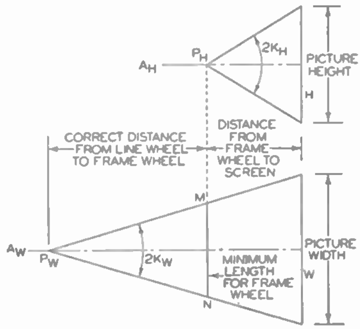
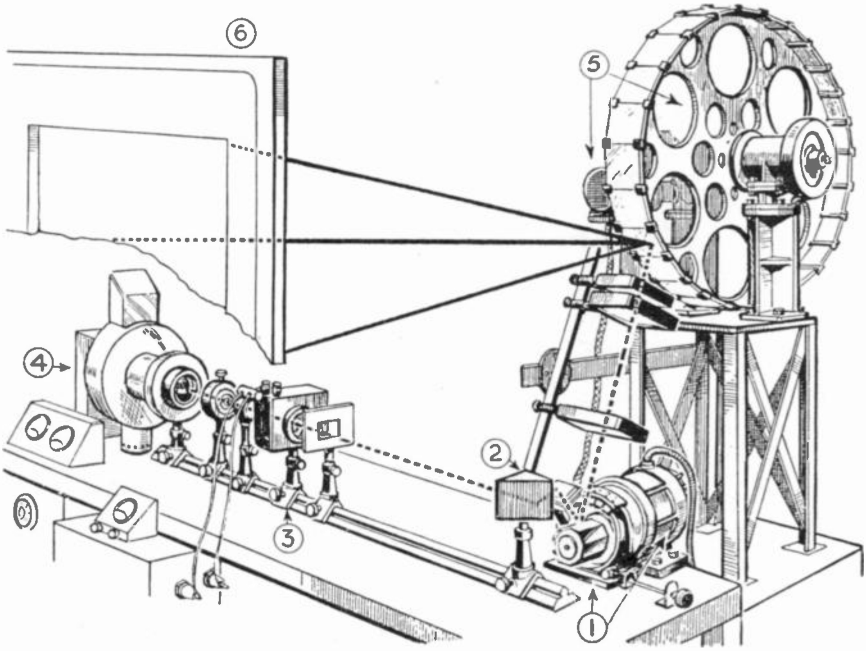


FIG. 19A. Graphical method of determining the proper mirror positions when using the double mirror wheel scanning system.

height of the picture is increased, but at the same time the width of the picture is increased. Thus, by varying the distance between the two mirror wheels and between the frame mirror wheel and the screen, any desired size and shape of image can be obtained.

The exact positions of the mirrors could be determined by mathematical formulas, but the most practical procedure is to make a scale drawing like that shown in Fig. *19A*. First draw vertical lines *H* and *W* to a scale which will make them represent the desired picture height and picture width respectively. Now draw horizontal axial lines A_H and A_W through the centers of *H* and *W*. Compute the mirror angle for the frame wheel (360 divided by the number of mirrors on the frame wheel), call this angle K_H and draw a triangle whose base is the picture height line *H* and whose apex angle (at the point opposite the base of the triangle) is equal to twice the mirror angle. Now compute the mirror angle for the line wheel (360 divided by the number of mirrors on this wheel), call this angle K_W and draw a triangle whose apex angle is $2K_W$, as shown in Fig. *19A*.

The number of mirrors on the frame wheel in our example is less than the number on the line wheel; K_W will therefore be much less than K_H. Since the diagrams in Fig. *19A* were made to scale, the distance between the frame wheel and the screen is determined by the distance between point P_H and line H. The minimum length for the frame wheel mirrors can also be determined from these diagrams; project a line down vertically from point P_H until it intersects both sides of the lower triangle. Line MN then represents the minimum length for the mirrors on the frame wheel, and the distance between line MN and point



Courtesy Television and Short Wave World

FIG. 19B. Sketch showing apparatus used in one form of double mirror wheel scanning system (the Mihaly-Traub television system, developed in England). The units marked by numbers are: *1*, line scanning mirror wheel driven by a synchronous motor; *2*, prism for changing direction of light beam; *3*, light valve consisting of polarizer, Kerr cell and analyzer; *4*, arc lamp forming powerful light source; *5*, frame scanning mirror wheel, driven by a synchronous motor; *6*, screen on which image is projected. The metal bar on which light source, lenses, light valve, aperture and prism are mounted is a laboratory type lens test bench, used here to simplify changing of the positions of any parts in the optical system during experimental tests.

P_W represents the correct distance between the frame mirror wheel and the line mirror wheel.

The mirrors on the line wheel may be of any desired length, as long as they intercept the entire cone of light from the objective lens. The size of either wheel is not critical, as long as a narrow cone of light is used. All distances are measured from the center of the screen to the center of a mirror surface, and the mid-points of the axes of the two wheels must be on the same level as the center of the screen.

By using, in connection with two mirror wheels arranged as shown in Fig. *19B,* an initial optical system employing a Kerr cell and two polarizing elements, a picture reconstructor is obtained; by using with the double mirror-wheel system a source which produces an intense and very narrow beam of light, a flying spot of light can be directed upon a scene and the reflected light picked up by light-sensitive cells. In this latter case a scene can be scanned by flooding it with light and placing a light-sensitive cell at the position occupied by the light source in Fig. *18*.

TELEVISION USES FOR MAGNIFYING LENSES

In the early days of television development, the magnifying glass was used extensively in image reconstructors. The equipment consisted of a pin-hole disc which was revolved in front of a flat plate neon glow lamp; the speed of rotation of the disc was equal to the frame frequency, and the number of pin-holes in the disc was equal to the number of lines per frame. When the pin-hole discs in the transmitter and receiver were

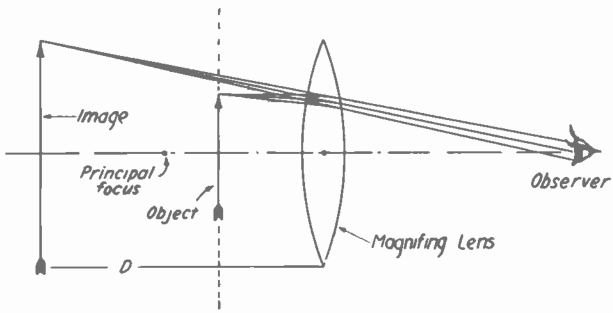


FIG. 20. Method of using a magnifying glass to enlarge an object (which can be either a real image formed on a scanning disc or the image formed on a cathode ray tube screen).

in synchronism (were running at the same speed and in phase) a real image of small size could be seen. To enlarge this image, a double convex lens was placed next to the disc, so that the real image was inside the focal point of the lens and an erect vertical image of enlarged size was obtained.

Many electronic television experts are even today suggesting that a small cathode ray tube be used and the real image formed on the tube screen be enlarged by a magnifying glass. It is evident, then, that the magnifying glass plays a sufficiently important part in television to make it worthy of further study here.

Let us see how a magnifying glass behaves in various television systems. A double convex lens is usually used; when held close to the image-producing mechanism in a mechanical or electronic television system, a virtual, upright and enlarged image of the scene is produced. The requirements are that the object must be *between the principal focus and the lens*, and that the object must be a *real* (not a virtual) *image*. This optical system is shown in Fig. *20*. It is interesting to note that the shorter the focal length of the lens used, the larger will be the image but the greater will be the spherical aberration.

It has been found that when a simple lens is used, there is one point at which the image of the object is clearest for the normal eye; this point is that where the image is about 10 inches behind the lens.

A short focal length also requires that the observer be close to the axis of the lens if he is to see all of the image. Because of these limitations, it is impractical to enlarge the images encountered in television systems more than 3 or 4 times their actual size without introducing distortion or limiting too greatly the angle over which the images are visible. These undesirable effects can be avoided to some extent, however, by combining two lenses of long focal length, corrected for spherical aberration, to give a composite lens having the desired short focal length. Such a procedure would not be practical in the old pin-hole disc systems, but could readily be adapted to electronic systems where small high-definition cathode ray tubes are used.

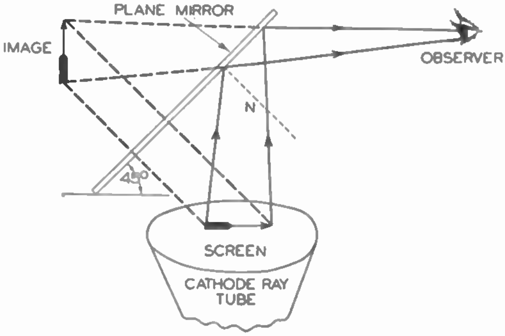


FIG. 21. When a cathode ray image reconstructor tube is mounted vertically in a television receiver, a plane mirror is generally mounted above the tube to permit a seated audience to view the image.

The magnifying lens should be protected from stray light by a visor, the inside of which is a dull black. All lights in front of the magnifying lens should be out to prevent glare on the surface of the lens. Under these conditions, from three to five persons can view the scene.

IMAGE-REFLECTING MIRRORS FOR CATHODE RAY RECONSTRUCTORS

In television receivers where the reconstructor is a cathode ray tube radiovisor, the tube is often placed with the flattened end (on which the image is formed) facing the observer; in some cases it is more convenient to mount the tube vertically, but to view the reproduced image you would have to look down upon the tube while standing. To allow a number of people in a room to see the image while seated, in the case where the tube is mounted vertically, a plane mirror can be placed at an angle of 45 degrees above the tube; the observers then see a virtual image in back of the mirror. The distance of the virtual image behind the mirror is, of course, equal to the distance between the real image (on the cathode ray tube screen) and the mirror. The optical paths of the reflected ray, showing how the virtual image is formed, are traced in Fig. 21.

TEST QUESTIONS

Be sure to number your Answer Sheet with the *number* appearing on the front cover underneath the title of this text.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your Course, and you will receive the best possible lesson service.

1. If an automobile headlight lamp is placed near the focal point of a double convex lens, and the light emerging from the lens spreads out (diverges), in which direction would you move the lamp to make the beam converge?
2. What kind of optical arrangement will produce a parallel beam having a greater intensity than can be secured with a lens or parabolic mirror?
3. Why is a visor placed over a light-sensitive cell?
4. Give a practical method of producing a ribbon of light.
5. Are the lenses used in the kinescope television camera any different from the lenses used in high-grade cameras?
6. If spherical aberration is found to be excessive in a certain lens, how can it be reduced?
7. What lenses are used in television and photographic work for "long shots"?
8. What form of light beam should be directed through a Kerr cell system for most efficient operation?
9. How can the mirror swing angles be controlled in the vibrating mirror type of television reconstructor?
10. What is the purpose of each mirror wheel in the double mirror-wheel television reconstructor system?

NATIONAL RADIO INSTITUTE
16TH & U STS., N. W. WASHINGTON, D. C.

MODEL ANSWERS

Uses for Optics in Electronics and Television. No. 58 RH-1

1. Away from the lens.
2. An elliptical mirror and lens.
3. To keep out undesirable light.
4. Use a flat ribbon filament lamp with the filament parallel to the straight side of a cylindrical lens.
5. No.
6. By stopping down the lens.
7. Telephoto lenses.
8. A parallel beam.
9. By controlling the magnitudes of the electromagnetic coil currents.
10. One produces horizontal displacement, while the other gives vertical displacement of the light spot.

In order to get the greatest good from your work on this lesson, go over your graded answers carefully. Give special attention to any written comments. Reductions in grade are shown as follows: -2. Mistakes in answers and drawings are marked. Refer to the textbook where improvement is desired and review subject thoroughly.

ESSENTIAL CIRCUITS IN A TELEVISION RECEIVER

59RH-1

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

FIGHTING FOR SUCCESS

If things look sort of gloomy
  And your prospects mighty slim,
If your creditors are pressin'
  And the future's pretty grim,
If your hopes are all a crumblin'
And everything goes wrong;
Just grit your teeth and clench your fists,
And fight ten times as hard!

Worrying never brings results
  And grumbling never pays;
So what's the use of broodin'
  And wasting hours or days?
Look for that silver lining
Which dark clouds nearly hide;
Grit your teeth and clench your fists
And fight ten times as hard!

NATIONAL RADIO INSTITUTE

WASHINGTON, D. C.

1942 Edition

A LESSON TEXT OF THE N. R. I. COURSE
WHICH TRAINS YOU TO BECOME A
RADIOTRICIAN & TELETRICIAN
(REGISTERED U. S. PATENT OFFICE) (REGISTERED U. S. PATENT OFFICE)

NCP17C342

Printed in U. S. A.

Essential Circuits in a Television Receiver

Tracing Signals Through a Television Receiver

BEFORE we proceed to analyze in detail the various types of circuits which may be used in each section of a television receiver, it will be wise to trace the sound and picture signals through a typical television receiver, then study a typical circuit for each section of this receiver.

A Television Channel. Let us assume that the receiver through which we are to trace signals is tuned to the 44-50-megacycle television channel. This means that the r.f. carrier for the audio signal will be at 49.75 mc. The r.f. carrier for the video signal will be 4.5 mc. below, at 45.25 mc. If modified single side-band transmission is employed in accordance with R.M.A. standards, this entire television channel will be as shown in Fig. *1*.

The Receiving Antenna. The essential sections of a typical television receiver are shown in block form in Fig. *2*. The antenna intercepts the 49.75-mc. audio r.f. carrier, causing a modulated r.f. current like that shown

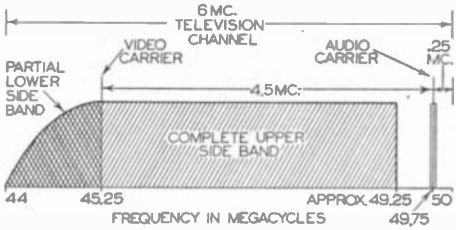
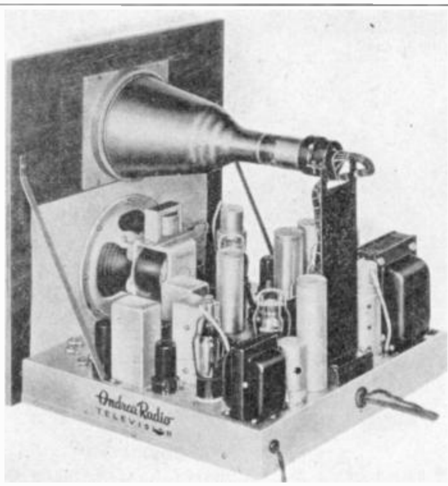


FIG. 1. Relationship of audio carrier, video carrier and side frequencies in the 44-50 mc. television channel.

in Fig. *3A* to flow down the transmission line to the first section of the receiver. This same antenna also intercepts the 45.25-mc. video r.f. carrier, along with its side frequencies extending down to 44 mc. and up to about 49.25 mc., and sends down the



Courtesy Andrea Radio Corp.

Rear and front views of Andrea model KT-E-5 sight-sound television receiver. This set employs 17 tubes, including the 5-inch diameter television cathode ray tube which produces black and white images approximately 3" x 4" in size. The six controls on the front panel are, left to right: *TONE* control for sound programs; *ON-OFF & VOLUME* control for turning entire set on and controlling the volume of the sound; *BRILLIANCE* control for varying the bias on the t.c.r. tube to make the pedestals line up with cut-off; *FOCUS* control for the t.c.r. tube; *STATION SELECTOR* for tuning sight and sound sections simultaneously to either the 44-50-mc. television channel or the 50-56-mc. channel; *CONTRAST* control for changing the amplification of picture signal stages in order to get the desired contrast between light and dark portions of the image.

transmission line an r.f. signal current like that shown in Fig. *3B*.

R.F. Amplifier. The first section of a television receiver is the r.f. amplifier. This section increases the amplitudes of both the sound and sight r.f. signals without changing their characteristics in any way, and hence must have a pass band of 44 to 50 mc. In addition, the r.f. amplifier must reject any carrier frequencies (outside of the 44-50-mc. channel) which might cause image interference.

Local Oscillator and Mixer-First Detector. The amplified sight and sound r.f. signals are fed into the mixer-first detector section, where they are combined with the unmodulated r.f. signal produced by the local oscillator. A video i.f. value of somewhere between 10 and 15 mc. is favored by television engineers, since it permits the use of simple preselector circuits while still providing a reasonable image-rejection ratio.

Let us assume that the video i.f. value in this receiver is 13 mc. This means that the local oscillator frequency will be 45.25+13, or 58.25 mc. The local oscillator delivers a sine wave output as shown in Fig. *3C*.

I.F. Values. In the mixer-first detector section the 58.25-mc. local oscillator signal will beat with the 45.25-mc. video r.f. carrier and its side frequencies to produce a video i.f. carrier signal of 13 mc., along with side frequencies ranging down to 9 mc. and up to 14.25 mc.* At the same time, the 58.25-mc. local oscillator signal will beat with the 49.75-mc. sound r.f. carrier and its side frequencies to produce an 8.5-mc. sound i.f. signal with side frequencies extending for 10 kc. in either direction. These i.f. signals will have essentially the same characteristics as the original signals shown in Figs. *3A* and *3B*.

Video signals are separated from audio signals by the two i.f. amplifier

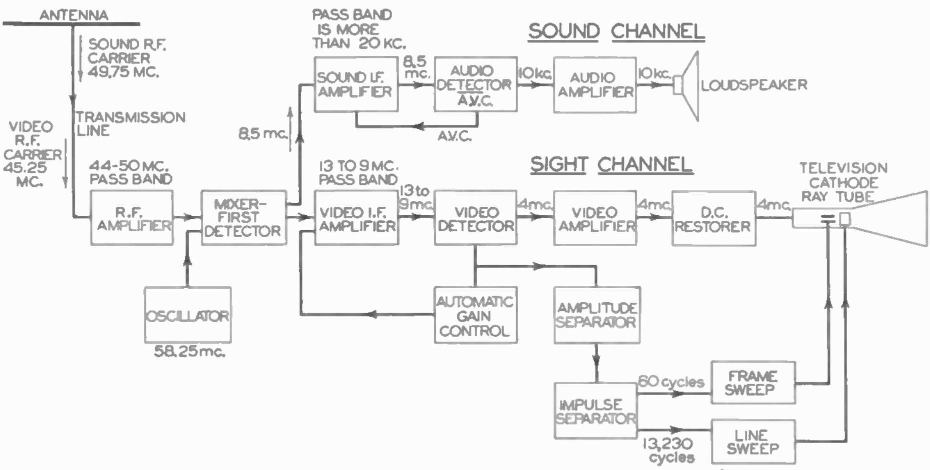


FIG. 2. Main sections of a typical television receiver. The amplitude separator is also called a clipper; the impulse separator is also called a frequency separator.

* Frequency conversion reverses the relationship of the desired side frequencies to the carrier. The desired band of side frequencies is *above* the video r.f. carrier in the r.f. amplifier, but is *below* the carrier in the video i.f. amplifier. Thus, when the highest side frequency (49.25 mc.) for the original video r.f. signal beats with the 58.25 mc. oscillator signal, we get 9 mc. as the *lowest* video i.f. side frequency value. The side frequencies extending from 13 mc. to about 14.25 mc. correspond to the partial lower side band in the original signal, for as yet these undesired side frequencies are not completely eliminated at the transmitter.

sections in a television receiver. Assuming good separation, we have the mixer-first detector feeding into a *sound* (audio) *i.f. channel* and a *sight* (video) *i.f. channel.*

Sound I.F. Amplifier. This i.f. amplifier section must pass the complete 20-kc. wide range of side frequencies associated with the 8.5-mc. sound i.f. carrier, and must be enough wider *to permit passage of the entire sound i.f. signal despite normal frequency drift of the local oscillator circuit.* Furthermore, it must be selective enough to reject 9-mc. video side frequencies.

Audio Detector. The audio detector will invariably utilize a diode, as this can serve also for a.v.c. purposes. The output circuit of the audio demodulator will have a simple r.f. filter to reject i.f. signals.

Audio Amplifier. The signal at the output of the audio demodulator will have a maximum frequency of 10 kc. and will have the general appearance of the signal shown in Fig. *3D.* This audio signal is fed into a conventional audio amplifier, where it undergoes voltage and power amplification before being converted into sound by the loudspeaker.

Video I.F. Amplifier. Considering the sight channel next, the video i.f. amplifier must have a pass band of from 9 to 13 mc. and a frequency response characteristic which will suppress the undesired side frequencies (those above the 13-mc. i.f. carrier).

Video Detector. The amplified video i.f. signal passes into the video detector section, where its envelope is "stripped" from the carrier. The resulting demodulated television signal may be as shown in Fig. *3E.* The video detector circuit will usually employ a diode tube for rectification, followed by a condenser-coil filter circuit which rejects all i.f. components while passing the entire television signal ranging from 10 cycles to 4 megacycles.

The demodulated television signal (Fig. *3E*), consisting of the synchronizing impulses and the video signal, is actually a pulsating d.c. signal.

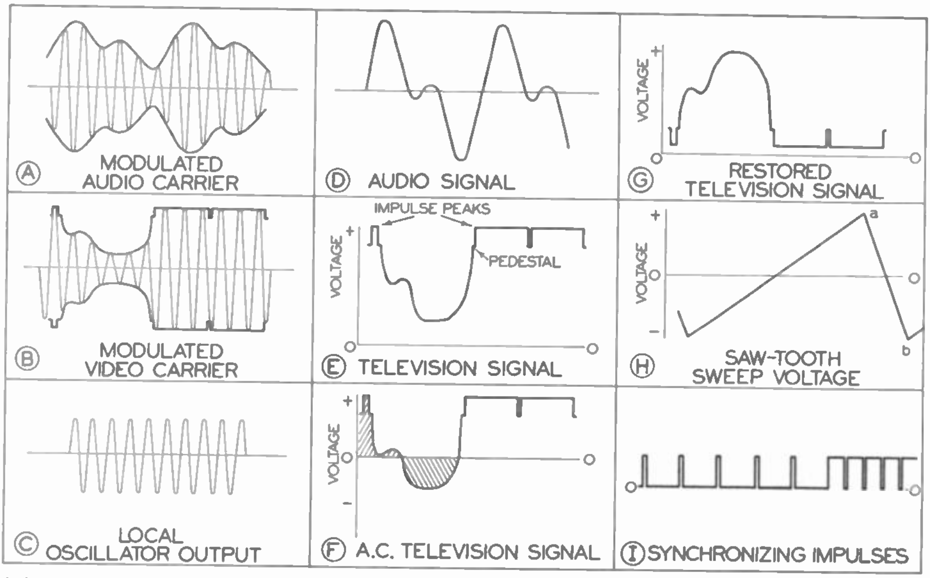


FIG. 3. Wave forms of signals at various points in a television receiver. For simplicity, the equalizing pulses which must precede and follow each vertical impulse have been omitted in these diagrams.

The signal voltage across the load resistor of the diode video detector in a television receiver is therefore *a pulsating d.c. voltage, with the pedestals all lined up at one d.c. voltage value and the impulse peaks lined up at another d.c. voltage value.*

Automatic Gain Control. The impulse level in the received television signal *is independent of picture briliancy;* synchronizing impulses are therefore utilized to actuate the automatic gain control (a.g.c.) section of a television receiver. A portion of the output of the video demodulator is fed into the a.g.c. section through a network of radio parts which is so designed that only the impulses are effective in producing an a.g.c. voltage for biasing purposes. Since the output of this a.g.c. circuit is quite low, it is usually boosted by a d.c. amplifier stage before being distributed through resistance-capacitance filters to the grids of the video i.f. amplifier tubes.

Video Amplifier. The phase of the television signal applied to the image-producing tube must be opposite that of the signal in Fig. *3E*. Each video amplifier stage reverses the phase, and consequently both the phase and the amplification requirements must be considered when designing the v.f. amplifier. One stage will give sufficient amplification for small t.c.r. tubes; this will usually be a d.c. amplifier stage, passing both the a.c. and d.c. components of the television signal. When more than one v.f. amplifier stage is required, resistance-capacitance coupling will be used between the stages; this passes only the a.c. component.

Video frequency amplifier stages must amplify equally well over a range extending from about 10 cycles to about 4 megacycles. Furthermore, these stages must not introduce phase distortion, for any distortion of this type would cause elemental impressions of gray, white or black to be shifted either ahead of or behind their proper positions along a line.

D.C. Restorer. Removal of the d.c. component throws the pedestals of a television signal out of line, giving the a.c. signal shown in Fig. *3F*. This means that when resistance-capacitance - coupled v.f. amplifier stages are employed, a *d.c. restorer* section must be used to restore the d.c. component and realign the pedestals. This section adds to the a.c. television signal a d.c. voltage which varies from instant to instant in exactly the proper manner to make the pedestals line up again. The restored television signal with the correct phase for the t.c.r. tube is shown in Fig. *3G*.

T.C.R. Tube. Two anodes in the t.c.r. tube serve to focus the electron beam to a point on the screen. The application of a television signal to the control grid of this tube serves to modulate the beam, thereby varying the brightness of the spot on the screen. Since the impulses are more negative than the video signal in the television signal as applied to this tube (see Fig. *3G*), the impulses and the blanking level prevent retraces from being visible during the fly-back period.

While the electron beam is being modulated by the television signal, it is simultaneously being swept back and forth both horizontally and vertically by saw-tooth-shaped voltages like those in Fig. *3H*, produced by the line and frame sweep generator sections. In accordance with present R.M.A. standards, the horizontal sweep will have a frequency of 13,230 cycles per second, and the vertical sweep will have a frequency of 60 cycles per second.

Synchronization. Each horizontal and vertical sweep in the receiver must start at exactly the same instant that the corresponding sweep starts at the transmitter. The impulses are sent along with the video signal for this purpose. These impulses must be separated from the video signal, after which the horizontal impulses must be separated from the vertical impulses. Finally, each type of impulse must be made to control the start of its own sweep circuit.

Amplitude Separator. If we pass the demodulated television signal shown in Fig. *3E* through a triode tube which has a high negative bias, only the positive peaks of the signals (the impulses) will cause variations in plate current. We thus have only the impulses in the plate circuit of this triode; since this separation of impulses from video signals is dependent upon the *amplitude* of the television signal, the section containing this tube is the *amplitude separator* or *clipper*. The signal at the output of this section will appear as in Fig. *3I*. As you can see, it now contains only the horizontal impulses, the serrated vertical or field impulses and any equalizing pulses transmitted along with these.

Impulse Separator. Our next problem is the separation of the serrated vertical impulses from the line and equalizing impulses. This is accomplished in the *impulse separator* (sometimes called the *frequency separator*), which also converts the serrated vertical impulses into single impulses by an integrating action.

Sweep Circuits. The separated impulses are fed into the frame (vertical) sweep oscillator and the line (horizontal) sweep oscillator, where they control the starting times of the sweeps.

Power Supply. The power supply can be omitted in this brief analysis of a complete television receiver, for even though it is a necessary part of any system employing vacuum tubes, it is conventional in design.

Having traced the television signal through the different essential sections of the receiver, let us now study a typical circuit for each section, to see just how it performs its required duties.

The Receiving Antenna

The antenna employed with a television receiver must intercept radio waves in the channels which the television receiver is designed to receive. In addition, the antenna should reject any noise signals which exist in the locality of the receiver. A doublet type antenna with twisted two-wire transmission line, as indicated in Fig. *4*, it generally the best for the purpose. The length of the doublet must be so chosen that it will never become a full-wave antenna, for such a condition would give zero current at the center and there would be no signal current flowing down the transmission line to the receiver.

Some engineers prefer to use a doublet antenna which will be a half wavelength long at the highest frequency to be received, as this will act as an untuned doublet shorter than $\lambda/2$ for all lower frequencies and will always have maximum current at the center. This maximum value of current becomes quite low at lower frequencies, however, and the antenna impedance becomes so high that it is difficult to secure a satisfactory impedance match between the antenna and the transmission line.

Better results are obtained with a doublet which is resonant ($\lambda/2$) at a middle frequency in the entire range to be received; this calls for resonance at 75 mc., which is about midway between 44 mc. and 108 mc. An antenna approximately 2 meters or 6.6 feet long will be a half-wave antenna at about 75 megacycles, and will furnish signals to the transmission line on all television channels.* Each half of the doublet is only 3.3 feet long, indicating that television receiving antennas are considerably shorter than ordinary broadcast or short-wave antenna. This antenna does not become a full-wave doublet until about 150 mc., considerably higher than any regular television channel. With this antenna, variations in pick-

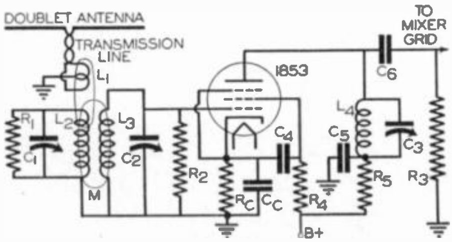


FIG. 4. Typical r.f. amplifier circuit of a television receiver. This circuit amplifies the modulated r.f. carriers for both the sound and picture portions of a television program.

up and antenna impedance over the frequency range will be only half as great as in the previous case.

A transmission line having a surge impedance of about 100 ohms is satisfactory for a television receiver. With this line, no antenna matching transformer will be necessary at the center of the doublet antenna. The twisted transmission line will inherently reject noise signals; these will flow down both wires in the same direction to the center tap on coil L_1 in Fig. *4*, then flow to ground. The transmission line may be any reasonable length. A long twisted line loads the antenna and broadens its tuning, which is a desirable condition in that it tends to make the sensitivity of the antenna more uniform for all television channels.

The R.F. Amplifier

The preselector or r.f. amplifier has two important functions. It must amplify equally well all signal components in the television channel to which it is tuned, and it must exclude image frequency signals (outside of this channel). In a sight-sound television superheterodyne receiver we must consider *two image interference signal frequencies*, both *above* the desired television channel. If, for example, the preselector is tuned to the 44–50-mc. channel, one image interference frequency will be 71.25 mc., for an undesired signal at this frequency could beat with the 58.25-mc. local oscillator signal to produce the correct 13-mc. value for the video i.f. channel. The other image interference frequency will be 66.75 mc., for this will beat with the 58.25-mc. oscillator signal to produce the correct 8.5-mc. value for the sound i.f. channel.

The response of the preselector can be made essentially uniform over a band width of 6 megacycles by employing three tuned circuits. Two of these are resonant to considerably different frequencies and are used in a pass-band circuit to give the required wide response. Two circuits alone give a deep valley between the peaks of response, so the third circuit is tuned to a mid-frequency and serves to fill in the valley.

Figure *4* shows one way in which these three tuned circuits can be arranged. Tuned circuit L_2–C_1 is tightly coupled to tuned circuit L_3–C_2. Resistors R_1 and R_2, having ohmic values which may be as low as 2,000

* To convert frequency in megacycles to wavelength in meters, divide the number 300 by the frequency in megacycles. Thus, 75 megacycles is 300÷75, or 4 meters. This would be the length of a full-wave antenna at 75 mc., so divide by 2, getting 2 meters as the length required for a λ/2 antenna at 75 mc. Multiply the length in meters by 3.3 to get length in feet.

ohms each, are shunted across these first two tuned circuits to broaden their response. The third tuned circuit, L_4–C_3, is in the plate circuit of the first tube. This third parallel-resonant circuit is loaded through coupling condenser C_6 by resistor R_3, which may have a value of about 2,000 ohms. With proper design, L_4–C_3 can be made to tune broadly in the mid-range of the 6-mc. preselector pass band, thereby building up the valley in the response curve for the preselector. The values of R_1 and R_2 and the value of mutual inductance M for the first two tuned circuits play important parts in securing the required wide response.

The tube used in the preselector section is a pentode r.f. amplifier; it may be of the variable mu type if it is to be controlled by an a.g.c. voltage, but is shown with conventional cathode bias in Fig. *4*. This tube must have certain characteristics which make it suitable for amplification at ultra-high frequencies. Its grid-to-plate capacity must be low if feedback is to be kept at a negligible value. For the same reason, the capacity between the grid and plate leads to this tube must be as low as possible. In addition, the grid-to-cathode and plate-to-cathode interelectrode capacities and the capacities between the leads to these electrodes must be low enough so the preselector can be tuned to the highest desired television carrier frequency when tuning condensers C_1, C_2 and C_3 are set at minimum capacities.

The fact that the load in the plate circuit of the preselector tube has a low resistance, often less than 2,000 ohms, makes it extremely difficult to secure high amplification in this stage. The plate resistance of the pentode tube is of the order of 1 megohm, and consequently very little signal voltage is developed across the load even though the amplification factor of the tube may be well over 1,000. The mutual conductance of the tube (the a.c. plate current divided by the a.c. grid voltage) determines what the true amplification of the stage will be; the higher the value of g_m (mutual conductance or transconductance), the higher will be the true amplification.

The mutual conductance of a type 6D6 tube, such as is widely used in the preselector stages of all-wave sound receivers, is about 1,600 micromhos. With a plate load resistance of 2,000 ohms, this would give an over-all amplification of only 3.3 for the first stage of a television receiver. The mutual conductance of the type 1853 tube indicated in Fig. *4* is 5,000 micromhos; this tube, designed especially for ultra-high-frequency work, will give an over-all gain of about 10 for the stage.* Tubes with even higher mutual conductance values will undoubtedly be developed for use in television receivers in the near future; already we have the type 1852 television tube which has a mutual conductance of 9,000 micromhos.

Filter circuits R_4–C_4 and R_5–C_5, in the screen grid and plate supply circuits respectively of Fig. *4*, prevent mutual couplings between stages through the power supply circuits. These filter circuits thus prevent uncontrollable degeneration or regeneration at television carrier frequencies.

Automatic C bias is provided for the type 1853 tube in the circuit shown in Fig. *4* by the flow of average

* To compute the over-all gain of a preselector stage, multiply the load resistance in ohms by the mutual conductance g_m in micromhos, then divide the result by 1,000,000. Example: Load resistance = 2,000 ohms; g_m = 5,000 micromhos; 5,000 × 2,000 = 10,000,000; 10,000,000 ÷ 1,000,000 = 10, over-all gain of stage.

cathode current (plate current + screen grid current) through cathode resistor R_C. The C bias voltage employed in this first stage may be quite low, for the peaks of the r.f. voltage will be well under .5 volt. The value of the average cathode current for the type 1853 tube at a C bias of —3 volts is quite high, about 15 ma., so a cathode resistor of about 200 ohms will provide this bias.

The Oscillator and Mixer-First Detector

As you already know, the process of frequency conversion involves mixing the unmodulated constant-voltage output of a local oscillator with the

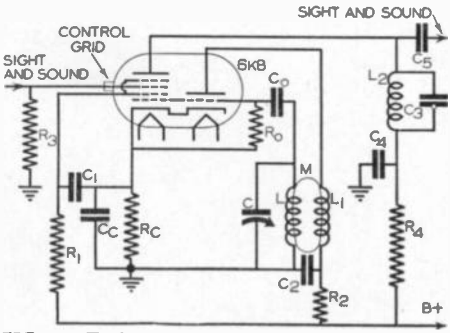


FIG. 5. Typical mixer-first detector and local oscillator circuits for a television receiver.

incoming modulated carrier signal. This process is basically the same in television superheterodyne receivers as in conventional sound superheterodyne receivers. Because we are dealing with ultra-high frequencies, however, precautions must be taken to prevent degeneration and to prevent shifting of the oscillator frequency due to the process of frequency conversion or to other causes.

These difficulties are eliminated by the use of a separate oscillator tube, injecting its output into the mixer-first detector circuit by means of a connection to an injector grid. Combination triode-hexode tubes built into one envelope have been developed for this purpose. The type 6K8 tube is typical of these, and is employed in the typical mixer-first detector and oscillator circuit shown in Fig. *5*. You will also find the more conventional circuits employed in this section of a television receiver, but invariably there will be separate oscillator and mixer-first detector tubes (not pentagrid converters) in ultra-high-frequency circuits.

Coil L and tuning condenser C determine the frequency of oscillation in the circuit of Fig. *5*. Coil L_1 in the plate lead of the oscillator triode section is inductively coupled to coil L, thereby providing the feed-back required for oscillation. The voltage developed across the L–C oscillator tank circuit is electronically injected into the mixer (hexode) section of the 6K8 tube by means of an internal connection between the triode grid and the first grid (the injector grid) of the hexode section. Automatic C bias for the oscillator section is produced by resistor R_O and condenser C_O. The plate of the triode tube is supplied with d.c. voltage through filter circuit R_2–C_2 and feed-back coil L_1.

The preselector feeds two carrier signals, one modulated with sight and the other with sound, into the control grid (top cap) and cathode terminals of the hexode mixer-first detector tube (R_3 in Fig. *5* is the same as R_3 in Fig. *4*). With the mixer-first detector operating at the correct voltages for detection, rectification of both signals takes place in the conventional manner, and two different beat frequencies are produced between the two incoming carrier signals and the local oscillator signal.

R_C and C_C produce the required C bias for the mixer-first detector stage. Screen grid voltage is applied to this stage through filter R_1–C_1, and plate voltage is fed through resistance-capacitance filter R_4–C_4 and coil L_2. The latter coil is common to both i.f. amplifier channels, and is broadly tuned by C_3 so that signal voltages of both beat frequencies are developed across it for transfer to the next section through coupling condenser C_5.

The Video I.F. Amplifier

The process of frequency conversion produces, in the typical receiver which we are studying, video i.f. signals ranging from 9 mc. to 14.25 mc. and sound i.f. signals extending for about 10 kc. on either side of 8.5 mc. The i.f. amplifiers in a television receiver must separate and amplify these signals.

The video i.f. amplifier must be reasonably flat from 13 mc. to 9 mc., so it will amplify uniformly the important video i.f. components; if peaked at all, it should be at about 9 mc., to compensate for attenuation of the higher-frequency signal components (near 4 mc.) by the video-frequency amplifier. It is equally important that signals below 9 megacycles in frequency be attenuated, in order to prevent 8.5-mc. sound i.f. signals from getting through the video i.f. channel.

Experience has shown that for successful single side-band reception, amplification at the picture carrier frequency should be about *one-half the average amplification of the desired side frequencies* in the video i.f. amplifier. This is secured by placing the 13-mc. video i.f. carrier on a slope of the pass-band response characteristic for the video i.f. channel, as shown in Fig. 6. Undesired side frequencies (above 13 mc.) receive very little amplification with this arrangement, and hence are suppressed. Side frequencies just above 9 mc. are amplified more than normal, to compensate for attenuation of high video frequencies in the v.f. amplifier.

The circuit for a typical i.f. amplifier stage is shown in Fig. 7. As you can see, three resonant circuits (L_2–C_3, L_1–C_1 and L_3–C_6) are employed to give the required wide response characteristics shown in Fig. 6. Note that parallel-resonant plate circuit L_2–C_3 is coupled to parallel-resonant grid circuit L_3–C_6 by coupling condenser C_5 and parallel-resonant circuit L_1–C_1. The value of C_5 is usually about 500 mmfd. This condenser serves primarily to block the d.c. plate current.

Circuits L_2–C_3 and L_3–C_6 form a pass-band resonant circuit which gives a resonant response characteristic having two widely separated peaks. Resistor R_1, having a value of about 2,000 ohms, loads this pass-band circuit, broadening the response characteristic and making the peaks less sharp. By properly adjusting condensers C_3 and C_6, it is possible to make the response peak near 9 mc. greater than the peak near 13 mc., as shown in Fig. 6.

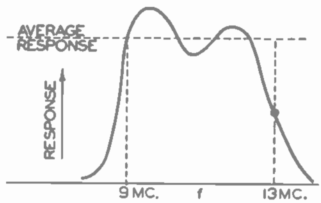


FIG. 6. Type of response characteristic desired for the video i.f. amplifier in the case of single side-band transmission.

With L_1–C_1 out of the circuit, the sides of the response characteristic would drop more or less gradually; this would be satisfactory for the high frequencies above 13 mc., but would be undesirable at the low video frequencies because it would allow a portion of the 8.5-mc. sound i.f. signal to enter the video channel. It is for this reason that resonant circuit

L_1–C_1, tuned to 8.5 mc., is employed. This circuit rejects the 8.5-mc. sound i.f. signal and attenuates signals just below 9 mc., thereby giving the desired steep side for the response characteristic. Between 9 mc. and 13 mc., resonant circuit L_1–C_1 becomes a capacitive reactance, thereby providing capacitive coupling between L_2–C_3 and L_3–C_6.

The insertion of L_1–C_1 also provides a suitable connecting point (*a*) from which the sound i.f. signal can be fed into the sound i.f. channel. For signals at 8.5 mc., L_1–C_1 will act as a high resistance (any parallel-resonant circuit is a high resistance at resonance), while parallel-resonant circuit R_3–C_{11}, with R_3 also serving to reduce the voltage applied to the screen grid. The cathode of the tube is grounded to the chassis, since the a.g.c. source also supplies the minimum C bias voltage for the tube. A self-bias cathode resistor with a condenser could be used for this same purpose; it would be inserted at point *x*.

Condenser C_7 in the video i.f. amplifier stage of Fig. 7 is somewhat unusual, for it is seldom used in sound receivers in the location shown. This condenser *provides a path to ground for any r.f. signals which may be in the filament circuit, thereby preventing these signals from entering other*

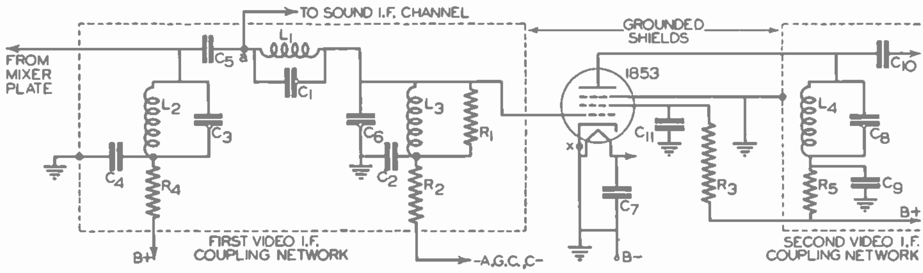


FIG. 7. **Typical video i.f. amplifier stage in a television receiver.**

circuit L_3–C_6 will act as a low reactance at 8.5 mc. since it is tuned to a higher frequency (13 mc.). Practically all of the sound i.f. voltage which exists between point *a* and ground will therefore appear across L_1–C_1 for transfer to the sound i.f. channel, and very little will be developed across L_3–C_6 for transfer to the sight i.f. channel. We will not consider the sound i.f. channel now, since it is more or less conventional in design.

The automatic gain control voltage for the video i.f. amplifier stage in Fig. 7 is supplied to the control grid of the type 1853 tube through filter and time-delay circuit R_2–C_2 and through L_3. Screen grid voltage for this tube is supplied through filter *circuits*. High-frequency signal currents flowing from the cathode through leads which run parallel to the filament leads cause r.f. signal currents to be induced in the filament circuit through the electrostatic coupling between the leads. These currents might cause undesirable interaction between stages if they were not shunted to ground by condenser C_7, which has a value of about .01 mfd. This filament by-pass condenser may be found in any or all stages of a television receiver up to and including the video detector and audio detector stages.

R_1 in Fig. 7 is in effect shunted across the plate load of the mixer-first detector stage at video i.f. frequencies; the impedance of the plate load on this stage (the combined effects of everything within the dotted box in Fig. 7) will therefore be less than 2,000 ohms at these frequencies. Each video i.f. amplifier stage will have essentially this same

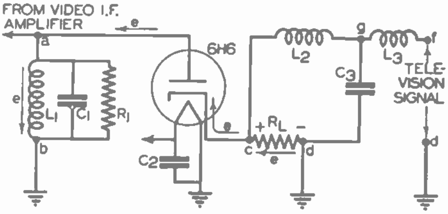


FIG. 8A. Typical video detector circuit employing a diode for half-wave rectification, followed by a low-pass filter which feeds into the video frequency amplifier. Terminal *f* is *positive* with respect to the chassis. Arrows *e* indicate directions of electron flow.

plate load, and consequently the gain per stage will be very low. With tubes having a high transconductance, a gain of from 10 to 15 per stage is possible. This means that at least two, and usually three amplifier tubes are required for the video i.f. channel of a television receiver.

The first video i.f. coupling network in Fig. 7 (within the dotted box) can be considered as corresponding to the i.f. transformer in a sound broadcast receiver. The coupling network between each stage can be identical to that shown in Fig. 7, for each stage must have the same pass-band characteristic response. Four video i.f. coupling networks are required in a video frequency amplifier having three stages.

The Video Detector

The television signal at the output of the sight i.f. amplifier is still of the form shown in Fig. *3B*, with the video signal and the synchronizing impulses modulated on the i.f. carrier. This signal will usually be fed into a linear detector circuit which cuts off one-half of each sight i.f. cycle. By passing the rectified modulated carrier through a low-pass filter which blocks all signals above 4 mc., we obtain the desired television signal, having a frequency range of from about 10 cycles to about 4 mc. This demodulated output signal of the video detector will have the form shown in Fig. *3E*.

Now let us consider a typical video detector circuit such as that shown in Fig. *8A*. The video i.f. amplifier output signal, existing across the final resonant circuit L_1–C_1 of the video i.f. amplifier, sends electrons through a load made up of the diode detector tube (one-half of a type 6H6 tube) and resister R_L, producing across R_L a pulsating d.c. voltage. Low-pass filter network L_2–C_3–L_3 shunts to ground through C_3 all a.c. components above 4 mc., so that the video detector output voltage contains only the desired a.c. components and the d.c. component of the demodulated television signal. The pedestals for the line and frame impulses will all line up at the same level.

The direction of electron flow through diode load resistor R_L determines whether impulses will make output terminal *f* swing in a positive direction or in a negative direction with respect to the chassis. In the circuit of Fig. *8A*, electrons enter R_L at point *d*, making that end of the

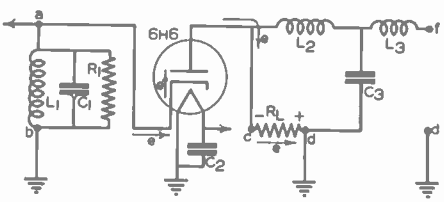


FIG. 8B. Video detector circuit of Fig. *8A* with connections to the diode reversed in order to make terminal *f* *negative* with respect to the chassis.

resistor negative with respect to point *c*. Under this condition the video detector output voltage (a modulated d.c. voltage) will vary as shown in Fig. *9A*, with the impulses making point *f* swing more positive, and with bright areas in the original scene making point f swing *in a negative direction* from the pedestal level. Since this corresponds to *negative modulation* such as is employed at the transmitter, the modulated d.c. signal is in this case said to have a *negative picture phase.*

The phase of the picture signal at the output of a diode video detector can be reversed simply *by reversing the connections to the diode detector tube,* as is indicated in Fig. *8B.* This reversal of connections makes electrons flow from c to d through resistor R_L, making point c negative with respect to the chassis. Point f is therefore also negative with respect to the

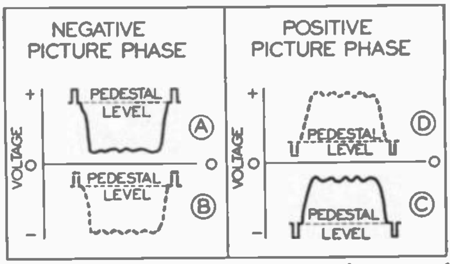


FIG. 9. When a diode video detector is connected as in Fig. *8A,* the output signal has a negative picture phase (*A* and *B*); with diode connections as in Fig. *8B,* the output signal has a positive picture phase (*C* and *D*).

chassis, and the video detector output signal appears as shown in Fig. *9C.* Note that bright lines now drive the signal in a positive direction from the pedestal level, giving the equivalent of *positive modulation,* while impulses drive the signal in a negative direction from the pedestal level. The modulated d.c. output signal of the video detector is in this case said to have a *positive picture phase.*

The addition of a d.c. bias voltage to a video frequency television signal has *no effect upon the phase of the signal.* For example, if a negative d.c. voltage is added to the signal in Fig. *9A,* making the entire television signal negative with respect to the chassis as shown in Fig. *9B,* we still have the required conditions for negative picture phase (bright lines swing the signal in a negative direction from the pedestal level). Likewise, adding a positive bias to the signal in Fig. *9C* may make all parts of it positive as shown in Fig. *9D,* but we still have the equivalent of positive picture phase.

The Video Amplifier

If we assume for the moment that the signal level at the output of the video detector is strong enough to excite the cathode ray tube in the receiver, which signal in Fig. *9* would we select? This question can be quickly answered by considering the E_g–B (grid voltage-brilliancy) characteristic of a cathode ray tube, as shown in Fig. *10.* If we choose a signal with negative picture phase and apply it in such a way that the pedestals line up with point b on the E_g–B characteristic in Fig. *10,* spot brilliancy will vary in the manner shown by curve N. Obviously this type of signal is incorrect, for bright portions of the scene at the transmitter would be reproduced as dark portions.

In the case of a signal having a positive picture phase, with the pedestals lined up at point a by adjusting the bias properly, spot brilliancy will vary as shown by curve P. Impulses darken the spot and increasingly brighter video signals give increasingly brighter spots on the receiver screen. If point a on the E_g–B characteristic is at the brilliancy cut-off point for the tube, the impulses will always drive the spot into the blacker-than-black region, and the video signal will always make the spot more or less brilliant, which is exactly what we desire. Obviously, *the cathode ray tube in a television receiver must be fed with a signal having a positive picture phase,* and a bias voltage must be applied in series with the signal to make the pedestals line up with the cut-off point.

Unfortunately, the output of the video detector is not sufficient to drive the control grid of the cathode ray tube directly; amplification is required. This calls for one or more

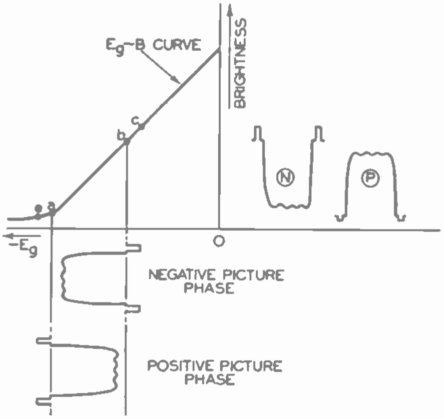


FIG. 10. Grid voltage-brilliancy (E_g-B) characteristic curve for a television cathode ray tube.

video frequency (v.f) amplifier stages between the video detector and the cathode ray tube. These v.f. amplifier stages introduce a number of problems which we shall consider one at a time.

First of all, the v.f. amplifier must respond more or less uniformly to signals over the entire range of from 10 cycles to 4 megacycles. This means that resistive loads must be used, and these in turn introduce the problem of phase reversal, for a resistance - capacitance - coupled video amplifier stage will *reverse the phase of the picture signal.* Thus, if a signal with a *negative* picture phase (Fig. *9A*) is fed into a stage, the signal at the output of that stage will have a *positive* picture phase (Fig. *9C*).

We can see exactly how this reversal in phase occurs by studying the action of the simplified video amplifier stage in Fig. *11*. When e_g is zero (such as when no television signal is present), a definite d.c. plate current will flow through load resistor R_L, its value being determined by the d.c. plate voltage and the negative C bias voltage. During this steady-state condition, point *4* on the load resistor will be negative with respect to point *3*, for electrons flow from cathode to plate, enter the resistor at *4*, and flow through it to point *3*.

Now suppose that we feed into this circuit the television signal shown in Fig. *9A*. This signal has a negative picture phase and makes point *2* have a varying positive potential with respect to point *1*. This varying positive potential cancels out part of the fixed negative C bias, making the grid-to-cathode voltage on the tube less negative and therefore making plate current *i* increase. This increase in *i* serves to increase the voltage drop across R_L, making point *4 more negative* than before with respect to point *3*. In other words, when point *2* swings *positive* with respect to *1*, point *4* swings *negative* with respect to *3*, thereby giving a 180° phase reversal. This means that if a signal having a negative picture phase (Fig. *9A*) is applied to the grid of an amplifier having a resistance load like that in Fig. *11*, the output signal will have a positive picture phase, as in Fig. *9C*. Likewise, if the signal in Fig. *9C* is applied to the grid, the output signal

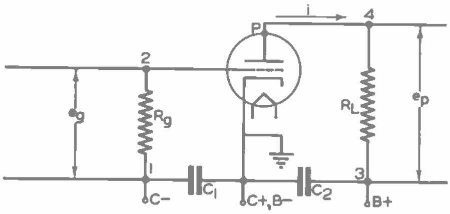


FIG. 11. Simplified video amplifier stage.

will be like that in Fig. *9A*. A resistance - capacitance-coupled amplifier stage thus *reverses the phase of the applied signal.*

Suppose we utilize the output signal between point *4* and ground in Fig. *11* instead of that between points *4* and

3. If the signal between points *4* and *3* corresponded to Fig. *9C*, the resulting signal between point *4* and ground would be like that in Fig. *9D*. If the signal in Fig. *9A* existed between points *4* and *3*, a connection between point *4* and ground would give exactly this same signal, but at a higher positive bias.

Keeping in mind that the television signal at the input of the cathode ray tube must have the equivalent of positive modulation, we can make two general conclusions as to the type of video detector circuit required:

1. If two stages of v.f. amplification are employed after the video detector in order to secure the required television signal voltage at the input of the cathode ray tube, the video detector circuit must be of the type shown in Fig. *8B*, delivering a signal with a *positive picture phase*.

2. If either one or three stages of v.f. amplification are employed, the video detector circuit must be of the type shown in Fig. *8A*, delivering a signal with a *negative picture phase*.

In high-definition reproduction of television signals it is absolutely essential that the pedestals shall all line up at the same constant signal level at the input of the cathode ray tube. When this condition is met, it is possible to adjust the bias on the cathode ray tube so that impulses will always drive the spot into the blacker-than-black region, and video signals will always make the spot more or less bright. It is a fundamental fact that the demodulated television signal (including the impulses and equalizing pulses along with the video signal) will retain its alignment of pedestals only *as long as it has its d.c. component*.

The only way in which we can amplify the d.c. component along with the television signal, thereby retaining the alignment of pedestals, is by using d.c. amplifier stages in the video amplifier. Unfortunately, however, the use of d.c. amplifiers introduces serious practical problems. These amplifiers require higher plate supply voltages, draw more power from the power supply, are unstable in operation, and cause an undesirable direct connection between low- and high-voltage supply circuits.

With only one stage of video frequency amplification, it is possible to connect the load of this stage directly to the cathode and grid of the cathode ray tube, giving true d.c. amplification. With two or more stages in the video amplifier, a practical solution involves the use of resistance-capacitance coupling; this allows each tube to be supplied with plate voltage from a common B+ terminal, but the coupling condenser *removes the d.c. component* from the television signal.

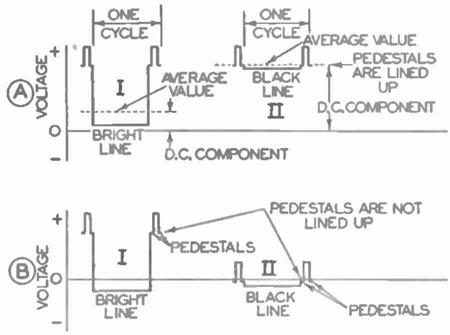


FIG. 12. Passing the demodulated television signal *I* in *A* through a condenser removes its d.c. component, giving a.c. signal *I* in *B*. Likewise, passing signal *II* in *A* through a condenser gives a.c. signal *II* in *B*.

It is important to visualize what happens to a demodulated television signal when it is passed through a condenser. Signal *I* in Fig. *12A* corresponds to a line having maximum and uniform brightness, while signal *II* corresponds to a solid black horizontal line on the scene being televised. These two signals are shown as they would appear across the detector load resistor, so the pedestals all line up at a constant level with respect to the zero-voltage line. Each signal is made up of an a.c. component (having equal areas on each side of the average-value line for each cycle) and a d.c. component, with the average values of the a.c. components considerably out of line, and with the d.c. component for the black line considerably larger than for the bright line.

When these television signals are passed through a condenser, the d.c. components are blocked out, bringing the average-value lines down to the zero-line. As a result, the average values of the a.c. components line up at zero (as in Fig. *12B*) after the signal has passed through the condenser.

however, that we chose two extreme line conditions in Fig. *12*. When the average brightness of a line is about the same for all portions of the televised scene, the difference between the pedestal levels will not be anywhere near as great as that shown in Fig. *12*. Under this condition it is possible to secure fairly satisfactory image reproduction by adjusting the t.c.r. tube bias to correspond to the average brightness level (average pedestal level in the a.c. signal).

For high-fidelity reproduction a d.c. restorer is essential, but on small low-priced television receivers it is sometimes omitted. After analyzing

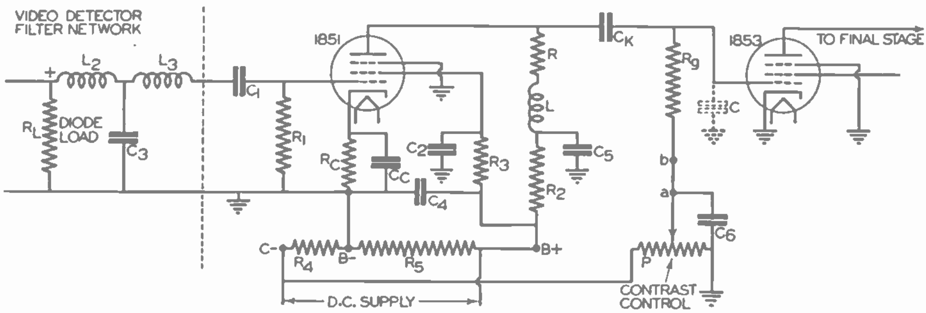


FIG. 13. Typical circuit for the first video frequency amplifier stage in a television receiver having three v.f. stages. Parts R_L, L_2, L_3 and C_3 are the same as in the video detector circuit of Fig. *8A*.

Obviously the pedestals are no longer lined up.

The addition of a fixed d.c. bias voltage to the a.c. signals shown in Fig. *12B* (placing the signal either entirely above or entirely below the zero-voltage line) would convert them into pulsating d.c. signals, but would not get the pedestals in line again. We must add a different d.c. bias voltage value for each line if we are to make the pedestals all line up again after a television signal has passed through one or more condensers.

With the pedestals in an a.c. television signal all at different levels, it is impossible to line up all the pedestals with the cut-off point on the t.c.r. tube characteristic. Remember,

a typical video frequency amplifier stage, we will take up the problem of realigning pedestals by properly restoring the d.c. components.

Typical Video-Frequency Amplifier Stage. Assuming that we have a television receiver which requires three v.f. amplifier stages between the video detector circuit shown in Fig. *8A* and the t.c.r. tube, we can consider the type 1851 tube circuit shown in Fig. *13* as being typical of that employed in the first v.f. amplifier stage. From the detector load resistor R_L, the television signal passes through a filter which removes i.f. components, then passes through coupling condenser C_1, which strips off the d.c. component. Only the a.c. component of the television signal is thus applied to the control grid of the type 1851 tube. This first v.f. amplifier tube employs self-bias, which is controlled by the value of cathode resistor R_C and is applied to the control grid through resistor R_1.

The remainder of this v.f. amplifier circuit is more or less conventional except for the presence of choke L in the plate load of the tube, but very careful circuit design is necessary in order that the required wide range of frequencies be passed with negligible frqeuency attenuation and negligible phase distortion. In this introduction to the study of television circuits, it is only possible to indicate a few of the design features which must be given consideration when building television receivers. Later lessons, dealing with the various types of circuits employed in any section, will take up this subject in far greater detail.

One fundamental consideration in building a v.f. amplifier stage like that in Fig. *13* is the value of capacity C. This capacity is shown dotted in the diagram, since it is a combination of the output capacity of the first stage, the input capacity of the second stage and stray lead capacities coupled together by C_K. The reactance of this capacity to ground becomes low enough, at the higher video frequencies being amplified, to provide a serious shunting effect. The presence of this capacity can be neutralized to a certain extent, however, by keeping plate load resistor R low in ohmic value, somewhere around 2,000 ohms. With such a low plate load value, tubes with a high transconductance are needed to provide the required amount of amplification.

Even more important than the attenuation of high-frequency components in the video signal is the phase distortion which is produced by capacity C. Coil L is introduced in the circuit for two reasons: *1.* Its inductive reactance partially or totally balances out the capacitive-reactance of C, thereby eliminating or at least reducing the amount of phase distortion; *2.* If the value of coil L is properly chosen, L and C can be made to resonate at the higher video frequencies, thereby giving a broad parallel-resonant circuit which boosts the gain at the higher frequencies and thus counteracts the shunting effect of capacity C. The value of coil L thus depends upon the capacity of C, upon the ohmic value of the load resistance, and upon the amount of phase correction which is desired.

You will remember that a video amplifier must handle frequencies down to as low as 10 cycles. At frequencies below about 60 cycles, coupling condenser C_K will not allow square-top impulses or flat (constant-level) video signals to pass without causing a gradual drop in the flat top; this means that above-normal gain is required at these low frequencies. Furthermore, the process of correcting for phase distortion at the higher frequencies produces undesirable effects at the extremely low frequencies. For these reasons, R_2 and C_5 are inserted in the plate load circuit as shown. The value of C_5 is chosen so that it acts as a shunt to ground for the high frequencies, but is not a complete shunt to ground at the low frequencies. This means that at low frequencies the effect of C_5 is negligible, and R_2 then acts as a part of the plate load, increasing its resistance and thereby raising the gain. Filter circuit R_2–C_5 also compensates for phase distortion at low frequencies, and serves to reduce any degeneration which may exist at low frequencies due to the practical limitations in the value of condenser C_C.

By-pass condenser C_4 must have a

high capacity, so its reactance at low frequencies will be lower than that of the path through the power supply. This is necessary in order to prevent low signal frequencies from passing through the power supply and causing either regeneration or degeneration.

A tube capacity which tends to shunt higher-frequency signal components to ground is also present at the input of the type 1851 tube in Fig. *13*. It is possible to adjust the value of condenser C_3 in the low-pass filter circuit of the video detector to compensate for this attenuation of high frequencies, for a filter network like this can also be made to serve as a phase-correcting and gain-equalizing network.

In addition to its other functions, filter circuit R_3–C_2–C_4 prevents v.f. signals from entering the power supply. To be effective at low frequencies (below 60 cycles), the condensers in these filters must have high capacity, oftentimes as much as 80 mfd. Electrolytic condensers are a logical choice for these high capacities, but at high frequencies their by-pass action is negligible due to the inductive reactance of the spirally-wound foil strips in the condenser. It is for this reason that electrolytic condensers in television circuits are generally shunted with non-inductive mica or paper condensers of about .05 mfd. Condenser C_5 in Fig. *13* will have less capacity than C_C, C_2 or C_4, for C_5 must not by-pass the very low signal frequencies.

Another important consideration is the method of C bias employed in a v.f. amplifier stage. When only the a.c. component of the television signal is amplified, either self-bias like that employed for the type 1851 tube in Fig. *13* or a form of fixed bias may be used. The type 1853 tube in Fig. *13* has an adjustable C bias; this could be converted to a fixed bias by connecting point *a* directly to the C- terminal of the power supply or by grounding point *a* and inserting a C battery at point *b*. The choice of a bias method will generally depend upon such considerations as equalization of gain and isolation of the C bias supply.

With a d.c. video amplifier, self-bias should not be used. The plate current of a d.c. amplifier stage varies over a wide range in accordance with the brightness of the lines being televised, and this condition would cause a widely varying voltage drop in the cathode resistor for C bias purposes. Of course, if the signal level could be kept sufficiently low so that operation would be over the linear portion of the E_g–I_p characteristic of the amplifier tube regardless of how the C bias varied, there would be no distortion and self-bias could be used, provided there were no other undesirable effects. With a variable transconductance tube, self-bias definitely cannot be employed, for even though shifts in C bias did not create distortion, they would cause variations in picture contrast.

The variable C bias arrangement for the type 1853 tube in Fig. *13* provides a manual contrast control. Contrast control potentiometer *P* is connected in parallel with voltage divider section R_4, and consequently the C bias voltage can be varied from zero to the potential of the C— terminal of the power supply.

The D.C. Restorer

The d.c. component of a television signal can be restored in the output stage of a resistance-capacitance-coupled video amplifier in such a way that the pedestals will all line up at the same potential, simply by eliminating the fixed C bias in this last stage and allowing the impulses which are applied to the grid of this tube to develop their own C bias by means of rectified grid current flow through a grid resistor of high ohmic value.

A typical video output circuit which reverses the phase of the a.c. signal and at the same time restores the d.c. component in the correct manner to make the pedestals line up is shown in Fig. *14*. Although this circuit employs a triode tube, a pentode output tube could just as well be used. Component *L* in this circuit is designed to give gain equalization, while R_L and C_1 serve their usual functions as plate load and plate by-pass condenser respectively. When an a.c. television signal of the form

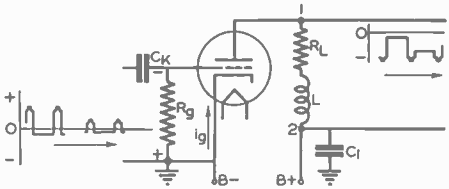


FIG. 14. Video output stage designed to restore the d.c. component and align the pedestals.

shown at the left in Fig. *14* (having a negative picture phase) is applied to this circuit, the output signal will be of the form shown at the right, with pedestals all lined up to give proper restoration of the d.c. component and with the positive picture phase required by the t.c.r. tube.

Grid resistor R_g plays an important part in the d.c. restoration process. This resistor has a high ohmic value, generally between .5 and 1 megohm. In order to understand the action of this resistor, we must consider both the E_g–I_p and E_g–I_g characteristic curves of a triode tube, as shown in Fig. *15*. Since there is no fixed C bias in Fig. *14*, the initial application of a.c. signals *I* and *II* to the input of the tube makes the average values of these signals line up with the zero-bias line in Fig. *15*, and the grid of the tube is therefore driven in both a positive and a negative direction about point *a* on the E_g–I_g characteristic curve. Since signal *I* in Fig *15* corresponds to a bright line and signal *II* to a black line, we can see that the amount which the grid swings positive is proportional to the brightness of the line being transmitted. These conditions hold true only at the instant of application of the a.c. signal to the grid.

Earlier in your course you learned that a small amount of grid current flows in a tube even at negative grid bias values, for some of the electrons which flow from the filament to the plate under the influence of the plate voltage will hit the grid, then flow through the grid resistor to ground. Curve E_g–I_g in Fig. *15* shows how this grid current begins at a negative C bias value corresponding to point *b*, and increases as the grid is driven less negative and finally is driven positive.

The application of an a.c. television signal (either *I* or *II* in Fig. *15*) to the output stage will cause grid current to flow at all instants when the signal is to the right of point *b*. Electrons will travel from the cathode to the grid inside the tube and then through resistor R_g to the cathode again in Fig. *14*, producing across R_g a voltage drop which drives the grid negative. We thus have a negative voltage on the grid, acting in series with the applied a.c. television signal. The value of this negative voltage depends upon how much the a.c. signal swings positive from the zero-bias line, and this in turn depends upon the brightness of the line being transmitted. We are thus applying, in series with the television signal, a d.c. voltage whose value is proportional to line brightness. If the ohmic value of R_g is made sufficiently high, the impulses alone will be sufficient to produce the grid current required for this form of automatic C bias and d.c. restoring action. Use of part or all of the video signal for this purpose would result in undesirable amplitude distortion.

With a negative C bias whose value is proportional to line brightness, each line of the a.c. television signal will be moved in a negative direction along the E_g–I_p characteristic curve in Fig. *15* an amount corresponding to the brightness of the line. Signal *I* (for a bright line) will be shifted automatically to position *I–I*, and signal *II* (corresponding to a black line) will be shifted only a small amount, to position *II–II* in Fig. *15*. The result is automatic alignment of the pedestals. The alignment is not exactly perfect, but it is near enough for all practical purposes. The operating C bias for the output stage will shift with each change in line brightness, but the tube will always be acting on the linear portion of the E_g–I_p characteristic (as a class A amplifier), producing an output signal which has the required phase and the required alignment of pedestals.

The time constant of parts C_K and R_g in Fig. *14* must be so chosen that it is at least equal to the time period for one line, in order to make the instantaneous grid bias dependent upon the average brightness of a line. Since average brightness ordinarily does not change rapidly from line to line, the time constant can be increased considerably; in fact, a time constant equal to the time of about ten lines appears to be quite satisfactory.

The Cathode Ray Tube

The C bias voltage for the control grid of the television cathode ray tube (abbreviated t.c.r. tube) must be a value which will make the pedestals in the television signal line up with the cut-off point on the grid voltage-brightness characteristic curve for the t.c.r. tube. Let us see how this is accomplished in a typical television receiver.

When no television signal is being fed to the grid of the video output tube in Fig. *14*, there is zero C bias, and plate current for the output tube is consequently a maximum. This

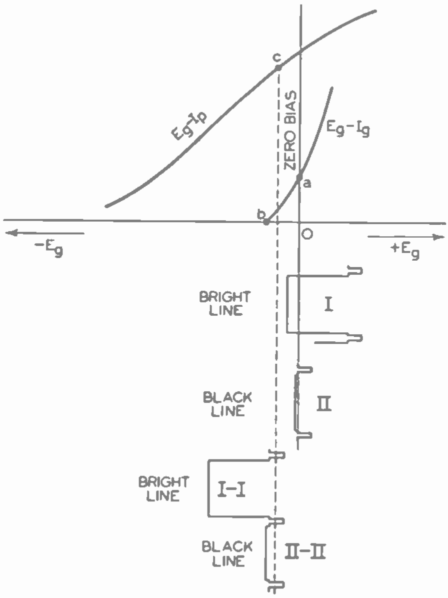


FIG. 15. Characteristic curves for a triode video output tube.

gives a maximum voltage drop between points *1* and *2* on the plate load, with point *1* negative with respect to point *2*. If the grid of the t.c.r. tube is connected to point *1* and the cathode to point *2*, the negative C bias on the t.c.r. tube for no-signal conditions would be the entire drop across R_L and *L;* this might correspond to voltage *a* on the E_g–*B* characteristic curve in Fig. *16*. This voltage places the C bias for the t.c.r. tube beyond cut-off; this means that the screen will be dark when no station program is being received.

Application of an a.c. television signal to the grid of the video output stage initiates d.c. restoring action, producing the varying negative C bias required to align the pedestals. As a result, the instantaneous voltage on

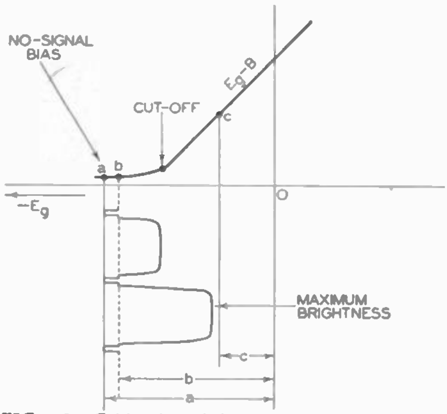


FIG. 16. Grid voltage-brightness characteristic curve for a cathode ray tube, with the television signal shown for the condition where the pedestals are *not* at the cut-off point.

the grid of the video output tube varies from nearly zero (for an impulse) to a maximum negative value corresponding to a bright line (as shown at *I–I* in Fig. *15*), making plate current vary correspondingly and thereby making the voltage on the control grid of the t.c.r. tube vary between values *a* and *c* in Fig. *16*. The pedestals might all line up at voltage *b* in this case; obviously this is not a desirable condition, for it allows parts of the video signals to swing beyond cut-off.

To make the pedestals line up at the cut-off voltage, it is necessary to introduce in the grid circuit of the t.c.r. tube a positive voltage of the proper value. This can be done in the manner shown in Fig. *17*, where the cathode of the t.c.r. tube is connected to the movable arm of a potentiometer which is part of a voltage divider connected between B++ and B— of the video output tube.

Although the circuit in Fig. *17* provides a means for making the pedestals line up with the cut-off point of the t.c.r. tube, this circuit is still not satisfactory for practical use. Suppose that after the receiver has been properly adjusted to reproduce a television program, the set is turned off long enough to allow all tube filaments to cool, and is then turned on again. The rectifier tube in the power pack warms up first, and the resulting voltage between points *4* and *P* in Fig. *17* makes the control grid of the t.c.r. tube positive. If the cathode of the t.c.r. tube warms up before the cathode of the video output tube, the positive bias on the t.c.r. tube will cause it to draw excessive current. This may damage the cathode, and may also damage the screen if sweep circuits are not acting at that moment. In other words, although the circuit in Fig. *17* is correct for operating conditions, it is not safe during the interval immediately after the set is turned on.

A video output circuit which is satisfactory under all conditions is shown in Fig. *18*. When a set having this circuit is turned on, the power pack tube may heat up first, making point *4* on the voltage divider negative with respect to point *5*. Since the cathode

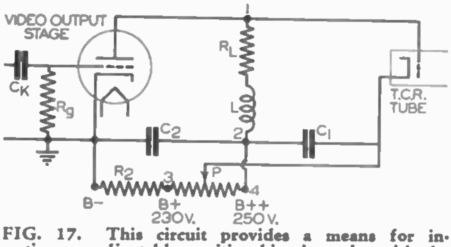


FIG. 17. This circuit provides a means for inserting an adjustable positive bias in series with the television signal applied to the grid and cathode of a cathode ray tube, but does not protect the tube while the set is warming up.

of the duo-diode-triode output tube has not yet become heated, no current flows through the diodes to potentiometer *P* and plate load R_L. The control grid of the t.c.r. tube is thus driven negative the instant the set is turned on, for the negative potential of point *4* (with respect to point *5* and cathode K of the t.c.r. tube) is applied to the control electrode G_1.

When the video output tube heats up, plate current flows through R_L,

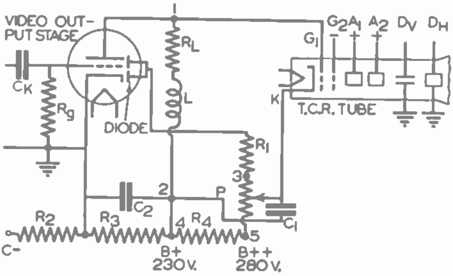


FIG. 18. This method of connecting the cathode ray tube to the video output tube is entirely satisfactory, as it provides the required adjustable bias for the cathode ray tube and at the same time protects this tube against damage during the warming-up period.

and the drop across it drives the grid of the cathode ray tube even more negative with respect to its cathode. At the same time the diode becomes conductive, so a part of this increased negative voltage is offset by the positive voltage between the movable arm of P and point *5*. With a proper choice of values for P and R_1, and proper adjustment of the movable arm on P, sufficient positive voltage can be applied to the cathode ray tube in series with the negative voltage drop across R_L and L to make the pedestals line up with the cut-off point. Since adjustment of P varies the brilliancy of the scene, this potentiometer is commonly called the *brilliancy control.*

When no television signal is present, the C bias on the triode in Fig. *18* becomes zero, maximum plate current flows through R_L and L, and the control grid of the cathode ray tube consequently gets a bias corresponding to a point beyond cut-off, darkening the spot on the screen.

The important electrodes in a television cathode ray tube are shown in schematic form in Fig. *18*. In addition to the electron emitter (the cathode) and control electrode G_1 (the control grid), there is a second grid G_2 (often called the screen grid) which is positive with respect to the cathode and serves to acelerate electrons, thereby increasing spot brilliancy. Anodes A_1 and A_2, which are positive with respect to the cathode, provide further acceleration of electrons. Anode A_2 is higher in potential than A_1, and the difference in potential between these two anodes serves to produce an electric field which makes the electrons focus to a point on the screen. Finally, there are electrostatic deflecting plates D_V and D_H (or deflecting coils) which serve to sweep the beam horizontally and vertically across the screen. At this time we will consider the sweep circuits only for tubes employing electrostatic deflecting plates.

Sweep Circuits

Let us first consider the case where one of each pair of deflecting plates in a t.c.r. tube is grounded. The other must therefore be charged first negatively and then positively in order to sweep the beam from side to side or from top to bottom across the screen. The voltage applied to either pair of deflecting plates should have the form shown in Fig. *3H*, which is an a.c. voltage having a saw-tooth wave form.

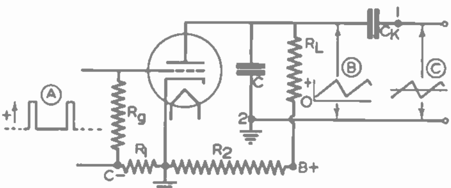


FIG. 19. Saw-tooth sweep circuit.

The circuit shown in Fig. *19* will produce a saw-tooth pulsating a.c. voltage if its grid is controlled by impulses, and consequently this circuit is satisfactory for a television receiver. The circuit employs an ordinary high-vacuum triode tube, with plate voltage being applied through resistor R_L. A C bias voltage applied through grid resistor R_g makes the grid sufficiently negative to give plate current cut-off. Under this condition there is no plate current, and condenser *C* becomes charged to the full plate-cathode voltage of the tube.

Each time a positive synchronizing impulse (*A*) reaches the grid of this tube, the impulse overcomes the negative grid bias and makes the tube conductive for the duration of the pulse. Condenser *C* then discharges through this tube, which has a definite resistance when conductive. At the end of an impulse, plate current flow stops and condenser *C* charges up again through R_L. Since the tube when conductive has a considerably lower ohmic value than R_L, the discharge is far more rapid than the charge. We thus have a gradual build-up in the voltage across *C* until a pulse arrives, then a sudden drop in voltage during the pulse interval, with this process repeating itself for each impulse. The voltage across *C* will be a d.c. voltage having the saw-tooth wave shown at *B* in Fig. *19*. When this voltage is applied through condenser C_K, the d.c. component is removed, giving the a.c. saw-tooth wave shown at *C* in Fig. *19*.

The chief drawback to the use of the saw-tooth generator circuit in Fig. *19* by itself is the fact that the shape of its saw-tooth output wave depends upon both the amplitude and the duration of the synchronizing impulses fed into it. It is absolutely essential to maintain a constant and correct saw-tooth sweep voltage at all times, yet the synchronizing impulses are never sufficiently constant nor free from interference under practical receiving conditions to provide this voltage. For this reason we need, ahead of each saw-tooth generator circuit, an oscillator circuit *which will produce impulses* of constant amplitude and the correct duration to make the saw-tooth generator circuit produce the required sweep voltage. Each oscillator circuit must produce positive pulses at a rate slightly lower than the correct frequency for that generator, and must be so designed that its frequency will be increased to the correct value automatically when fed with the synchronizing impulses associated with the television signal.

An oscillator circuit which meets these requirements is shown in Fig. *20*; it is known as a *self-blocking oscillator*. Transformer *T* in this circuit

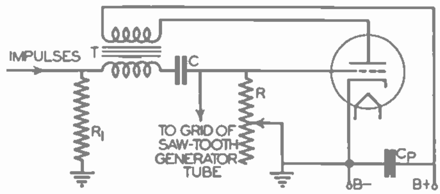


FIG. 20. Self-blocking oscillator circuit which can be controlled by synchronizing impulses.

provides feed-back from the plate circuit to the grid circuit. Transformer connections are such that when the circuit is in operation, the feed-back voltage drives the grid positive, just as in a conventional oscillator. The resulting flow of grid current through rheostat *R* produces across *R* a voltage drop which drives the grid highly negative and at the same time charges condenser *C*. This charging action lasts only for a very brief interval, equal to the time required for the negative grid to stop all electron flow in the entire circuit. Condenser *C* then begins discharging through resistor *R* at a rate determined by the values of *C* and *R* (both R_1 and the grid winding of transformer *T* have a low resistance, and consequently one terminal of *T* can be considered as connected to ground during this discharging process). When the charge on C has leaked off enough to lower the negative C bias on the grid sufficiently to allow plate current to flow again, feed-back then occurs again, driving the grid positive and causing a repetition of the entire cycle.

The frequency of the self-blocking oscillator circuit in Fig. *20* is controlled by the ohmic value of variable resistor R, for this controls the time constant of C and R. The natural frequency of blocking should always be *lower* than the frequency of the impulse fed into the circuit. Under this condition, impulses will arrive just before C has discharged to the point where the tube begins conducting. An impulse will swing the grid positive almost instantly, starting a new cycle a short time before it would normally occur. The same form of impulse is produced by this self-blocking oscillator regardless of the amplitude and duration of the synchronizing impulses (provided the amplitude is sufficient to swing the grid positive). Synchronizing impulses thus control the exact frequency of the new impulses which are fed into the saw-tooth generator and these new impulses always have the correct amplitude and duration to produce the desired sweep voltage.

In an actual television receiver, resistor R is of the semi-adjustable type and is adjusted at the factory (or by a Teletrician) to a compromise setting which gives maximum sensitivity to weak impulses and at the same time insures that the impulses will control the frequency of blocking under all normal receiver conditions.

The grid of the self-blocking oscillator circuit in Fig. *20*, being highly negative with respect to the chassis except for the duration of each impulse, may be connected directly to the grid of the saw-tooth generator circuit in Fig. *19*. With this connection, no separate negative bias is needed for the saw-tooth generator grid, and parts R_g and R_1 in Fig. *19* may therefore be omitted. Usually the two triodes are in a single envelope, with a double-triode tube such as the type 6N7 tube serving both circuits. One double-triode with its self-blocking oscillator and saw-tooth generator circuit must be provided for the horizontal sweep, and another similar system for the vertical sweep, with each circuit being adjusted to give the proper sweep frequency.

Spot-Centering Control

The required sweep voltage exists between points *1* and *2* in the saw-

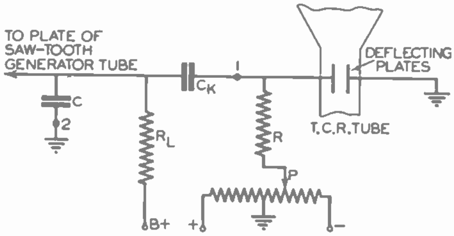


FIG. 21. Spot-centering circuit for a cathode ray tube, and method of connecting a saw-tooth generator circuit to the deflecting plates of the cathode ray tube.

tooth generator circuit in Fig. *19;* this voltage must therefore be applied to the deflecting plates of the cathode ray tube. One way in which this can be done is shown in Fig. *21*. One deflecting plate of a pair is grounded, and the other is connected to point *1*. The chassis provides the connecting path between the grounded deflecting plate and point *2* in the saw-tooth generator circuit.

It is not economically practical to build a cathode ray tube which will produce a spot in the exact center of the screen when there are no voltages on the deflecting plates. For this reason, we need a biasing voltage which will move the spot to the exact center and thereby center the reproduced image on the screen. Center-tapped potentiometer *P* in Fig. *21*, connected between power supply terminals which are respectively positive and negative with respect to the grounded center tap, will provide the required positive or negative voltage to bias the deflecting plates and center the spot. Resistor *R*, having an ohmic value of about 1 megohm, must be connected into this bias voltage circuit to prevent shorting of the saw-tooth generator circuit.

Impulse-Separating Circuit

Before the synchronizing impulses which accompany the video signal can be made to control the horizontal and connected to a point in the video amplifier where pedestals are not lined up (where only the a.c. component of the television signal is present), *the pedestals must be lined up by properly restoring the d.c. component* before the signal can be fed into the amplitude separator tube.

The amplitude separator will have a loading effect upon any stage to which it is connected, even though the separator tube is negatively biased, for the amplitude separator circuit has an input capacity which can affect the high-frequency response of the video amplifier. There is one point in a television receiver to which this input capacity can be connected without affecting high-frequency response.

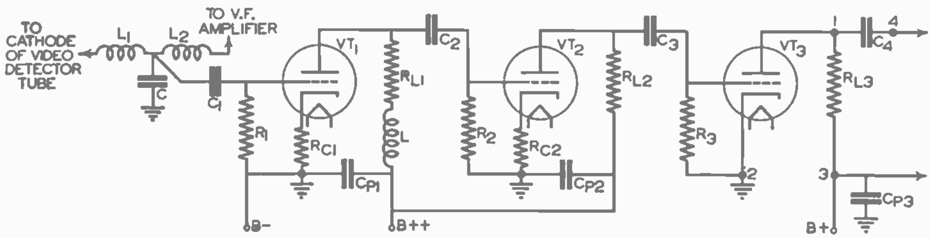


FIG. 22. Representative three-tube amplitude separator section, consisting of two a.c. amplifier stages and a combination d.c. restorer and biased amplitude separator stage.

vertical sweep circuits, the impulses must be separated from the video signal, and the horizontal impulses must be separated from the vertical impulses.

Either a triode tube which is negatively biased to plate current cut-off or a diode tube will separate the impulses from the video signal, provided that only the impulses cause plate current to flow. The television signal which is fed into the amplitude separator circuit can have either a positive or negative picture phase, but in either case *the pedestals must be lined up*. The latter requirement (alignment of pedestals) makes the use of a negative picture phase more desirable, as you will shortly see.

If the amplitude separator is to be

Referring back to Fig. *8A*, you will note that condenser C_3 in the low-pass filter network is connected across the video detector output. By connecting the input of the amplitude separator to points *d* and *g* in this circuit (across C_3), and lowering the value of C_3 by an amount equal to the input capacity, we can maintain the correct capacity across the video detector and at the same time secure the desired connection to the amplitude separator.

Although this connection eliminates the problem of input capacity, it brings up another problem due to the use of a negatively biased amplitude separator tube. With a direct connection between the video detector and this tube, the bias will also act upon the video detector, distorting the rectified signal. To overcome this, it is wise to insert an a.c. amplifier between the video detector and the amplitude separator; the coupling condenser at the input of this amplifier then prevents the d.c. bias voltage from acting on the video detector. A d.c. restorer circuit must now be employed to line up the pedestals again. If this restorer circuit is independent of the amplitude separator, it must be designed so the phase of the restorer output signal is correct for the separator circuit used.

At this time we will consider only one type of amplitude separator circuit, that shown in Fig. *22*. This is typical of the circuits which connect to the video detector and provide amplification of the impulses. Tubes VT_1 and VT_2 serve as an a.c. amplifier; two stages are required since we are assuming a negative picture phase at the video detector, and we require this same phase for the d.c. restorer. The gain of this amplifier should be equalized up to at least 250,000 cycles, for equalizing impulses occur at the rate of 26,460 cycles, and harmonics of this frequency up to about the tenth should be passed in order to maintain the steep fronts of these impulses. Coil L is inserted in the plate circuit of tube VT_1 to provide this required equalization when high gain is required at each stage.

Tube VT_3 in Fig. *22* is both a d.c. restorer and an amplitude separator. Resistor R_3 has a high ohmic value, somewhere between 3 and 5 megohms, and consequently a very high negative voltage is produced across it. This voltage drives the grid of this tube beyond plate current cut-off for the video components of the television signal, but allows the impulses to swing more positive than cut-off. The tube also lines up the pedestals, in the same manner as did the circuit in Fig. *14*.

As a result, only the impulses cause plate current flow in VT_3. This plate current, flowing through resistor R_{L3} develops across it (between points *1* and *3*) impulse signals of the form shown in Fig. *23A*. Point *1* is always positive with respect to the chassis, and assumes B+ potential (that of point *3*) whenever plate current drops to zero, such as during transmission of the video signal. An impulse causes plate current flow, and the resulting voltage drop across R_{L3} opposes the B+ voltage, making point *1* less positive than before with respect to the chassis. Condenser C_4 in the output circuit of VT_3 strips off the d.c. component from the impulse signals, and consequently the signal at point *4* after passage through the condenser is of the form shown in Fig. *23B*. It is this signal which we feed into the impulse separator circuit in Fig. *24*. Let us see how this circuit separates the horizontal impulses from the vertical impulses.

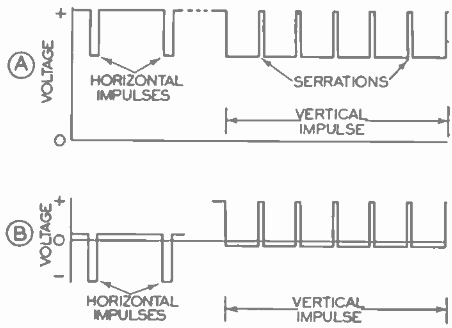


FIG. 23. Wave forms of impulses at the output of the amplitude separator section (*A*) and at the input of the impulse separator section (*B*).

Signals arriving at point *1* in Fig. *24* have two different paths to ground. The upper path has a short time constant, while the lower path is associated with a circuit having a long time constant. Considering the upper path first, horizontal impulse signals passing through 25-mmfd. condenser C_1 and .1-megohm potentiometer R_1 to ground will change the charge on this condenser twice for each horizontal impulse. During transmission of video signals (between impulses) the voltage acting on the 25-mmfd. condenser is constant, so no current flows over this path between impulses.

The beginning of a horizontal impulse changes the condenser voltage suddenly, causing current flow in one direction for an instant through the resistor-condenser circuit; the end of a horizontal impulse returns the condenser voltage suddenly to its between-impulse value, causing current flow in the reverse direction. The change in condenser charge occurs almost instantly due to the short time constant of this path.

The current pulse due to the beginning of an impulse produces between the movable arm of .1-megohm potentiometer R_1 and ground a voltage drop which makes the grid of triode section VT_H momentarily *negative with respect to cathode and ground;* the end of an impulse makes the grid momentarily *positive.* Only the negative grid voltages are effective in producing a change in plate current, however; positive voltages make the grid draw current, and the flow of this current through the upper section of R_1 produces a negative bias which counteracts the positive voltage drop and thus prevents a change in plate current.

The beginning of a horizontal impulse thus causes the plate current in VT_H to go down momentarily, reducing the current through the 3,000-ohm plate load resistor R_4 and thereby increasing momentarily the potential of the plate with respect to the cathode (making it more nearly equal to B+ potential).

Vertical impulses will also take this upper path to ground. The beginning of each vertical impulse and the beginning of each serration will also swing the grid of VT_H momentarily negative, thereby increasing momentarily the plate voltage. As a result, horizontal impulses are passed on to the horizontal blocking oscillator during both horizontal and vertical synchronizing periods, as is required.

Now let us consider the lower path in Fig. *24* and see how it reacts only to vertical impulses. The 1,000-mmfd. condenser C_2 and .1-megohm resistor R_3 in shunt with part of this path have a long time constant. Horizontal

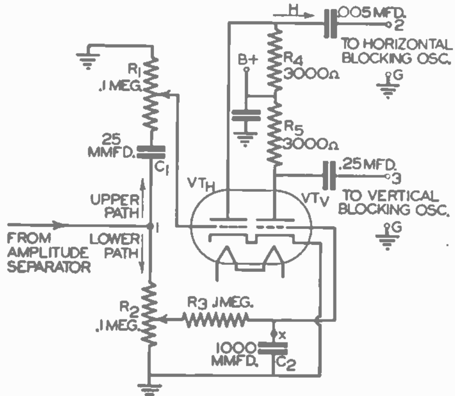


FIG. 24. Typical impulse separator circuit for a television receiver.

impulses taking this path to ground feed just as much energy to this condenser in one direction as in the other, and are of such short duration that they have essentially no effect on the condenser voltage. The grid and cathode of VT_V are connected directly across this condenser, and hence the plate current through R_5 in between vertical impulses corresponds to zero-bias conditions.

Vertical impulses taking the lower path to ground exist for the duration of three complete lines (considerably longer than the time constant of R_3 and C_2), and hence make point x and the grid of VT_V negative with respect to ground. This negative bias reduces the plate current through R_5, thereby increasing the plate-to-cathode voltage for the duration of each vertical impulse.

We thus see that tube section VT_H responds to the *beginnings* of all horizontal impulses, vertical impulses and serrations, while tube section VT_V responds only to the long vertical impulses. The impulse voltages developed across R_4 and R_5 in Fig. *24* are applied to the horizontal and vertical blocking oscillators (to the terminals of resistor R_1 in Fig. *20*) through d.c. blocking condensers which prevent the d.c. plate voltage of the impulse separator section from affecting the blocking oscillator sections.

Automatic Gain Control

The final television receiver section to be considered is that which provides the automatic gain control voltage. In this section, again, it is best to use the television signal in its d.c. form with pedestals lined up. The voltage for the a.g.c. circuit should be obtained across a load resistor which is shunted by a large condenser, in order to give a time constant so long that the voltage will follow the impulse peaks. Doing this insures that the a.g.c. voltage will depend upon carrier level (or its equivalent, the level of the impulse peaks), rather than upon line brightness.

A satisfactory arrangement is shown in Fig. *25*, where one half of a type 6H6 double diode tube serves as the video demodulator and produces, between points *f* and *d*, a television signal voltage with pedestals lined up. Since this voltage is a pulsating d.c. voltage, with point *f* always positive with respect to point *d*, electrons will flow from point *d* through resistor *R* and then from the cathode to the plate of the second diode section. This electron flow will produce across *R* a voltage having the polarity shown. Condenser *C* will tend to maintain this voltage constant.

When the television signal contains a bright line, the voltage across R_L in the video detector circuit will be low, and consequently the voltage acting on the a.g.c. diode will drop. Under this condition the a.g.c. diode acts as a very high resistance, preventing the voltage across *R* from discharging back into R_L. During impulses, the voltage across R_L will be high, a high d.c. voltage will be ap-

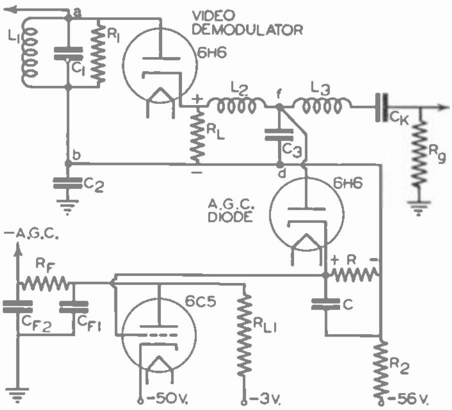


FIG. 25. Typical automatic gain control circuit for a television receiver. The diodes shown here are actually in the single envelope of a 6H6 double-diode tube.

plied to the a.g.c. diode, the diode will have a low ohmic value, and condenser *C* will charge up. In this way, parts *R* and *C* assume a voltage which depends upon impulse heights.

The voltage developed across resistor *R* in Fig. *25* is unfortunately too low for a.g.c. purposes. It must therefore be boosted by a d.c. amplifier, consisting of the type 6C5 tube in Fig. *25*. With this type of amplifier we encounter special voltage-feed problems. Observe that the plate of the 6C5 tube is connected through plate load resistor R_{L1} to a –3 volt terminal; as a result, this fixed negative bias is applied to the grids of all a.g.c.-controlled tubes. In order to place the plate of the 6C5 tube at a positive potential with respect to its cathode, the cathode is connected to a –50 volt supply terminal. The grid of this tube is connected to a –56 volt terminal through resistor R and R_2; this bias keeps the grid negative with respect to the cathode when no television carrier is tuned in, and at the same time prevents the type 6C5 tube from drawing grid current during the peaks of the television carrier.

In the video demodulator circuit of Fig. *8A*, point *d* was grounded. If this ground were present in Fig. *25*, the –56 volt terminal of the power supply would be grounded. To avoid this, condenser C_2 is introduced in the circuit of Fig. *25*. Being quite high in capacity, this condenser provides a return path for i.f. signals without affecting the rectified television signal.

When no carrier is tuned in, the voltage across resistor R in Fig. *25* is zero, and the grid of the 6C5 tube then has a negative bias of 6 volts with respect to its cathode. Plate current is therefore near zero, and the potential of the plate with respect to the chassis is –3 volts. When a high-level modulated r. f. television signal is tuned in, it develops across resistor R a positive voltage which is proportional to the peaks of the synchronizing impulses. This voltage makes the grid of the 6C5 tube less negative with respect to its cathode, giving greater plate current flow. Increased plate current through R_{L1} makes the plate end of this resistor more negative than before with respect to the chassis, and this increased voltage drop is added to the original fixed –3 volt bias on the grids of all a.g.c.-controlled tubes through time delay filters R_F, C_{F1} and C_{F2}, operating these controlled tubes at low-gain conditions. In this way the a.g.c. system provides essentially constant signal output at the video demodulator.

Review of Lesson

In reviewing this lesson, try to visualize the frequency conversions which occur as the television signal progresses through the receiver. Learn the frequency ranges which are handled by each stage and section, and above all, try to visualize the characteristics of the television signal at each stage or section. Furthermore, keep in mind that in television literature the terms *picture signal*, *video signal*, *image signal* and *sight signal* are used interchangeably. The terms *sound* and *audio* are likewise used interchangeably.

TEST QUESTIONS

Be sure to number your Answer Sheet with the number appearing on the front cover underneath the title of this text.

Place your Student Number on every Answer Sheet.

Send in your answers for this lesson immediately after you finish them. Doing this insures that the graded answers will reach you while the subject matter is still fresh in your mind, and you will get the greatest possible benefit from our speedy personal grading service. *Never hold up a set of lesson answers.*

1. Why must the pass band for the sound i.f. amplifier be greater than the 20-kc. value required for a 10-kc. audio signal?

2. Are the pedestals lined up in the signal voltage which exists across the load resistor of the diode video detector in a television receiver?

3. How many image interference signal frequencies (outside the desired television channel) must be considered in a sight-sound television superheterodyne receiver?

4. When a television system employs single side-band transmission, is the picture carrier amplified as much as the desired side frequencies in the video i.f. amplifier?

5. What is the purpose of condenser C_7, connected between ground and the ungrounded filament lead of the video i.f. amplifier stage in Fig. 7?

6. What change can be made in a diode video detector circuit in order to reverse the phase of the picture signal at the output of the video detector?

7. Does the addition of a bias voltage to a video frequency television signal change the *phase* of the signal?

8. What phase should the picture signal have at the input to the television cathode ray tube?

9. What effect does a resistance-capacitance-coupled video amplifier stage have upon the phase of a picture signal?

10. If the amplitude separator is to be connected to a point where only the a.c. component of the television signal is present, what must be done to the pedestals before the signal can be fed into the amplitude separator tube?

Essential Circuits in a Television Receiver. No. 59 RH-1

1. To permit passage of the entire sound i.f. signal despite normal frequency drift of the local oscillator circuit.

2. Yes.

3. Two.

4. No.

5. It provides a path to ground for r.f. signals in the filament circuit, thus preventing them from entering other circuits.

6. By reversing connections to the diode detector tube.

7. No.

8. A positive picture phase.

9. It reverses the phase of the picture signal.

10. The pedestals must be lined up by properly restoring the d.c. component.

CATHODE RAY TUBES FOR TELEVISION RECEIVERS

60RH-1

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

Know Your Natural Talents

No two persons are alike. Even with identical training, no two persons will do the same job in exactly the same way. That is human nature.

You have a particular combination of natural talents—every one has. When you are applying your efforts to a field which utilizes these natural talents along with radio training, your chances for success will be greatest.

You may be a natural-born salesman because of your pleasing personality, quick wit and ability to talk persuasively. These talents will come in mighty handy in radio servicing, but consider also the true merchandising branches of radio. You can sell sound and television receivers to the public; you can be a manufacturer's salesman, selling receivers in wholesale quantities to jobbers and dealers. You can be a radio parts salesman, selling radio parts to receiver manufacturers or selling radio tubes in quantities to dealers and servicemen.

You may be a natural leader of men, able to make them do exactly the kind of work you desire. Manufacturers have need for this talent. Large radio service shops need foremen to supervise the servicemen. Radio stations need chief engineers who can handle men.

If business transactions fascinate you, you stand a good chance of success with a business of your own, or as business manager for almost any enterprise connected with radio and television.

Study yourself *now* for just a few minutes. What are your own natural talents? In what branch of radio and television will these talents fit in best with your technical training? Get to know yourself, then concentrate your efforts in a field where they will be most effective.

J. E. SMITH.

NATIONAL RADIO INSTITUTE

WASHINGTON, D. C.

1941 Edition

A LESSON TEXT OF THE N. R. I. COURSE
WHICH TRAINS YOU TO BECOME A
RADIOTRICIAN & TELETRICIAN
(REGISTERED U. S. PATENT OFFICE) (REGISTERED U. S. PATENT OFFICE)

NCP17C941 Printed in U. S. A.

Cathode Ray Tubes for Television Receivers

Importance of Studying Television Cathode Ray Tubes

THE cathode ray tube in a modern television receiver outwardly appears to be a simple device. At the narrow end of the tube is an *electron gun* which produces a beam of electrons. This gun is equipped with an electrical "valve" which varies the number of electrons in the beam (the intensity of the beam) in accordance with variations in the television signal. In front of the gun are a number of coaxial cylinders which focus this electron beam to a spot on the screen at the large end of the tube. Elements which are built into the tube or placed around it deflect the beam both horizontally and vertically in accordance with synchronizing impulses received along with the television signal. The result is that the rapidly moving electron beam "paints" on the screen of the cathode ray tube a duplicate of the scene being viewed by the television camera in the transmitting studio.

Courtesy DuMont Labs., Inc.

Production line scene in a cathode ray tube factory. Surplus fluorescent screen material is wiped off by a cloth supported on a stiff iron rod, as this glass blank for a 14-inch t.c.r. tube is slowly rotated by an electric motor.

But there is much more to a modern television cathode ray tube than is evident from a casual inspection of a tube or a simple description of its operation. The factors which make for high-definition reproduction are the result of careful study by tube design engineers, and are important enough to warrant devoting an entire lesson in your course to the construction and operating characteristics of t.c.r. tubes. The Teletrician will often be called upon to make adjustments on television receivers; unless he understands the various factors which affect image fidelity, his adjusting technique will necessarily be somewhat of a hit-and-miss procedure.

The final design of a t.c.r. tube is a compromise between a number of desirable characteristics, with cost and operating voltages receiving major consideration. As a result, even the best cathode ray tubes which can be made today are not perfect. A Teletrician must know when a defect in an image is due to the limitations in the design of the tube or is due to a defect in a television receiver circuit. Mastery of the fundamental operating principles of a t.c.r. tube will insure your being able to recognize each type of defect in performance.

A separate power supply for the t.c.r. tube is highly desirable. In this lesson we study typical power supplies for t.c.r. tubes along with such topics as production of electrons in an electron gun, electrostatic and magnetic focusing of the beam, deflection of the beam, image size, fluorescent screens, and t.c.r. tube specifications.

Source of Electrons

In a t.c.r. tube, the number of electrons in the beam and the speed at which these electrons strike the screen both affect the brightness of the fluorescent spot on the screen. The engineer designing a t.c.r. tube must therefore provide a source which will give an adequate number of free electrons. In all t.c.r. tubes, regardless of whether focusing is accomplished electrostatically or electromagnetically, the electrons are produced by thermionic emission from a hot cathode which serves as the source.

Figure *1* shows the arrangement of the elements in a typical electron emitter. A cap made of nickel is heated from the inside by a non-inductive filament, so no stray fields are produced by the alternating currents flowing through the filament. The end of this cap is coated with a special chemical oxide mixture which emits electrons freely when heated. Electrons leave the end of the cap more or less at right angles to the surface, and consequently these electrons travel over paths essentially parallel to the principal axis of the t.c.r. tube.

When the coated end of the cathode is not heated, we have a condition of equilibrium. An electron (negatively charged particle) leaving the cathode surface gives to the cathode a positive charge which serves to attract the electron back to the cathode, and consequently just as many electrons return to the cathode as leave it. Heating the surface of the cathode provides the free electrons with sufficient additional energy to move beyond the attraction of the positive charges on the cathode.

Electron emission should take place in a vacuum for at least two important reasons. First of all, the absence of air particles in the vicinity of the cathode makes it easier for electrons to jump away from the cathode. Secondly, in a vacuum the emitted electrons cannot create heavy positive ions which would be attracted to the cathode, bombarding it and destroying the coated emission surface.

A mixture of about 40% barium oxide and 60% strontium oxide on the cathode surface has been found to give far better electron emission than either oxide alone. A mixture such as this emits electrons generously at relatively low temperatures, beginning at about 850° Centigrade. As a rule, the oxide coating is sprayed on the end of the cathode in the form of a liquid made up of strontium and barium carbonate or nitrate. While the t.c.r. tube is being evacuated, an intense heat is applied to the cathode (usually by inducing strong eddy currents in the nickel cap), changing the sprayed-on materials to the desired active oxides.

Electron Guns

Early Electron Guns. Until recent years the focusing of electrons in a cathode ray tube to a point on the fluorescent screen was accomplished largely by experiment, without an understanding of the principles involved. The designs used for the early electron guns are of sufficient interest to warrant brief consideration at this time.

The most widely used experimental electron gun arrangement is that shown in Fig. *2A*, in which a filament having a tip coated with barium and strontium oxides served as the cathode. This cathode was surrounded by a negatively charged cylinder called a *Wehnelt cylinder*. Electrons emitted from the tip of the filament tended to move outward in all directions, but the negative charge on the cylinder forced them back to the desired axial path. The positively charged anode attracted and accelerated these electrons, with the result that they traveled through the hole in the center of the anode and passed on to the screen in the form of the desired narrow beam.

Focusing was accomplished by varying the negative potential on the Wehnelt cylinder. Too low a negative potential on this cylinder allowed the electron beam to diverge, giving a broad and dim spot on the screen, while too high a negative voltage caused the beam to converge to a point before it reached the screen, then spread out again to form an undesirable large and dim spot on the screen. Varying the positive potential on the anode varied the speed of the electrons in the beam, thereby changing the point at which they focused to a spot. This meant that for every change in anode voltage, the beam had to be refocused by varying the potential on the Wehnelt cylinder.

Research engineers experimented continually with different focusing electrode structures. An improvement over the original structure is shown in Fig. *2B*. Here a Wehnelt cylinder (focusing electrode) is provided with an end disc having a hole in its center through which only the electrons which are properly beamed and focused can pass. The anode in this tube has somewhat the shape of a gun. Experiments showed that the difference in potential between the gun type anode and the focusing electrode had an effect upon the shape of the electron beam.

A further improved version of the early electron gun is shown in Fig. *2C*. Here the coated end of the filament served as the cathode K, just as in the previous designs. Surrounding the cathode was a Wehnelt cylinder E_1, having a hole along the principal axis of the tube through which only properly focused electrons could pass. These electrons were then acted upon by accelerating electrode E_2, which was operated at a positive potential and served to focus as well as speed up the electrons. Passing through the holes in E_2 and through cylinder E_3, electrons were accelerated further by the very high positive potential on the funnel-shaped anode E_4. Early experimenters found that the use of extra electrodes like E_3 improved performance, but these men were generally unable to explain why a particular arrangement gave good results. With the present knowledge of electron optics, the action of any of the electrode structures in Fig. *2* can be explained in terms of the movements

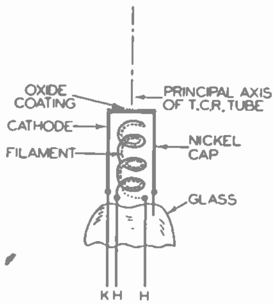


FIG. 1. Electron emitter in a typical t.c.r. tube.

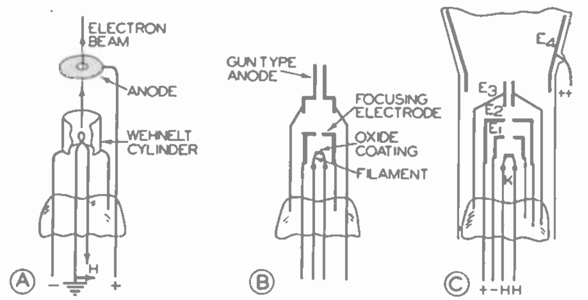


FIG. 2. Electron guns formerly used in cathode ray tubes to produce an electron beam and focus it to a spot on a fluorescent screen.

of electrons through electric lines of force which are created by electrodes having different potentials.

Modern Electron Guns. In the electron gun structures thus far studied, there were no provisions for modulating the electron beam in order to vary the brightness of the spot on the screen. These early tubes were made only for cathode ray oscilloscope use, where the only essential requirement was a spot having a fixed brightness, and hence no control electrode was needed. The size of the spot was relatively unimportant as long as it was of reasonable size and was clearly focused.

With cathode ray tubes for television use, the size of the spot is extremely important. The diameter of the spot must be almost equal to the width of a line in order to prevent lines from being visible in the reproduced image. Furthermore, the electron beam must be modulated by the television signal, and this action must not defocus the beam. Brightness of the spot is another important consideration in a t.c.r. tube; modern tubes must be designed to concentrate into the electron beam as many as possible of the electrons emitted by the cathode.

Theory of Electron Guns

Modern t.c.r. tubes are designed on a strictly engineering basis according to well-understood principles, and electron gun structures which lend themselves to be more or less accurate computation of performance are employed. A knowledge of the general principles on which electron gun design is based will be of value to the Teletrician.

Equipotential Lines. When two bodies are separated by an insulating medium such as air or a vacuum and are at different potentials, electric lines of force will exist between the two bodies and will have many different paths. The potential at each point along any one of these paths will be a value somewhere between the potentials of the two bodies. Along each path we can locate one point which has a definite in-between value of potential. A line or curve drawn through all of these points of equal potential will give us what is commonly known as an *equipotential line.*

A free electron which is traveling along the path of an electric line of force between two bodies in the direction of i n c r e a s i n g potential (toward the highest positive body) *will gain velocity.* The engineer says that the electron gains *potential,* for that is his way of assigning a definite velocity to the electron. Since the electron has mass, it is also gaining *energy* as it travels along the path in the direction of increasing potential. (A rock traveling down to earth from a height of 20 feet will have acquired far more energy at the bottom of its fall than would a rock dropped from a height of 5 feet.) This means that when an electron travels through an electric field in a direction of *increasing potential,* it will receive energy (or potential, or velocity, as you prefer) from the electric field.

An electron traveling in a direction of decreasing potential (toward the lower-potential body) will be retarded, and will lose some of its energy, potential or velocity. An electron moving *along* an equipotential line will *neither gain nor lose velocity, energy* or *potential.*

An e q u i p o t e n t i a l line passes through all points having the same potential. Any number of equipotential lines, each corresponding to a different potential, can be drawn between two charged bodies; some will have low potentials and some high potentials. When an electron moves *from a low* equipotential line *to a high* equipotential line, its velocity is *increased*. An electron moving from a high to a low equipotential line will lose velocity.

An electron traveling *at right angles* to equipotential lines is speeded up or retarded, as the case may be, but is not diverted from its plates. In all other cases, equipotential lines will be curved. In t.c.r. tubes, we deal almost entirely with curved equipotential lines.

Let us consider first the condition shown in Fig. *3A*, where electron *e* is traveling at an angle to the principal axis of a cathode ray tube and is passing from a low-potential region to a high-potential region. The change

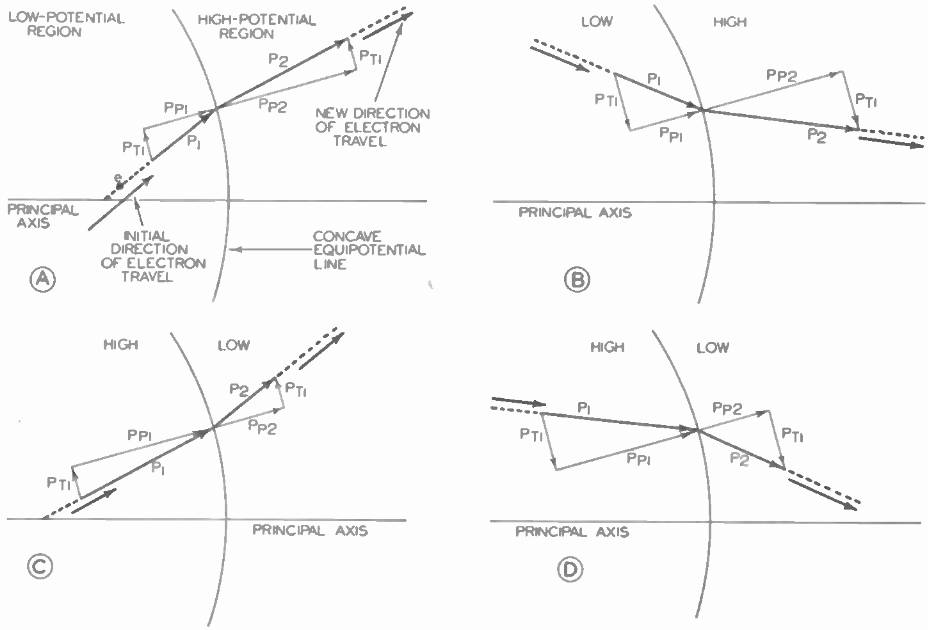


FIG. 3. An electron traveling through an equipotential line at various angles is diverted from its path in the manner shown here. In each case the electron approaches a *concave* equipotential line when traveling in the direction indicated by the heavy arrows. When an electron travels in the reverse direction over any one of these paths, it is said to approach a *convex* equipotential line. All velocity components, such as P_{T1}, P_{P2}, etc., are assumed to exist at the point where the electron path crosses the equipotential line. The arrow-line triangles are drawn away from each equipotential line in these diagrams merely for clarity.

straight path of travel. Only when an electron is traveling through an electric field at some angle other than 90° to the equipotential line is its direction as well as its velocity changed. This change in the direction of travel of an electron merits further study, for it is the fundamental action of all focusing systems in t.c.r. tubes.

Equipotential lines are straight and parallel only when the charged bodies are two large parallel metal plates; the lines are then parallel to the flat

in potential along the path of the electron is actually quite gradual, there being no definite boundary for a region, but we can simplify our study greatly by assuming that the curved equipotential line represents the boundary between regions of different potential. The results obtained with this assumption will be sufficiently accurate for our purpose.

In the low-potential region in Fig. *3A* electron *e* has a velocity P_1, which may be broken up into two components, P_{T_1} tangential to (along) the equipotential line and P_{P_1} perpendicular to the equipotential line.

The tangential velocity component P_{T_1} remains unchanged as the electron moves from a low to a high-potential region, for this component represents motion along the equipotential line. The velocity component perpendicular to the equipotential line increases as the electron crosses this line, so that the velocity perpendicular to the line in the high-potential region is P_{P_2}. Combining the two velocity components again after the electron has crossed the equipotential line, we get P_2 as the new electron velocity. This is larger than the original electron velocity P_1 and is bent closer to the principal axis.

The passage of an electron from a low-potential region to a high-potential region under the conditions in Fig. *3A* thus results in *increased electron velocity* and a travel path *more nearly parallel to the principal axis.* By repeating this process for three other conditions of electron travel, as indicated in Figs. *3B*, *3C* and *3D*, we can determine the nature of the bending in each case.

All four diagrams in Fig. *3* are reversible; that is, the indicated electron paths are correct for either direction of electron travel along the path.

If we limit ourselves to equipotential lines which are portions of circles having their centers on the principal axis, we can summarize the results of the diagrams in Fig. *3* as follows:

1. Electrons approaching a *concave* equipotential line, moving *away from* the principal axis, and passing from a *low-* to a *high-potential* field are bent *back toward* the principal axis.

2. Electrons approaching a *concave* equipotential line, moving *toward* the principal axis, and passing from a *low-* to a *high-potential* field are bent *away* from the principal axis.

3. Electrons approaching a *concave* equipotential line, moving *away from* the principal axis, and passing from a *high-* to a *low-potential* field are bent *away from* the principal axis.

4. Electrons approaching a *concave* equipotential line, moving *toward* the principal axis and passing from a *high-* to a *low-potential* field are bent *towards* the principal axis.

5. Electrons approaching a *convex* equipotential line, moving *toward* the principal axis, and passing from a *high-* to a *low-potential* field are bent *towards* the principal axis.

6. Electrons approaching a *convex* equipotential line, moving *away from* the principal axis, and passing from a *high-* to a *low-potential* field are bent *away from* the principal axis.

7. Electrons approaching a *convex* equipotential line, moving *toward* the principal axis, and passing from a *low-* to a *high-potential* field are bent *away from* the principal axis.

8. Electrons approaching a *convex* equipotential line, moving *away from* the principal axis and passing from a *low-* to a *high-potential* field are bent *towards* the axis.

Although these eight statements take care of all conditions in t.c.r. tubes, it is far easier and better to remember the method shown in Fig. *3* for deriving these facts than to memorize the eight statements.

Bi-potential Electronic Lens

In a practical t.c.r. tube, a beam of electrons which focuses to a small spot on the fluorescent screen is produced by two distinct sections: 1. A hot cathode and an electrode system which converges the emitted electrons to a point quite near the cathode on the principal axis of the tube; 2. One or more electronic lens systems located between the first converging point and the fluorescent screen, to produce equipotential lines which will converge the electron beam to a small spot on the fluorescent screen. This second section will now be considered in its simplest form, as a bi-potential electronic lens.

In Fig. *4A* is shown a cross-section view of a simple bi-potential lens made up of two metallic cylinders placed end to end on a common principal axis. The smaller cylinder has a lower positive potential than the larger cylinder, and the difference in potential between the cylinders results in equipotential lines distributed as shown in Fig. *4A* for any lengthwise cross-section of the cylinders.

Point *O* can be considered as the concave inside the larger cylinder. Let us see what happens to electrons as they pass through one convex equipotential line and one concave equipotential line.

An electron traveling from point *O* through the 1,100-volt convex equipotential line (shown by itself for clearness in Fig. *4B*) is bent *toward* the principal axis. If this were the only equipotential line acting upon electrons, the beam would be focused

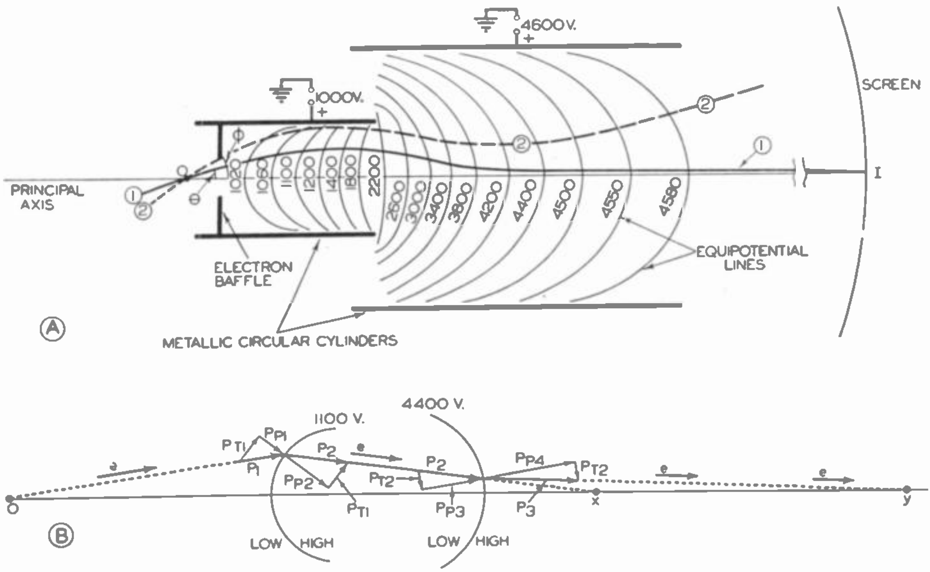


FIG. 4. Electron paths through a typical bi-potential electronic lens for a t.c.r. tube.

point source for the electronic lens in Fig. *4A*, as electrons are concentrated at this point by the first section of the t.c.r. tube (by the cathode and its associated focusing system). Since the two metal cylinders produce the same electric field for any cross-section, electrons leaving *O* in all directions at any given angle with the principal axis will be acted upon in a similar manner by this electronic lens.

Notice that electrons traveling to the right from point *O* first encounter convex equipotential lines. These lines gradually straighten out, then become to point *x* on the principal axis. In passing through the 4,400-volt convex equipotential line, however, the electron beam is bent away from the principal axis, so that it now focuses at a point farther away along the principal axis, at *y*.

Returning to Fig. *4A*, the convex equipotential lines having potentials from 1,020 volts to 2,200 volts will progressively bend the electron beam toward the principal axis, and at the same time will increase the velocities of the electrons. The concave equipotential lines from 2,200 volts to

4,580 volts will gradually straighten out the electron beam until it is almost parallel with the principal axis and is converged to a spot of the desired size at point *I* on the fluorescent screen. Line *1* in Fig. *4A* represents the path to the screen taken by electrons leaving point source *O* at the angle θ with the principal axis, when this electronic lens is properly adjusted by varying the electrode voltages. Electrons leaving point *O* along the principal axis will be accelerated but not bent, since these electrons will travel at right angles to all equipotential lines.

There is a practical limit to the angle at which electrons can leave point *O* and still be focused to a point on the screen. For example, electrons leaving point *O* at the angle ϕ are acted upon by the electronic lens in such a way that they take path *2*. Obviously these electrons would cause undesirable spreading of the beam. To overcome this, one or more electron baffles (each a disc with a hole in its center) are used in a t.c.r. tube *to block all electrons which do not converge to the desired narrow beam along the principal axis.*

Designing a T.C.R. Tube

The information just given you about electronic lenses in cathode ray tubes is sufficient for all practical purposes, as it allows you to visualize the actions involved in focusing the electron beam to a spot of the required size on the screen. The manner in which a cathode ray tube designer utilizes these principles and makes the computations necessary for designing a cathode ray tube are sufficiently interesting, however, to merit a brief discussion at this time.

It is possible to consider the electronic lens represented by Fig. *4B*, as a thick lens having true spherical surfaces, and calculate the dimensions and voltages required for each cylinder in a cathode ray tube having a specified length and face diameter. The formulas for thick lenses are rather cumbersome to handle, however. Since there is always an opportunity to adjust the characteristics of an electronic lens by varying the anode voltages, it is quite possible to reduce the complex arrangement of equipotential lines in Fig. *4A*, to the simple equivalent lens arrangement shown in Fig. *5*.

In Fig. *5*, our electronic lens system is looked upon as a thin lens having two focal points, f_1 and f_2. With this assumption, the design engineer is able to determine the position and

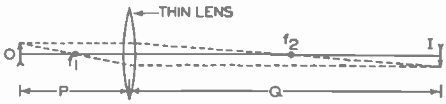


FIG. 5. The complex electronic lens shown in Fig. *4A* can, for design purposes, be considered equal to the thin double-convex lens shown here.

size of image *I* for a given object size and object position, just as is done in geometric optics. The ratio of image distance *Q* to object distance *P* determines the amount of magnification provided by the lens; this means that if the size of the source of electrons is known, the size of the spot on the screen can readily be calculated.

Mathematical study of electronic lenses has shown that both focal lengths in Fig. *5* *decrease* (points f_1 and f_2 move closer to the lens) as the ratio of the voltage on the larger cylinder to the voltage on the smaller cylinder is *increased*.

The simple lens in Fig. *5* is imagined to exist inside the smaller cylinder (the first anode) in an actual tube, near the right-hand end of this cylinder. Increasing the ratio of the anode voltages moves this equivalent lens closer to the right-hand end of the smaller cylinder.

The *ratio* of the diameter of the largest cylinder to that of the smaller is known as the *gun diameter*. This gun diameter ratio or cylinder diameter ratio has an important effect upon the characteristics of the lens.

Suppose that a tube designer is called upon to design a t.c.r. tube having a definite screen diameter. Since the R.M.A. standards call for 441 lines per picture, he can readily figure out how large the spot on the screen should be. He next selects a suitable cathode and heater combination to serve as an electron source, basing his choice upon past experience. Knowing the object and image sizes, he can now determine the magnification which the electron lens must provide. For a definite tube length, the gun diameter and approximate anode voltage ratio can now be calculated.

We need not go farther into the problem of designing television cathode ray tubes, since this is a job for highly specialized engineers. Our chief interest is in the characteristics of the tube after it has been properly designed and constructed.

The Cathode Lens

As has already been pointed out, there are two electrostatic lens systems in a t.c.r. tube. The first one is near the cathode and is used to bring the emitted electrons to a more or less sharp point which can act as a source of electrons for the second lens.

The first lens is essentially produced by the control grid, which is a Wehnelt cylinder located in front of the cathode. This first lens is known as the *cathode lens* or *immersion lens* (any electrostatic lens in which the object or source of electrons is inside or immersed in the lens is an immersion lens.) The Wehnelt cylinder is usually given a negative bias with respect to the cathode, and is excited with the television signal; it thus serves as the control electrode.

The cross-section diagram in Fig. *6A* shows a typical arrangement of the electrodes located near the cathode of a t.c.r. tube. These electrodes are circular metal cylinders, and consequently they act uniformly on electrons traveling in any direction. The equipotential lines in Fig. *6A* are shown for the condition where the control electrode is at zero potential with respect to the cathode, a condi-

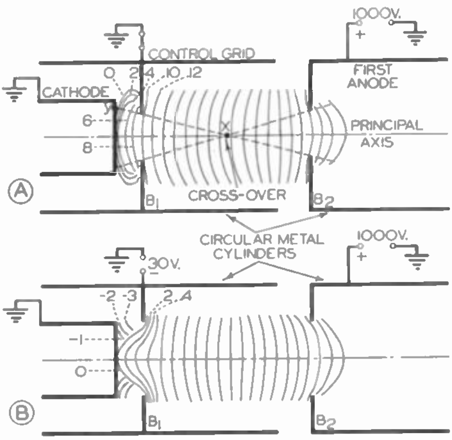


FIG. 6. Equipotential lines produced by the immersion lens of a t.c.r. tube when the control grid voltage is zero (*A*) and when there is a grid bias of —30 volts (*B*). The numerals on the lines indicate potential along the lines with respect to ground (the cathode is grounded here).

tion corresponding to maximum brilliancy of the spot on the screen.

Since the first anode is at a high positive potential with respect to the cathode, positive equipotential lines exist right up to the cathode in Fig. *6A*. (The position and distribution of equipotential lines in any structure can be determined experimentally by engineers with suitable apparatus, or can be computed by means of a complex mathematical analysis.) Along the face of the cathode, the positive potentials pull electrons out of the heated electron-emitting surface. Those electrons which are traveling along the principal axis are accelerated but not bent as they move toward the first anode perpendicular to the equipotential lines.

An electron leaving the cathode at a point away from the principal axis, such as at point y, will encounter convex equipotential lines of increasingly higher potential; these will force the electron to take the indicated path from y to the cross-over point, and at the same time will accelerate the electron.

Any electrons traveling from point y away from the principal axis will follow an equipotential line without accelerating, until they are redirected toward the principal axis again. They are then attracted by the first anode, and are accelerated along with the other electrons in the beam. Stray electrons may form an electron cloud around the cathode, outside of the zero equipotential line. This electron cloud will tend to repel electrons back to the principal axis and force them to go through cross-over point X.

Most of the electrons which make up the final beam will be pulled out from the center of the cathode and will be accelerated rapidly with a minimum of change in direction. Electrons emitted at such angles that they could not possibly go through the cross-over point are blocked by electron baffle B_1. The first anode has another electron baffle (B_2), which also blocks electrons outside the desired beam.

When the control electrode has a negative bias of 30 volts with respect to the cathode (a condition corresponding to a low-brilliancy spot on the t.c.r. tube screen), the equipotential lines will be arranged as shown in Fig. *6B*. The negative charge on the control electrode has the effect of making the positive equipotential lines sharply convex for electrons leaving the cathode; furthermore, this positive potential increases rather slowly in the vicinity of the control electrode.

We also have negative equipotential lines in the vicinity of the cathode in this case. Many of the electrons which would normally leave the cathode because of the potential given them by the heat of the filament cannot overcome the repelling force of these lines, and consequently are kept at the cathode. The result is that only electrons near the principal axis are pulled away from the cathode by the first anode. We thus see that a negative charge on the control grid *reduces the number of electrons which can enter the electron beam.*

The control electrode has its greatest effect in the region between the cathode and electron baffle B_1. The electrostatic field between electron baffles B_1 and B_2 is essentially constant for a definite first anode voltage. With proper electrode design, the equipotential lines in this region will be so shaped that there will be convex lines for focusing the electrons to cross-over point X, and concave lines for narrowing the beam again as the electrons spread out after leaving point X.

A Complete Electrostatic Lens

The general arrangement of the electrode elements in a t.c.r. tube employing electrostatic focusing is shown in Fig. *7*. Having considered the action of each component of the system, let us now review the action of the entire system.

Cathode K serves as the primary source of electrons. The control electrode G_1 produces between baffle B_1 and the cathode an electrostatic field which essentially controls the number of electrons emitted by the cathode. The first anode A_1 provides between it and G_1 an electrostatic field which focuses the emitted electrons to cross-over point X. The first and second anodes, A_1 and A_2, together form a bipotential electronic lens which converges the electron beam back into a narrow stream again and focuses the beam to a spot of the desired size on the fluorescent screen. Electron baffles B_1, B_2 and B_3 block any electrons which tend to widen the final electron beam.

The number of electrons in the

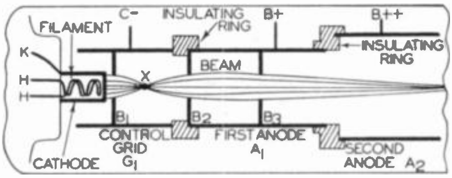


FIG. 7. General layout of electrodes in a t.c.r. tube employing electrostatic focusing. Insulating rings increase the rigidity of the gun structure.

beam will vary at different points, for the baffles will divert some electrons to the positive supply leads. If milliammeters are inserted in the B+ and B++ leads, the sum of their readings will be approximately equal to the electron currents at cross-over point X. The current in the second anode supply lead is a better indication of screen spot brightness, however. This anode usually extends into the funnel of the t.c.r. tube; in addition to accelerating the electrons as they move toward the screen, it collects the electrons from the fluorescent screen. Oftentimes a conductive carbon coating inside the funnel of the tube is connected to the second anode.

Increasing the voltage on anodes A_1 and A_2 will speed up the electrons in the beam, thereby increasing the second anode supply current. Increases in anode voltages must be made in such a way that the ratio of voltages remains constant, in order to maintain proper focus of the electron beam on the screen.

The introduction of a baffle or auxiliary electrode S_g between the first anode and the control grid in the manner shown in Fig. *8*, with a positive voltage of from 100 to 250 volts applied to this electrode, increases the electron current at cross-over point X greatly without seriously affecting the focusing of the beam. When this electrode (commonly called the *screen grid* or *second grid*) is employed to accelerate electrons, the important function of beam focusing can be given more attention in the design of the first and second anodes (without a screen grid, these anodes would have to perform the entire job of accelerating the electron beam, in addition to focusing the beam).

T.C.R. Tube Adjustments

The Teletrician's primary interest in a t.c.r. tube is centered around the effects which variations in electrode voltages have upon spot size and spot brilliancy. By referring to the schematic circuit diagram for a typical t.c.r. tube (Fig. *9*) and utilizing the

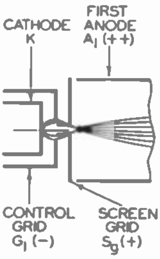


FIG. 8. Introducing a screen grid between the control grid and the first anode increases the beam current.

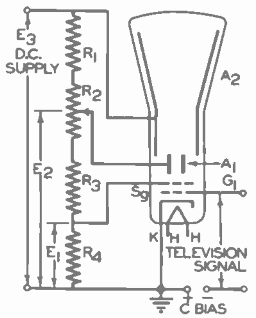


FIG. 9. Schematic circuit diagram of a t.c.r. tube having a screen grid, showing the d.c. voltages applied to the various electrodes. Filter and by-pass condensers are omitted.

principles just presented, these effects may be deduced.

The voltages applied to the various electrodes in a t.c.r. tube depend a great deal upon the size of the tube. For a tube having a face diameter of 9 inches, the highest d.c. supply voltage E_3, applied between the second anode and the cathode, may be as much as 7,000 volts, and the first anode may have a potential of about 2,000 volts. The screen grid in this case might be 250 volts positive with respect to the cathode. The television signal and a C bias voltage are applied between the control electrode and the cathode, with the control electrode always negative. Now let us see how spot size and spot brilliancy will vary as these voltages are varied.

Assume first that the control grid is highly negative, with spot brilliancy correspondingly low. Electrons under this condition are flowing to the screen in a narrow cone, with the result that the beam is focused to a small spot. As the control grid is driven in a positive direction, more and more electrons enter the stream, and spot brilliancy increases. At the same time, the electrons in the stream repel each other more than before, and spot size is therefore increased when the control grid is driven more positive. By careful tube design, the spot diameter can be maintained within about 40% of a definite size for normal variations in the control grid voltage. This variation will not materially affect line definition if the largest spot diameter is less than the width of a line.

Raising voltages E_1, E_2 and E_3 will increase spot brilliancy. Conversely, reducing these voltages will reduce spot brilliancy. To see how these voltages affect spot size, we will consider each electrode by itself. Increasing screen grid voltage E_1 causes electrons to be drawn from a larger area on the cathode, giving more electrons in the beam and a larger cone at the cross-over; the result is a "stiffer" beam, with less effective focusing due to the greater repelling action among electrons in the beam. These factors together cause spot size to be increased when screen grid voltage E_1 is increased.

Provisions are usually made for varying electrode voltage E_2 in a t.c.r. tube, for this voltage has a pronounced effect upon spot focusing. Increasing E_2 without changing E_3 reduces the potential difference between E_3 and E_2. The equipotential lines then become flatter (less convex and less concave), there is less bending as the electrons pass through the second electrostatic lens, and the point of focus (the point at which the beam is focused to a sharp spot of minimum size) is moved farther away from the second anode. Increasing E_2 also gives increased acceleration of electrons. We can therefore say that *increasing* the voltage E_2 on the *first anode* will move the focus point *outward* and at the same time give a *brighter* spot. If the point of focus is originally between the second anode and the screen (so that electrons are diverging again as they reach the screen), increasing the first anode voltage will move the point of focus closer to the screen, thereby reducing spot size. When the point of focus is exactly at the screen, spot size will be a minimum, and all changes in anode voltages will increase spot size. Decreasing first anode voltage E_2 will reduce spot brilliancy and bring the point of focus closer to the second anode. With most t.c.r. tubes designed for electrostatic focusing, it is customary to vary the first anode voltage E_2 until a sharply focused image is obtained on the screen.

Provisions are seldom made for adjusting the second anode voltage E_3, for this is invariably the maximum voltage obtainable from the d.c. power supply. We can readily see, however, that increasing this voltage would increase spot brilliancy since it gives increased acceleration of electrons. At the same time, an increase in E_3 will increase the potential difference between E_3 and E_2, thereby making the equipotential lines more concave and more convex, and moving the point of focus closer to the second anode. Lowering the value of the second anode voltage (E_3) in a t.c.r. tube will *reduce spot brilliancy*, and increasing the second anode voltage will *increase* spot brilliancy.

Magnetic Focusing

The fact that an electron in motion in a vacuum is the equivalent of a current and is producing magnetic lines of force makes it possible to employ a magnetic field for focusing a divergent stream of electrons to a point. To understand exactly how this magnetic field (commonly called the magnetic field produced by the focusing coil which surrounds the neck of the tube. The magnetic lines of force produced by this coil are essentially parallel to the principal axis of the tube and are distributed uniformly through the neck of the tube.

In Fig. *10* the path taken by an electron leaving point x at the angle θ with the principal axis is shown as a long sweeping curve, first away from the principal axis and then toward it. Actually, however, the electrons are twisted around the principal axis in a spiral manner at the same time that it is moving away from or toward the axis.

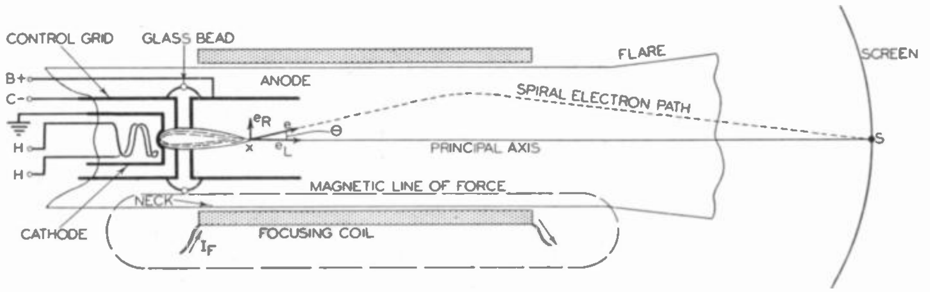


FIG. 10. Elements in a t.c.r. tube employing magnetic focusing.

a magnetostatic field because it is fixed in value) can be utilized for electron beam focusing, we must first consider a few fundamental principles pertaining to the behavior of electrons in magnetic fields.

A typical t.c.r. tube employing magnetic focusing is shown in Fig. *10*. At the left end of the tube is a conventional electrostatic lens made up of a heated cathode, a negatively biased control grid and an anode which serves both for focusing and for accelerating the electrons. This electrostatic lens focuses the emitted electrons to cross-over point x. From this point the electrons spread out into a cone, and are focused to a spot of the desired size on the screen by

In order to prove that electron e leaving cross-over point x will take the path shown in Fig. *10*, we must consider its velocity as having two components. Velocity component e_L provides motion *longitudinally* along the axis, while velocity component e_R provides motion radially outward from the principal axis. You will shortly see that motion along the axis is not affected by the magnetic field, whereas radial motion through the magnetic field forces electrons to bend back to the principal axis.

Electron e is thus moving longitudinally along the axis toward the screen at the same time that it is moving radially away from and back to the principal axis. If the radial motion back to the axis can be completed by the time the electron has reached the screen, the desired focusing is secured.

Suppose that a straight wire is placed in a uniform magnetic field made up of straight parallel magnetic lines of force, with the wire parallel to these lines of force. When a current is sent through this wire, the current will set up a magnetic field of its own surrounding the wire. These circular magnetic lines of force will be at right angles to the existing straight lines of force at all points, and consequently the interaction between the two fields will be exactly the same at all points around the wire. The result is that the original magnetic field has no effect whatsoever upon the flow of electrons through the wire.

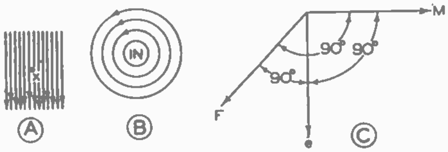


FIG. 11. An electron moving at right angles to a magnetic field is forced out of its straight path.

We can replace this wire with a stream of electrons flowing parallel to magnetic lines of force, because it is electrons in motion which produce magnetic fields; we thus see that when magnetic focusing is employed, *electrons traveling along the principal axis are unaffected by the magnetic field.*

When a wire carrying current is placed at right angles to a magnetic field, we know that there will be interaction of magnetic fields and a resultant force tending to move the wire (this is the principle of an electric motor). Electrons traveling at right angles to the focusing magnetic field in a t.c.r. tube are acted upon by a resultant force in much the same manner.

Imagine that the magnetic lines of force shown in Fig. *11A* are parallel to the plane of this page, and electrons are moving into the field (into the paper) at point *x*, along a path or beam which is at right angles to the page. Associated with these moving electrons will be circular magnetic lines of force having the directions shown in Fig. *11B*. When these circular magnetic lines of force exist in the magnetic field of Fig. *11A*, there will be a crowding of flux at the left of point *x* and a thinning out of flux at the right of point *x*. This unbalance causes electrons to move to the right, thereby rebalancing the field.

The complete picture of this action is shown in the three-dimensional diagram in Fig. *11C*. The initial direction of electron movement (*e*) and the direction of the magnetic flux (*F*) are at right angles (90°) to each other. As a result of the interaction between the magnetic lines of force, the electrons will be moved to the right (arrow *M* indicates this motion), at right angles to both the initial electron flow and the original magnetic field. From this fundamental analysis, we see that an electron traveling perpendicular to a magnetic field is forced to move in a direction *at right angles to both its original path and the original magnetic field.*

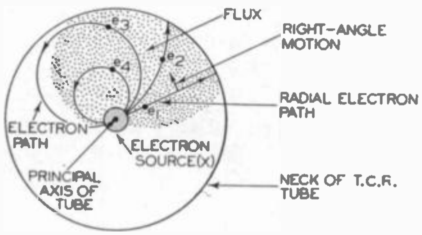


FIG. 12. Electron paths for various focusing magnetic field strengths in a t.c.r. tube.

Returning to Fig. *10*, we can now see that it is the reaction between the radial electron velocity component

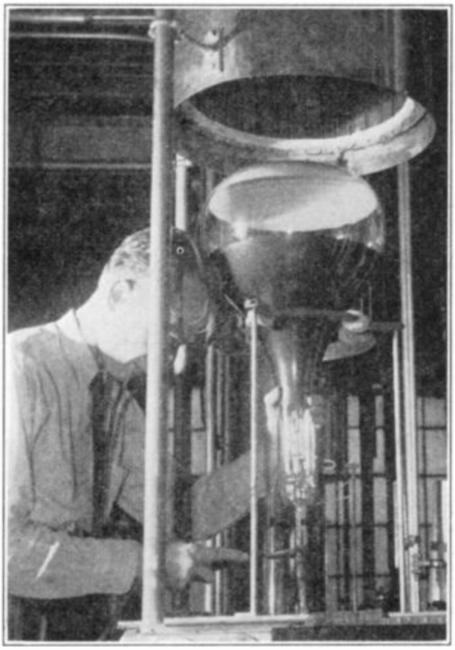
e_R and the focusing magnetic field which causes electron e to be redirected back toward the principal axis of the tube. We may consider the effects of the magnetic field upon each velocity component individually, then combine the effects to get the resultant.

It has already been shown that velocity component e_L is not changed by the magnetic field, so let us concentrate upon e_R. It will be more convenient to look at a cross-section diagram through cross-over point x of the t.c.r. tube (Fig. *12*) while studying this action.

Assume that electrons are moving radially away from cross-over point x, which is our electron source. If there were no magnetic field in the vicinity, these electrons would move radially out to the neck of the tube, as indicated by path e_1. With a focusing magnetic field here, at right angles to the electron path, these electrons are given a side push at right angles to their original path, with the amount of this push depending upon the flux density. For a low flux density the electrons would therefore take path e_2, and for increasingly greater flux densities they would take paths e_3 and e_4 respectively. In a system of magnetic focusing, the magnetic field density is increased simply by increasing the value of direct current through the focusing coil.

Note that paths e_3 and e_4 in Fig. *12* are both complete circles which bring the electrons back to the principal axis. For a given initial electron velocity, increasing the magnetic field density shortens this circular path back to the principal axis. By adjusting the field strength so it takes electrons just as long to travel this circular path back to the axis as it does for them to travel longitudinally along the axis to the screen, we can make electrons hit the screen right at the principal axis even though they leave the cross-over at an angle. Varying the focusing coil current I_F in Fig. *10* changes the magnetic field strength; therefore, in a t.c.r. tube employing electromagnetic focusing, *the focusing coil current* (I_F in Fig. *10*) *is varied* in order to focus the electron beam.

It is not essential that the focusing coil enclose the entire distance from the cross-over point to the screen. A short coil located near the cross-over point will give electrons the essential twist back to the principal axis, so they will focus to the desired spot size at the screen.



Courtesy DuMont Labs., Inc.

Sealing off a 14-inch t.c.r. tube following evacuation and bombarding of electrodes. The glass tubing going to the vacuum pump in the base of this exhaust position is carefully heated just below the neck of the tube. As the glass softens, air pressure forces the walls of the glass tubing inward, closing the opening and sealing the tube.

There is a definite relationship between the velocity of the electrons at the cross-over point and the magnetic field strength required for correct focusing. The greater the electron velocity, the greater must be the flux density in order to secure the desired focusing. Any change in electrode voltages in the first electronic lens changes the electron velocities, making it necessary to readjust the focusing coil current in order to maintain the desired sharply focused spot on the screen.

In t.c.r. tubes employing magnetic focusing, the control grid is so designed that it essentially controls only the *number* of electrons in the beam. The first anode, aside from its action in focusing electrons to the cross-over point, determines the velocity of the electrons at the cross-over point. With this arrangement, there is a minimum of defocusing when the electron beam is modulated with a television signal.

Beam Deflection

Having passed the focusing structure (a bi-potential lens or electromagnetic focusing coil), the electron stream travels to the screen in the form of a pencil-like beam along the principal axis of the tube. This electron beam must be swept horizontally across the screen 13,230 times per second, and must be swept vertically up and down the screen 60 times each second, with each sweep consisting of a linear forward travel of the spot and a more or less linear but very fast return of the spot.

There are three methods for accomplishing this sweeping of the electron beam across the screen: 1. *Electrostatic deflection,* in which the beam passes between charged parallel metal plates which attract or repel the electrons to produce the desired bending of the beam; 2. *Electromagnetic deflection,* in which an electromagnetic deflecting yoke produces a magnetic field which interacts with the magnetic field of the electron beam to produce the desired bending; 3. *Combination electrostatic and electromagnetic deflection,* in which charged metal plates produce one sweeping action and an electromagnetic yoke produces the other sweeping action.

Electrostatic Deflection

When using two parallel charged metal plates to deflect an electron beam, one plate is sometimes connected directly to the second anode. The other plate is fed with a sawtooth a.c. sweep voltage which makes this plate first above and then below the potential of the second anode, causing the beam to be deflected to one side of the principal axis and then

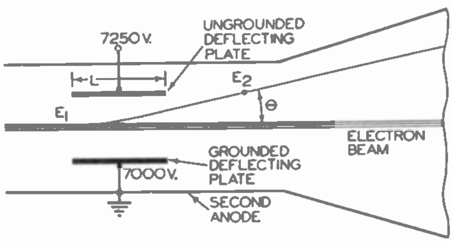


FIG. 13. Unbalanced electrostatic deflection, in which one deflecting plate is connected to the second anode. The second anode and the grounded deflecting plate are 7,000 volts positive with respect to the cathode.

to the other. This arrangement is shown in Fig. *13.*

It is customary to ground the second anode in a t.c.r. tube and make all other elements in the tube negative with respect to this second anode. If the anode requires a positive potential of 7,000 volts with respect to the cathode, this can be secured by making the cathode 7,000 volts negative with respect to the anode. This practice eliminates the danger of shock when touching the glass envelope of the t.c.r. tube, for this envelope assumes the potential of the second anode. The power supply which provides this high negative voltage must be adequately insulated from the chassis, and the high-voltage secondary winding of the power pack transformer must be properly insulated from the grounded metal core.

The sweep voltage makes the ungrounded deflecting plate alternately positive and negative with respect to the grounded plate, and alternately higher and lower in potential than the second anode with respect to the cathode. For example, if the sweep voltage swings positive and negative by 250 volts, the voltage at the ungrounded plate with respect to the cathode will vary between 7,250 volts and 6,750 volts when there is 7,000 volts on the second anode.

Electrons enter the region between the parallel plates in Fig. *13* with a definite velocity corresponding to the potential of the second anode; let us call this potential or velocity E_1. When the ungrounded plate is positive with respect to the second anode, it will attract the electrons in the beam and consequently pull the beam up toward it. Conversely, when the ungrounded plate is negative with respect to the second anode, electrons will be repelled away from the ungrounded plate and bent toward the grounded plate.

The amount of bending will depend upon the voltage difference between the two plates, upon the distance between the plates and upon the time the electrons are between the plates. The greater the voltage difference, the greater will be the bending or deflection. The closer together the plates are, the greater will be the deflection. The longer the electrons take to travel between the plates, the greater will be the deflection.

The time for electrons to pass through the plate depends upon the electron velocity (upon potential E_1) and upon the length of the plates along the principal axis (L). The higher the velocity, the shorter is the time an electron is between the plates. Looking at this condition in a slightly different way, we can think of a high-velocity electron beam as being "stiff" and hence more difficult to bend.

Television engineers describe the bending action of an electron beam in terms of the spot deflection on the screen rather than in terms of the bending angle θ. Obviously, for a given bending angle the spot move-

Courtesy RCA Mfg. Co., Inc.

Typical t.c.r. tubes or kinescopes as made by RCA. (Cathode ray tubes made for television receivers are called *kinescopes* by this firm; you will encounter this term quite often in television literature.) The 906-P4 is a 3-inch tube employing electrostatic deflection and a white phosphor on the screen; maximum second anode voltage is 1,500 volts. The 1802-P1 is a 5-inch tube employing electrostatic deflection and a green phosphor; maximum second anode voltage is 2,000 volts. Except for having a white phosphor, the 1802-P4 is the same as the 1802-P1. The 1803-P4 is a 12-inch tube (maximum bulb diameter is 12 3/16" and useful screen diameter is 10 3/4") employing electromagnetic deflection and a white phosphor; maximum second anode voltage is 7,000 volts.

ment on the screen will depend upon the distance between the deflecting plate and the screen, increasing as this distance is increased.

The deflection sensitivity of an electrostatic deflection system can be expressed either in terms of *the deflecting plate voltage required to move the spot on the screen a unit distance* (the lower the deflection voltage, the greater is the sensitivity), or *the distance which one volt will move the* *spot on the screen* (the greater the distance, the greater is the sensitivity). Remember, however, that the second anode voltage (which governs electron velocity) must be specified whenever a sensitivity rating is mentioned. This is necessary because increasing the velocity (by raising the potential of the second anode with respect to the cathode) will reduce the deflection sensitivity. From a practical viewpoint, increasing the velocity without increasing the sweep voltage will reduce the height or width of the picture on the screen.

Unbalanced Deflection. When the ungrounded plate in Fig. *13* is positive with respect to the grounded plate, it will be at a higher accelerating potential (E_2) than the second anode, and will speed up as well as attract the electron beam. This will make the electron beam stiffen as it bends toward the ungrounded plate, giving a lower deflection sensitivity in this direction than when the beam is bending toward the grounded plate. As a result, the spot travels farther from the axis in the direction of the grounded plate than in the direction of the ungrounded plate. The same effect occurs for the other pair of deflecting plates, with the result that the image is squeezed together by the adjacent ungrounded deflecting plates. With a large screen, this distortion may be quite objectionable.

Balanced Deflection. The type of distortion just described may be greatly reduced if the electron beam is accelerated equally as much when bent in either direction. The method commonly employed for doing this is quite simple and is shown in Fig. *14*. The deflecting plates are grounded through resistors R_1 and R_2, which have high ohmic values (from 1 to 10 megohms). The sweep voltage is applied directly to the two plates. Now, when plate x is driven positive, plate y is driven negative with respect to ground by an equal amount. Since each plate is alternately driven positive with respect to the second anode, the acceleration of the electrons in the beam is the same for either direction away from the principal axis.

Curved Deflection Plates. As has already been pointed out, the deflection sensitivity is dependent upon the lengths of the deflecting plates and upon their separation. For a given electron speed, there is an optimum length and optimum separation, but deflection sensitivity can be increased by keeping the beam close to the plates without actually hitting the

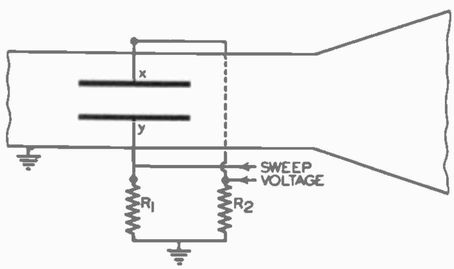


FIG. 14. Balanced electrostatic deflection.

plates. Curved plates which flare outward in the manner shown in Fig. *15* meet this requirement. You will find plates of this type used extensively in large t.c.r. tubes, for they permit a closer spacing at the cathode end and still do not intercept the beam when it is bent a maximum amount.

Effect of Deflecting Plates Upon Focusing. Up to this point it has been assumed that the equipotential lines in between the deflecting plates were parallel to the plates. We must not forget, however, that these plates have limited lengths, so that equipotential lines will curl around the front and rear ends of the plates. In a sense, this gives at each end an electrostatic lens which will defocus the electron beam, for only lines which are parallel to the electron beam have no effect upon focusing.

The curvature of the equipotential lines at the ends of the deflection plates is more marked for the unbalanced connection shown in Fig. *13* than for the balanced connection shown in Fig. *14*. The balanced connection of electrostatic deflecting plates thus has two important advantages, in that *it reduces pattern distortion* and *minimizes defocusing of the beam.*

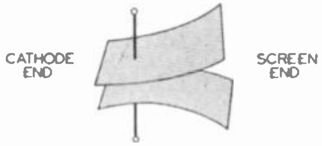


FIG. 15. Flared or curved electrostatic deflection plates like these increase the deflection sensitivity of a t.c.r. tube.

Electromagnetic Deflection

You already know that when an electron stream passes through a magnetic field at right angles to the lines of force, the stream is bent at right angles to both the lines of force and the original path. Fig. *16* illustrates how this principle is employed to give electromagnetic deflection in a t.c.r. tube. Electrons *e*, traveling along the principal axis of the t.c.r. tube in a stream, enter a uniform magnetic field having lines of force flowing *into the paper.* Applying the left-hand rule to determine the direction of the magnetic flux created by this electron flow, we find it such that there is a crowding of flux above the path, and a thinning out or canceling of flux below the path. The electron stream is thus bent downward in the plane of the paper, at right angles to both the original path and the magnetic lines of force. Reversal of the magnetic lines of force will cause the beam to be bent upward.

As long as the density of the magnetic field in Fig. *16* is constant, the bending action will be uniform at all points in the field, and the electron stream will follow a circular path having a radius *R*. Once electrons emerge from the field at point *2*, they travel in a straight line again. The path shown in Fig. *16* would take the electron stream to the outer edge of the fluorescent screen.

When an electron stream travels through a uniform magnetic field, the velocity of the electrons is not altered by the magnetic field. Increasing the flux density in the magnetic field shortens the length of radius *R*, thereby increasing the amount of deflection on the screen. Increasing the length of the magnetic field along the path of electron travel does not affect the value of *R*, but does increase the amount of deflection since the electrons are under the influence of the magnetic field for a longer period of time. The higher the velocity of the electrons in the stream, the greater must be the flux density in the field

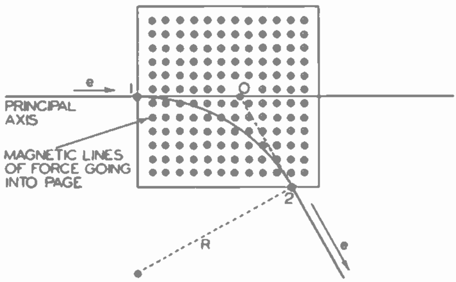


FIG. 16. Use of an electromagnetic field to bend an electron beam in a t.c.r. tube.

in order to secure a given amount of deflection, for a stiff (high-velocity) electron beam is not bent as readily as a low-velocity beam.

In a practical t.c.r. tube, the magnetic field is produced by an electromagnet which surrounds the neck of the tube. Once the poles of this electromagnet are identified, we know that the electron beam will be deflected at right angles to the line between the pole faces. Thus, the pair of magnetic poles which serves for vertical deflection of an electron beam will be mounted *horizontally,* and the poles which give horizontal deflection will be mounted vertically.

A simple electromagnetic deflecting

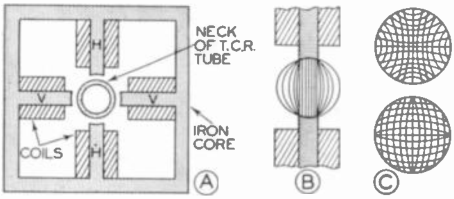


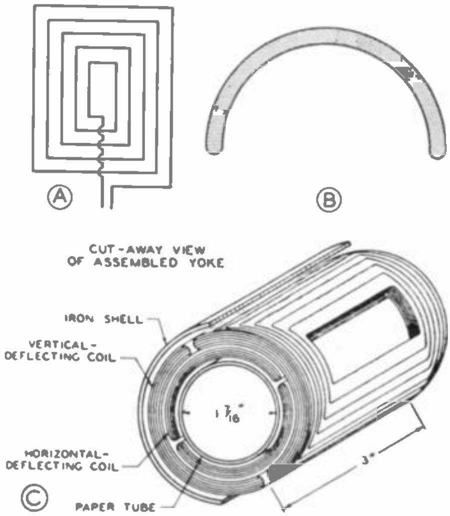
FIG. 17. Design and characteristics of a simple electromagnetic deflecting yoke.

yoke which provides both vertical and horizontal deflection is shown in Fig. *17A*. Note that the vertical deflecting poles *V* are arranged horizontally, and the horizontal deflecting poles *H* are arranged vertically. The yoke is constructed from laminated sheet steel, with the coils wound on bobbins or forms which slip over the poles. Opposite coils are connected in series in the correct manner to give opposite polarity.

Although the simple electromagnetic deflecting yoke in Fig. *17A* will give a spot deflection which is essentially proportional to the deflecting circuit current, it will also produce defocusing and pattern distortion. This is due to the fact that the magnetic field between opposite poles is not uniform, but rather has curved lines of force as shown in Fig. *17B*. It can be shown by means of a very complex analysis that when electrons travel through a non-uniform magnetic field the circular beam is flattened out to an egg-shaped cross section, giving an egg-shaped spot instead of a round spot on the screen.

When the fields for both horizontal and vertical deflection are non-uniform in density and are curved, pattern distortion of the type shown in Fig. *17C* occurs when an image made up of perfectly vertical and horizontal cross lines is being reproduced. We need not consider these defects in detail, since they can be avoided by using deflecting yokes which give uniform, straight-line magnetic fields.

In the improved type of electromagnetic deflecting yoke used with modern t.c.r. tubes, rectangular coils are wound in such a way that they fit inside one another as shown in Fig. *18A*. The windings for each coil are connected in series, then bent into the half-cylinder shown in Fig. *18B*. Two such systems of coils are placed around the neck of the t.c.r. tube and are connected together in series in such a way as to produce poles of opposite polarity. A pair of coil systems like this produces the de-



Courtesy RCA Mfg. Co., Inc.

FIG. 18. Improved electromagnetic deflecting yoke, designed to produce a uniform straight magnetic field.

sired uniform straight magnetic field. One pair of coils is placed directly over the neck of the tube and made to serve for horizontal deflection, and the other pair is placed over the first pair and made to serve for vertical deflection as shown in Fig. *18C*. The entire coil assembly is encased in a soft iron shell in order to reduce the reluctance of the magnetic circuit, prevent stray magnetic fields from affecting the deflection circuit, and prevent the magnetic fields of the coils from affecting the focusing field of the t.c.r. tube.

In an electrostatic deflection system, the sweep *voltage* applied to the deflecting plates must have a true saw-tooth characteristic. In an electromagnetic deflecting system, the *current* through the deflecting coils must have this same saw-tooth characteristic.

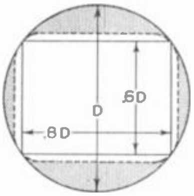


FIG. 19. Relationship between face diameter and image size for an aspect ratio of 4/3 in a t.c.r. tube.

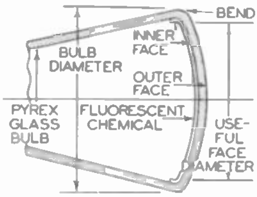


FIG. 20. The fluorescent screen material is deposited on the inner face of a t.c.r. tube.

Image Size

The size and shape of the reproduced image is controlled by the amplitudes of the sweep voltages in an electrostatic deflection system, and is controlled by the amplitudes of the sweep currents in an electromagnetic deflection system. Thus, to increase the width of the image on a t.c.r. tube employing electrostatic deflection, the *horizontal sweep voltage* would be increased.

The amplitudes of the sweep voltages or currents must be adjusted until the reproduced image has the desired aspect ratio of 4/3, with the width being greater than the height. The controls which give this adjustment in a television receiver are invariably of the semi-adjustable screwdriver type, for they need not ordinarily be touched once the correct image size has been obtained.

In a practical installation, the t.c.r. tube is placed behind a mask having an opening of the correct size and aspect ratio, and the controls are simply adjusted until the image fits the mask. The dimensions of the mask will depend essentially upon the diameter of the useful area on the t.c.r. tube screen, as indicated in Fig. *19*. For an image with *square* corners, multiply the *useful* face diameter by .6 to get the height, and multiply this diameter by .8 to get the width. These dimensions can be increased somewhat if the mask has rounded corners, as indicated by the dotted lines in Fig. *19*. Dimensions of *square-cornered* images for various *useful face diameter* values are given in the following table:

Face Diameter	3″	5″	9″	12″	14″
Width	2.4″	4″	7.2″	9.6″	11.2″
Height	1.8″	3″	5.4″	7.2″	8.4″

Fluorescent Screens

The special chemical material which is deposited on the inner face of a t.c.r. tube in the manner shown in Fig. *20* will produce light when bombarded with a stream of electrons. The explanation usually offered for this phenomenon is that the energy of electron impact disturbs the electrons in the atomic structure of the chemical material, thereby making this material absorb energy. In returning to their normal state, the electrons in this material give off light. Any material which behaves in this manner is known as a *phosphor*. The production of light by a phosphor while being excited by an electron stream is called *fluorescence*.

The preparation of phosphor material for t.c.r. tubes is a highly specialized branch of chemistry. The most commonly used materials are willemite and zinc sulfide. Willemite is a chemical made up chiefly of zinc, silicon and oxygen, and gives a green to yellow fluorescence when bombarded with electrons. Zinc sulfide phosphors are available under various trade names, and normally give a blue fluorescence. When used with small portions of other materials known as activators, the fluorescent action is increased and the color of the light is changed. By properly combining the different materials, it is now possible to secure an almost white fluorescence. The processes used for applying the phosphor material to the inside face of a t.c.r. tube will vary with different manufacturers and with the type of glass employed (usually pyrex).

Candlepower of a Screen. The intensity of the light given off from the viewing side of a t.c.r. tube screen can be expressed in terms of candlepower. It is not possible to measure directly the amount of light given off by a spot on a t.c.r. tube screen, for a stationary spot would ruin the fluorescent material. It is therefore customary to sweep the spot over a desired area on the screen, measure the total amount of light given off by this area, then compute the candlepower of the screen.

The electrical power which is supplied to the fluorescent screen in a t.c.r. tube depends essentially upon the voltage and the current of the electron stream. For practical purposes we can say that this power is the product of the voltage and current supplied to the final accelerating anode (the first anode in Fig. *10* and the second anode in Fig. *7*).

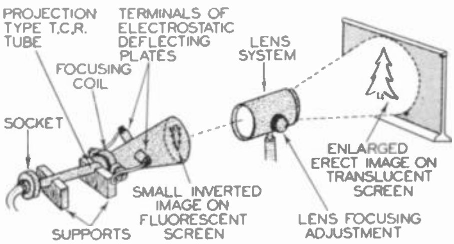
Only a small percentage of the power in an electron beam is transformed into light which is visible from the outer face of the screen. With the phosphor materials now being used, an efficiency of about 2% can be expected when converting electrical power into light in a t.c.r. tube.

The effectiveness of a screen in converting electrical power into light power is measured in terms of the total candlepower produced by the screen per watt input. A value of 2 candlepower per watt is typical of modern t.c.r. tubes. If a t.c.r. tube has a second anode voltage of 7,000 volts and a second anode current of 100 micro-amperes (.0001 ampere), the total beam power will be 7,000 $\times$ .0001, or .7 watts. The screen will deliver about .7 $\times$ 2, or about 1.4 candlepower.

Decay Time. Once a fluorescent material is bombarded by an electron stream, it will continue to glow even after the electron stream has moved away or has stopped. It is possible to make phosphor materials which will glow as long as one minute after excitation, but these materials would hardly be suitable for t.c.r. tubes. In television it is desirable to use materials which will fade out quite rapidly after the excitation has been removed.

The glowing of a screen after removal of excitation is referred to as the *persistence* of the screen, and the time it takes to reduce the glow a certain amount (say to 1/10 of its original brilliance) is known as the *decay time.* By selecting a decay time which will give a reduction in brilliancy to a negligible value in 1/30 of a second (the time for one frame), one image will be almost completely dark by the time the following image is produced, and there will be no overlapping of images. The persistence characteristic of a fluorescent screen is highly desirable in that it aids the persistence of vision of the human eye, thereby reducing flicker and helping to maintain screen brilliancy.

Importance of Having a Spherical Face. For viewing purposes, a flat face is the most desirable for a t.c.r. tube, but with a flat screen it is very difficult to maintain sharpness of focus. Referring to Fig. *21*, point *O* is the apparent source of the electron



Method of using a projection type television cathode ray tube to produce a large image on a screen. High anode voltages are employed, giving an intensely bright image on the relatively small fluorescent screen, and this image is projected onto a screen by conventional optical methods. Although projection t.c.r. tubes are still in an experimental stage, they have been used in demonstrations to produce images over 10 feet wide. In England at least two manufacturers have employed projection type tubes in home television receivers to give pictures up to 3 feet wide.

beam after it has been acted upon by the deflection system, and corresponds to point *O* in Fig. *16*.* The focusing system in a t.c.r. tube is designed to bring the beam to a spot of a definite area at a definite distance from the focusing electrode structure. Thus, with proper adjustments the spot will be focused at point *S* in the center of the screen in Fig. *21*. The spot will also be focused properly anywhere along arc *2*, for all points along this arc are the same distance from the focusing system as is point *S*.

If the face of the t.c.r. tube is made with a curvature corresponding to arc *2*, the spot will be in focus on the screen at all times. If a screen has too short a radius, as indicated by arc *3* in Fig. *21*, the image will be noticeably out of focus near the edges. It is possible to make the screen slightly flatter than the optimum curvature if the beam need not be focused too sharply. Shorter tubes are more conveniently accommodated in receivers and are widely used in spite of the increased face curvature which they require.

In large t.c.r. tubes, a curved face is essential from the standpoint of safety. A t.c.r. tube has almost a perfect vacuum inside, and consequently the normal atmospheric pressure of about 15 pounds per square inch is pressing against the glass envelope at all points, tending to collapse it. A 12-inch diameter t.c.r. tube has a face area of about 113 square inches (the area of a circle equals $\pi R^2 = 3.14 \times 6 \times 6 = 113$). Multiplying 113 by 15 gives a pressure of about 1,700 pounds on the face of this 12-inch tube.

A flat surface bends far more easily

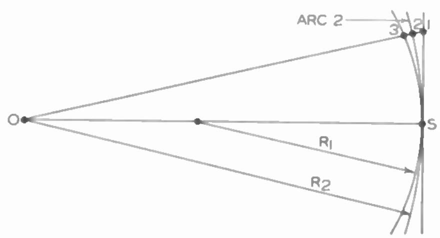


FIG. 21. Effect of screen curvature upon the sharpness of focus. A beam taking path *O-1* will be in focus at point *2*, but will be out of focus at points *1* and *3*.

than does a curved surface. If a flat screen were used on a tube of this size, a slight jar or blow might be sufficient to cause collapse at the face. Under this condition the glass flies inward (an implosion) and then outward again, with sufficient force in the case of the larger tubes to cause serious personal injury. The use of

* With double electrostatic deflection, point *O* for the horizontal sweep will be different from point *O* for the vertical sweep. With double electromagnetic deflection or with a combination electromagnetic and electrostatic system, point *O* will be the same for both sweeps. The latter two systems are therefore preferred for high-definition television receivers.

high-strength glass such as pyrex, carefully annealed so that there are no strains, and the construction of the glass envelope in such a way that there are curves rather than flat surfaces at all points, minimizes the danger of collapse.

Safety Rules. A Teletrician should always handle a t.c.r. tube with the utmost respect. Never drop a tube, not even from an elevation of a fraction of an inch. Do not slide a tube over any hard surface, for scratches at the bend around the face due to this sliding will greatly weaken the tube. Always place a t.c.r. tube in its carton or in a rack with face up when not in use. Never subject a tube to sudden changes in temperature; when a tube has been operating for some time, allow it to cool before taking it outdoors. The larger t.c.r. tubes are sometimes shipped with a funnel-shaped metal sleeve around the funnel; this should not be removed, even when installing the tube in the receiver. Observe these t.c.r. tube safety rules at all times.

Practically all large television receivers have a safety glass window over the viewing face of the t.c.r. tube. This window prevents accidental damage to the tube by objects falling on it and protects viewers from flying glass if an explosion occurs for any reason whatsoever. Never remove this protective glass window, even though it does reduce somewhat the brilliancy of the viewed picture.

Halation. Only a portion of the light produced by electrons bombarding the screen is visible from the outside. That point at which the beam strikes the fluorescent material becomes a source of visible light. Being more or less a point source, it produces light rays which spread in all directions. Most of the light in the forward direction goes directly through the screen and the glass envelope, as indicated by path *a* in Fig. *22A*.

Light rays at a large angle to this direct path are reflected back and forth between the inner and outer surfaces of the tube face, as indicated by path *b*. Some rays from this point source go directly to some other point on the screen, such as along path *c* to point *x*, causing excessive brightness (particularly when point *x* represents a dark spot).

A great deal of light from the point source is radiated backward toward the inner surfaces of the funnel, as indicated by path *d* in Fig. *22A*. This condition in t.c.r. tube operation must

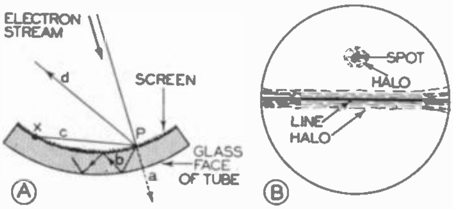


FIG. 22. Paths taken by light rays produced by the impact of the electron beam at point *P* on the screen.

be recognized by the Teletrician. It will be observed as a complete lighting up of the inside of the t.c.r. tube. For example, in t.c.r. tubes employing a zinc sulfide phosphor, the entire tube will have a blue color inside.

Along any one line the effect of halation will be as shown in Fig. *22B*, in which there are shadowy lines bordering the desired bright line. Around a spot when the beam is stationary there will be a halo, for this same reason. Focusing adjustments are always made for the sharpest possible line with minimum halo. A Teletrician must be able to recognize halation as an inherent defect in all t.c.r. tubes, and should not waste valuable time in attempting to correct the trouble.

Contrast. At its best, the t.c.r. tube emits very little light. To make the contrast between dark and bright elements in an image more noticeable, it is wise to operate a television receiver in a completely dark room. When this is not desirable for any reason, room illumination should at least be dimmed by drawing the curtains and shades during the daytime and by using a minimum of general room illumination at night.

T.C.R. Tube Specifications

The performance characteristics of a t.c.r. tube are generally expressed in the form of technical specifications giving or implying the following information which is of importance to the Teletrician:

1. Name of manufacturer of tube and type number assigned to tube. This is generally the only information needed for making an exact replacement of a t.c.r. tube in a receiver.

2. Heater voltage. Common ratings are 2.5 volts and 6.3 volts a.c.

3. Heater current. Average values are 2 amperes for a 2.5-volt filament and .6 ampere for a 6.3-volt filament, but these values may be higher for the larger tubes.

4. A statement indicating whether the cathode is insulated from or connected to the heater internally. Insulation is usually employed.

5. The control grid C bias value required for second anode current cut-off. Sometimes this is given as a percentage of the second grid voltage, and is usually about 30 per cent. For example, if the second grid voltage is +250 volts, the cut-off bias for the first grid is about −80 volts. The C bias is usually adjustable, being adjusted by the brilliancy control to line up the pedestal with cut-off and thus give suitable screen brilliancy without making retraces visible.

6. Control grid swing. This is the television signal voltage at the t.c.r. tube as measured from the top of an impulse (the blacker than black level) to the level for a bright line (the bright level).

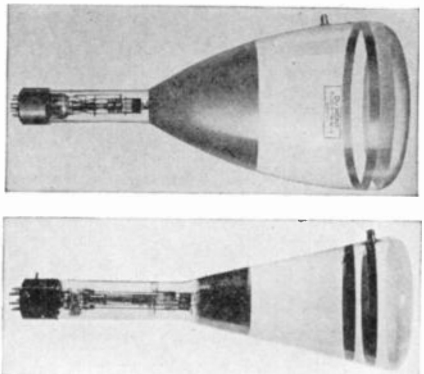
7. The second grid (screen grid) voltage. This is usually a fixed positive voltage.

8. The maximum allowable first anode voltage.

9. The maximum allowable second anode voltage. Exceeding this value may damage the screen.

10. Approximate first anode operating voltage which will give spot focus. This is usually made adjustable within 20 per cent, for it will vary with the second anode voltage.

11. Line width for a zero first grid (control electrode) voltage. This is usually expressed as the picture detail available for 441-line images. This specification may be omitted in the United States, for all tubes made for use in this country will be for this line definition.



Courtesy DuMont Labs., Inc.

Typical t.c.r. tubes, both with black-and-white screens. The upper tube has an egg-shaped funnel which in larger tubes provides several times the structural strength of the conventional straight-sided funnel. The egg-shaped envelope reduces breakage hazards to a minimum.

Both tubes shown here have an intensifier electrode in the form of one or two gold rings deposited on the inside wall of the tube near the screen. These electrodes, when operated at a higher positive potential than the second anode, accelerate the electrons after deflection, thereby increasing picture brilliance without a corresponding loss in deflection sensitivity. The high positive potential for the intensifier electrode may be obtained from the regular t.c.r. tube power supply by adding a half-wave rectifier tube, connecting it across the high-voltage secondary winding with polarity opposite that of the original rectifier tube. If the grounded second anode voltage is 7,000 volts more positive than the cathode, this arrangement will make the intensifier electrode 7,000 volts more positive than the second anode (14,000 volts more positive than the cathode). A single low-capacity filter condenser together with a bleeder resistor of about 10 megohms will meet filter requirements, since the current drawn by the intensifier electrode is low.

12. Deflection sensitivity. This will vary with the type of deflection employed. For electrostatic deflection, this will be given as so many millimeters or inches deflection per volt for a definite second anode voltage. To obtain the peak-to-peak deflection voltage, divide the total length of the sweep by the deflection sensitivity. For electromagnetic deflection, the length of the deflecting yoke and the total magnetic flux in gausses must

be specified, or a specific type of deflecting yoke must be specified.

13. Type of phosphor employed for the screen. This will usually be specified by a number following the tube type number, and the color of fluorescence will be given (white, green, yellow-green, etc.).

14. Diameter of the active or useful screen (commonly known as the face diameter). This is an important tube rating.

15. Maximum bulb length and maximum bulb diameter. The latter dimension will be greater than the face diameter. These dimensions are very important when replacing a t.c.r. tube, for even though the electrical characteristics of a replacement tube are correct, the size

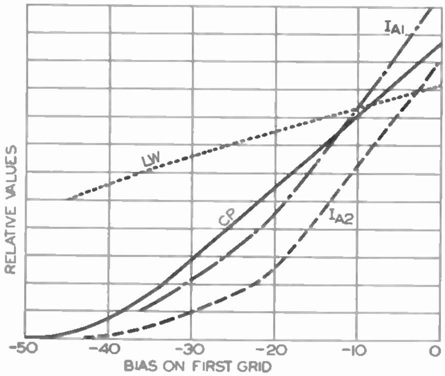


FIG. 23. Operating characteristics of a typical t.c.r. tube. The values are relative and are intended merely to show the nature of the variations.

must also be correct if it is to fit into the existing supporting fixtures.

16. Type of base. Location and identification of all tube terminals, such as base pins and terminals on the sides of the bulb.

In addition to the foregoing basic specifications, the following additional information is particularly useful to television receiver designers and is often given in t.c.r. tube specifications:

17. First anode current and second anode current (usually expressed in microamperes) for zero first grid (control grid) voltage. This data is valuable when designing the t.c.r. tube power pack and figuring the power input to the t.c.r. tube screen.

18. Screen efficiency. This is given as so many candlepower per watt input, for a definite second anode voltage.

19. Mutual conductance. This is usually expressed in micromhos, and is the change in second anode current for a 1-volt change in control grid voltage.

20. In addition to these fixed factors which specify operating values for the tubes, characteristic curves are often given. One particularly useful group of curves is shown in Fig. *23*. This chart shows that for fixed voltages on the second grid (screen grid), first anode and second anode, the first anode current, I_{A1}, the second anode current I_{A2}, the line width *LW* and the screen luminescence *CP* will increase as the bias voltage on the first grid is reduced. It is interesting to note that the screen candlepower increases more or less linearly as the grid bias is reduced. In charts of this type, the total screen candlepower is indicated, for this is easier to measure than spot brilliancy. It may be assumed that spot brilliancy will vary in the same manner.

Power Packs for T.C.R. Tubes

The t.c.r. tube is the only tube in an electronic television receiver which requires considerably higher voltages than are present in an ordinary radio receiver. Ordinary radio tubes whose d.c. voltage requirements need not exceed 450 volts are employed for all of the other tubes in a television receiver.

The total d.c. current drawn by all of the tubes except the t.c.r. tube may be quite high, as much as 200 milliamperes. If a single power pack were used to supply all of the tubes in the receiver, including the t.c.r. tube, it would have to supply this total current as well as the maximum voltage required by the t.c.r. tube. The cost of such a power pack would be prohibitive.

The practical solution involves the use of a separate power pack for the t.c.r. tube, and another to supply the requirements of the other tubes in the television receiver. In this lesson we will consider only the power requirements of the t.c.r. tube, and see how they are supplied by a typical power pack circuit.

First of all, it is essential that all of the voltages for the t.c.r. tube, including the filament supply voltage, be obtained from a single source. This permits isolating the entire t.c.r. tube power supply from the remainder of the television receiver, if necessary. For the t.c.r. tube power pack, we therefore need a power transformer which will step up the a.c. voltage to the required value for the second anode, and will also supply filament voltages for the rectifier tube and the t.c.r. tube (the latter voltage will be either 2.5 volts or 6.3 volts). The high-voltage rectifier circuit current rarely exceeds 2 ma., so a half-wave rectifier and a simple filter may be used. Common practice involves the use of a simple condenser filter or a choke-condenser filter employing condenser input.

If a single filter condenser is used, it must have a reasonably high capacity, of the order of 2 mfd. This condenser will be quite expensive and bulky since it must withstand the second anode voltage of from 3,000 to 7,000 volts, so it may be more economical to use a brute force choke-condenser filter employing low-capacity filter condensers (lower than .1 mfd.). High-inductance iron-core chokes will be needed, having ratings above 1,000 henrys. Since the d.c. current through these chokes will be quite low, they will be light in weight and fairly low in cost. The windings of these chokes must be well insulated from the iron core, giving a high breakdown voltage between the windings and the core, if the chokes are to be mounted on the chassis. The logical position for the choke is in the lead to the rectifier tube filament, as this will place the coils at a low potential with respect to ground.

A voltage divider is employed to provide the correct voltage values for the first anode, the second anode and the second grid (screen grid). Inasmuch as the first anode voltage must be variable in order to provide a focusing control, a potentiometer is usually incorporated in the voltage divider network.

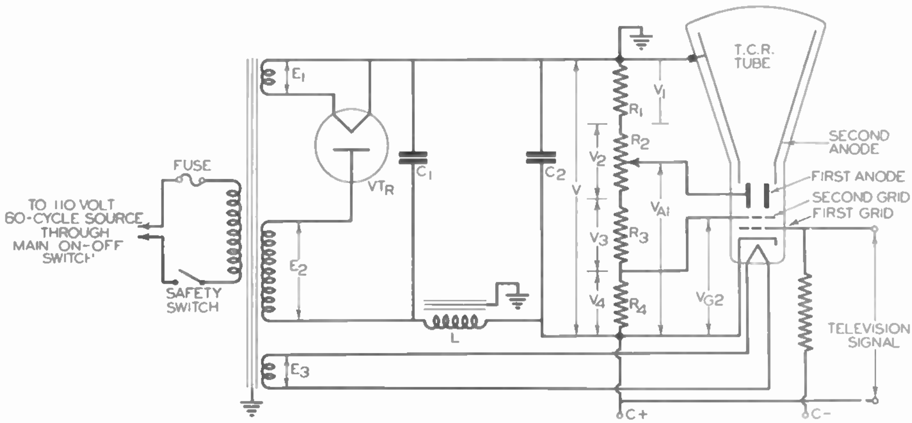


FIG. 24. Typical power supply circuit for a t.c.r. tube employing electromagnetic deflection.

A typical power pack for a 12-inch diameter t.c.r. tube requiring a maximum d.c. voltage of 7,000 volts is shown in Fig. *24*. This circuit employs a high-voltage vacuum tube rectifier VT_R of the half-wave type. This tube must be able to withstand an inverse *peak* voltage equal to at least twice the *peak* a.c. voltage (E_2) applied to it by the power transformer. Since the current drain through the rectifier tube is quite low, the *peak* voltage of the power transformer secondary (E_2) will be only slightly greater than the output d.c. voltage V. Thus, if a d.c. output voltage V of 7,000 volts is required, the *peak* value of E_2 need be only slightly higher than 7,000 volts. The *r.m.s.* value of E_2 will therefore be greater than 7,000 $\div$ 1.4, or a value slightly greater than 5,000 volts (about 5,200 volts).

Choke coil L in Fig. *24* will have an inductance of 1,500 henrys and a d.c. polarizing current of about 2 ma. Condensers C_1 and C_2 need not be any larger than .05 mfd., but they must have working voltage ratings higher than 7,000 volts. These condensers will therefore be of either mica or oiled paper types.

The full d.c. output voltage V is applied between the cathode and the second anode of the t.c.r. tube. The second anode usually extends all the way from the first anode to the fluorescent screen, with the portion inside the funnel of the tube consisting of a carbon deposit on the inside surface of the envelope (a chemical deposit called aquadag).

Assuming that the first anode in Fig. *24* requires 1,900 volts, we can see that resistor R_1 is called upon to drop 5,100 volts. If the current flowing through R_1 is about .001 ampere, this resistor will have an ohmic value of 5.1 megohms. A total of about 5 watts will be dissipated in it, so if a single resistor is used it should have a rating of at least 10 watts to give a reasonable safety factor. A single ordinary carbon resistor is not suitable for this circuit, for at this high voltage the resistor might sustain a continuous internal arc. It is common practice to use five or ten resistors in series, well insulated and well separated from each other so there will be a safe low voltage across each.

The voltage on the first anode in Fig. *24* (V_{A1}) must be variable between 1,900 volts and 1,300 volts. This means that potentiometer R_2 must drop 600 volts. If .001 ampere flows through this potentiometer, it must have a resistance of 600,000 ohms; a .75-megohm potentiometer with a wattage rating of 1 watt or higher will be satisfactory. This potentiometer should be well insulated from the chassis and from its control knob.

Voltage V_{G2} on the second grid is about 250 volts, which means that resistor R_3 must drop 1,050 volts. If we assume that the first anode is drawing .0005 ampere, this leaves .0005 ampere flowing through R_3, and this resistor must therefore have a value of 1050 $\div$ .0005, or about 2 megohms. Again it is advisable to use several resistors in series to reduce the voltage across any one resistor. Finally, resistor R_4 should have a resistance of about .5 megohm and should sustain a drop of 250 volts.

The exact calculation of resistor values for the voltage divider in a t.c.r. tube power pack will depend upon the maximum current drained by each electrode when the control grid is at zero bias, and upon the bleeding current through the entire voltage divider network R_1-R_2-R_3-R_4. This bleeding current should be as high as possible, in order that variations in electrode current will not materially change the applied electrode voltages. All this is of course a task for the television receiver designer.

If the second anode in Fig. *24* is grounded, as is common practice, and the cores of the power transformer and choke are also grounded, it will be necessary to have high-voltage insulation between all ungrounded windings on the power transformer as well as between the high-voltage winding and the core of the transformer. Furthermore, leads to C_1, C_2, L and the t.c.r. tube socket terminals must be adequately insulated.

From the standpoint of safety to both the Teletrician and the customer, the power supply unit of a television receiver must be completely enclosed, so that human hands cannot touch it while the receiver is in operation. Furthermore, in a properly designed receiver a safety switch (interlock switch) should be provided which will open the main supply circuit to the power pack automatically when the cover or shield on the power pack unit is removed. This safety switch is shown in series with the power transformer primary in Fig. *24*.

TEST QUESTIONS

Be sure to number your Answer Sheet with the *number* appearing on the front cover underneath the title of this text.

Place your Student Number on every Answer Sheet.

Send in your answers for this lesson immediately after you finish them. Doing this insures that the graded answers will reach you while the subject matter is still fresh in your mind, and you will get the greatest possible benefit from our speedy personal grading service. *Never hold up a set of lesson answers.*

1. Will an electron gain velocity when moving *along* an equipotential line?

2. When an electron is moving *from a low* equipotential line *to a high* equipotential line, what change occurs in its velocity?

3. Why are electron baffles used in a t.c.r. tube?

4. In a t.c.r. tube designed for electrostatic focusing, which electrode voltage is usually varied to get a sharply focused image on the screen?

5. What effect will a lowering of the second anode voltage have upon spot brilliancy in a t.c.r. tube?

6. In a t.c.r. tube employing electromagnetic focusing, what adjustment is made in order to focus the electron beam?

7. What is meant by deflection sensitivity in connection with a t.c.r. tube having electrostatic deflecting plates?

8. What two important advantages are obtained with a balanced connection of electrostatic deflecting plates?

9. When a pair of magnetic poles is employed for vertical deflection of an electron beam, should the poles be mounted vertically or horizontally?

10. In a t.c.r. tube employing electrostatic deflection, what voltage would be adjusted in order to increase the width of the image on the screen?

Cathode Ray Tubes For Television Receivers. No. 60 RH-1

1. No.

2. Its velocity is increased.

3. To block all electrons which do not converge to the desired narrow beam along the principal axis.

4. The first anode voltage.

5. It will reduce spot brilliancy.

6. The focusing coil current is varied.

7. The deflecting plate voltage required to move the spot a unit distance on the screen, or the distance which the spot will be moved by a deflecting plate voltage of one volt.

8. It reduces pattern distortion and minimizes defocusing of the electron beam.

9. They should be mounted horizontally.

10. The horizontal sweep voltage.

ANTENNAS, PRESELECTORS, FREQUENCY CONVERTERS AND SOUND CHANNELS FOR TELEVISION RECEIVERS

61RH-1

PIONEER HOME STUDY RADIO SCHOOL

NRI

NATIONAL RADIO INSTITUTE

EST. 1914

WASHINGTON, D.C.

TEN SUGGESTIONS FOR HOLDING AND IMPROVING A JOB

I. Accept and welcome fair criticism. When executives find that certain men resent criticism, they stop criticizing and begin firing.

II. Don't give out unfair criticism. Don't be a chronic grouch or petty complainer. Stop listening to grouchy associates or you'll get like them.

III. Develop a "we" and "our" attitude toward your company. Show an enthusiasm and interest in the company's success. Realize that what hurts company business hurts you also.

IV. Hard work brings success just as fast today as ever. Remember this—if you never do more than you're paid to do, you'll never get paid for more than you do.

V. Prepare yourself to handle part or all of the work of men above you. A good understudy for an executive is too valuable to fire.

VI. Always be ready to lend a hand to others or do new tasks. Willing workers are hard to fire.

VII. Develop confidence in your abilities, but avoid over-confidence. Bluffers eventually get deflated. Confine your clock-watching to alarm clocks, and make a habit of getting to work on time.

VIII. Keep your head when the routine of work is varied or when an emergency arises. Accept responsibility whenever opportunity offers; a refusal kills chances for advancement.

IX. Don't bury your nose in the details of your job. Organize your work and assign routine duties to your assistants whenever possible, so you will have time for more important things.

X. Devote a few minutes of each day to clear thinking about your job, your future and your company's future. Jot down each worth-while idea immediately, develop the idea in your mind for a few days, then write it up in detail for consideration by your superiors. Initiative of this form is welcomed and eventually rewarded.

J. E. Smith.

NATIONAL RADIO INSTITUTE

WASHINGTON, D. C.

1942 Edition

A LESSON TEXT OF THE N. R. I. COURSE
WHICH TRAINS YOU TO BECOME A
RADIOTRICIAN & TELETRICIAN
(REGISTERED U. S. PATENT OFFICE) (REGISTERED U. S. PATENT OFFICE)

NCP2M342 Printed in U. S. A.

Antennas, Preselectors, Frequency Converters and Sound Channels for Television Receivers

Television Receiving Antennas

THE success of a television receiver installation depends to a great extent upon the knowledge and skill of the Teletrician who erects the receiving antenna system. The mere connecting of the antenna terminal of a television receiver to a radiator or a wire strung around the room is entirely out of the question.

Even under the ideal condition where there is only one television station in a locality and every part of the antenna system can be adjusted for maximum response to the signals of that one station, the erection of a completely satisfactory antenna installation is sometimes a real problem. When there are two or more television stations in a given service area, the antenna problem becomes very much more difficult.

The erection of a successful television receiving antenna installation depends upon a knowledge of how ultra-high-frequency radio waves behave, a knowledge of the fundamental theories applying to the various types of television receiving antennas and transmission lines, and upon a certain amount of practical experience with television equipment.

Transmission Paths. The main and most desirable path for ultra-high-frequency radio waves to take between a transmitting antenna and a receiving antenna is along a straight line connecting together the two antennas. This *shortest and most direct route through space* between two points is shown as path *1* in Fig. *1*, and is usually called the *line-of-sight path. It is always a straight line.*

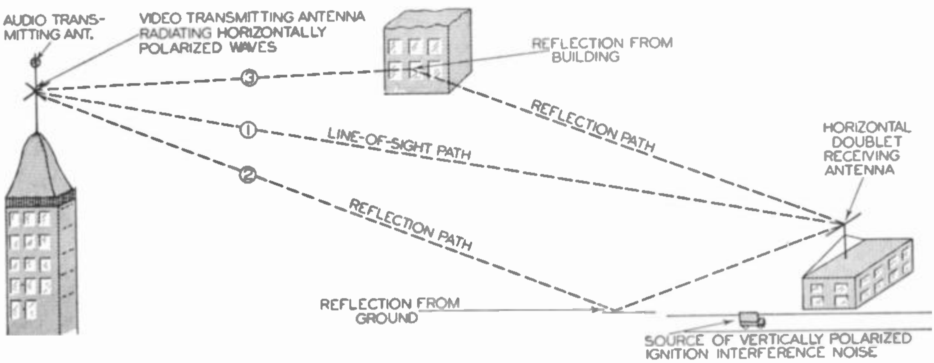


FIG. 1. Horizontally-polarized video carrier signals may arrive at a receiving antenna location over one or more reflected paths, in addition to the direct line-of-sight path. The receiving antenna must be oriented to receive signals over only one of these paths if signal interference is to be avoided. The transmitting antenna for the sound carrier also radiates horizontally-polarized waves, so a horizontal receiving antenna will intercept both sight and sound carrier signals.

Some signals from the television transmitter will travel toward the ground at just the right angle so they will be reflected up to the transmitting antenna, as shown by path *2* in Fig. *1.* This ground reflection path must *always* be considered along with the line-of-sight path when erecting a television receiving antenna at any location. In addition, there will be reflection of signals from metal structures such as steel buildings, metal roofs, other antennas, power lines, wooden buildings and masonry structures; path *3* in Fig. *1* illustrates one of these other reflection paths.

Radio waves travel through air at a definite speed of approximately 186,000 miles per second, and consequently those waves which take the shortest path will arrive first at a given point. This means that signals taking the line-of-sight path in Fig. *1* will reach the receiving antenna a short time before signals taking any of the reflection paths. Whenever the television receiving antenna accepts video carrier signals of approximately equal strength, coming from the same station over two or more paths which differ in length, three types of trouble can occur; there will be *phase interference*, *blurring* or *ghosts*, depending upon the amount of time delay between the signals arriving over the different paths.

Phase Interference. When the time difference between signals arriving over two different paths is relatively small, corresponding to only a few cycles of the r.f. carrier, the *phase difference* in degrees between the two signals determines whether the reflected signal will increase or decrease the amplitude of the main carrier signal at the receiver input. This particular type of interaction between two carrier signals can be called *phase interference*. Ordinarily its effect upon the brightness of the reproduced image will not be noticed, for a.g.c. in a television receiver tends to compensate for changes in input signal strength. When signal cancellation is severe, however, a.g.c. may increase receiver gain so much that external and circuit noise becomes apparent in the form of white splotches moving across the image.

Phase interference can be a serious problem at receiving locations near the extreme limits of the service area of a television station, for a slight reduction in signal strength here might mean the difference between good and bad reception.

A maximum reduction in the strength of the desired signal will occur when the difference in signal paths is effectively a half wavelength at the frequency of the picture carrier. At 40 megacycles this would be a path difference of 3.75 meters (about 12 feet). When one signal is weaker than the other, the cancellation will be partial; when both signals are equal, there will be practically complete cancellation, and no image on the screen.

A Teletrician can overcome phase interference either by placing the receiving antenna so it will accept signals from only one path, or by moving the antenna system to a new location where the phase difference will be such as to give reinforcement rather than cancellation of the desired signal.

Ghosts. When signals reach a television receiving antenna over two paths which are considerably different in length, the stronger signal will control the synchronizing circuits in the receiver, and the weaker signal will produce a second image which is shifted either to the right or to the left of that formed by the stronger signal. This second image is known as a *ghost*. When there are several undesired paths, each can produce its own ghost image. Wherever the ghost image overlaps the main image, blurring of detail will exist.

Experiments have shown that the outlines of a ghost are readily noticed if they are displaced 1/16 inch or more from the desired image. If the displacement is less than this amount, the effect will simply be blurring.

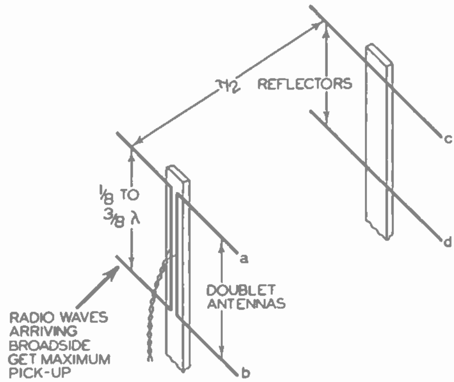
Let us see how much difference there must be between desired and undesired paths in order to produce a ghost. Suppose that we are viewing an image which is 10 inches wide. In this case, the time required for the spot to travel 10 inches horizontally one line will be .85 × 1/13,230 second, or .0000642 second. The velocity of the spot will therefore be 10 ÷ .0000642, or 156,000 inches per second. This is equal to a spot velocity of about 2.5 miles per second. Radio waves therefore travel about 75,000 times as fast as the spot in this particular tube (186,000 ÷ 2.5 = 75,000).

To get a ghost image which is 1/16 inch to one side of the desired image, the ghost signal in our example must travel 75,000 times 1/16 inch, which is 4,700 inches or 390 feet. This is the minimum difference between paths to get a ghost. We thus see that with a television receiver producing a 10-inch wide image, a ghost image will be noticeable on the screen when the length of an undesired transmission path is 390 feet or more longer than the desired path. Ghost images can be eliminated *by designing and positioning the television receiving antenna so it will accept signals arriving over only one path.*

Blurring. When the difference between the lengths of two signal paths is not sufficiently great to give discernible ghosts, but is greater than the value giving phase interference, the effect will generally be apparent as a *blurring* of the image. The displacement between the desired and undesired images will be somewhere between 1/16 inch and the width of the spot. The Teletrician can correct blurring by placing the receiving antenna in a position where it will receive signals over only one path.

The first step in eliminating any of the signal interference troubles just described is a shifting of the receiving antenna a few feet in all directions until a location is found which gives maximum signal strength for the desired signal and no blurring or ghosts due to reflected signals.

Measurement of the a.g.c. voltage in the receiver for each trial position



Arrays of doublet receiving antennas are being used more and more with television receivers and with ultra-high-frequency communication receivers, to give increased signal pick-up in a desired direction along with increased signal rejection in other directions. The typical television array shown above employs four half-wave doublets; doublets *a* and *b*, one mounted a fraction of a wavelength above the other, are connected in parallel to the transmission line, so that signals picked up by these two doublets are fed *in phase* to the transmission line. These doublets, if used by themselves, would serve as broadside arrays, giving maximum pick-up from two directions at right angles to the plane of the doublets. The increase in broadside pick-up over that provided by a single doublet varies with the vertical spacing between the doublets. Reflectors c and *d* are employed when multiple-path reception is a problem; they increase signal pick-up in the broadside direction indicated by the heavy arrow (for radio waves reaching the antennas first), and give rejection of signals reaching the reflectors first, over the other broadside path. By increasing pick-up from the desired direction, doublet arrays increase the signal-to-noise ratio, thereby making satisfactory reception possible in the outer fringes of the service area of a television station.

of the antenna is a good way of checking signal strength. This voltage can be measured with a high-resistance d.c. voltmeter or with a vacuum tube voltmeter connected between the control grid and cathode (or ground) of an a.g.c.-controlled stage in the video channel. If an adapter is slipped under the tube in question to make contact with the control grid prong, it will not be necessary to remove the chassis from the cabinet. Some one must actually watch the receiver while a program is tuned in, to tell when an antenna position which is free from blurring and ghosts has been found, and when the voltmeter indicates maximum signal strength. Another method for checking signal strength involves setting the brilliancy and contrast controls until the image is just barely visible; increases in signal strength will then give noticeable increases in image brightness.

If no position can be found which is free from reflected signal troubles when a simple doublet antenna is used, a directive receiving antenna must be used to secure the necessary rejection of reflected signals.

Transmission Line Problems. Phase interference, ghosts and blurring can be caused by an improperly installed and improperly adjusted transmission line even when the antenna is properly positioned to receive signals over only one path. The television receiving antenna will ordinarily be of the conventional doublet type, connected to the receiver by a 2-wire transmission line. This line may be made up of two parallel wires separated about 2 inches by insulators; it may consist of insulated wire placed inside metal loom or metal pipe to give a rubber-insulated coaxial cable; it may consist of bare copper wire centered by insulating beads inside metal tubing to give a low-loss air-insulated coaxial cable; it may be the conventional twisted 2-wire transmission line. Regardless of its construction, a transmission line will give no trouble as long as it is properly matched at each end.

We can best explain how signal interference occurs in a transmission line by considering an open-wire line more than 100 feet long, which is improperly terminated at the receiver and at the antenna. A signal picked up by the antenna will travel down this transmission line to the receiver input. Because of the improper match at the receiver, however, some of this signal will be reflected back to the antenna, and there reflected again so that it returns to the receiver after having traveled at least 200 feet up and down the transmission line. Although this extra path length may not be sufficient to produce a ghost, it can result in a blurred image. If reflection takes place a second and third time, a ghost image may be observed.

Only improperly matched open-wire transmission lines can produce signal interference. With twisted-pair lines and ordinary coaxial lines using rubber insulation, the reflected signal is attenuated about 1.5 db per wavelength of line, whereas the loss in an open line or in a low-loss coaxial line is less than .15 db per wavelength. Signals reflected in ordinary coaxial lines and twisted lines are attenuated so greatly that their effect upon the desired signal after reflection is negligible.

With open-wire lines or low-loss coaxial lines shorter than 100 feet, the difference in path lengths due to reflection back and forth along the transmission line may not even be enough to cause blurring of the image, but will still be enough to give phase interference.

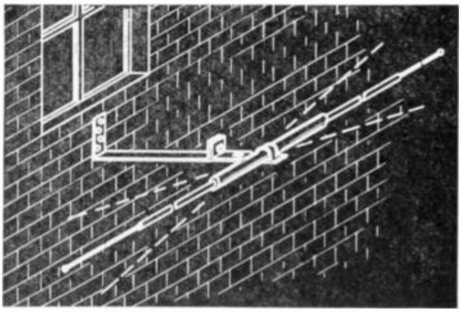
This does not mean that we can solve our transmission line problems by avoiding the use of low-loss coaxial lines or open-wire lines. Television receiver installations near the limits of the service area for a television station will generally require these lines in order to utilize the maximum amount of signal which reaches these locations. In these critical cases, it may be necessary to adjust line terminations for best possible match. Measurement of the a.g.c. voltage in the video channel will indicate when optimum conditions are obtained. Only by having a thorough understanding of the characteristics of television receiving antenna systems can the Teletrician make successful television receiver installations near the limits of the service area of a station.

Polarization of Television Waves. Although reception of radio signals at ultra-high frequencies is almost free from atmospheric interference and static, man-made interference is particularly severe at these frequencies in certain cases, and consequently presents quite a problem to the Teletrician. Automobile ignition interference and radiation from medical diathermy machines are the outstanding offenders.

Until such time as laws and regulations are set up to make suppressors mandatory on automobiles and to make doctors use diathermy machines only in properly shielded rooms, the Teletrician must provide ways and means for minimizing man-made interference when installing a television system. One objective in a television receiver installation is, therefore, the m a x i m u m possible signal-to-noise ratio.

Experience has shown that man-made interference is essentially vertically polarized near the ground. This means that a vertical television receiving antenna will pick up *more* man-made interference noise than will a horizontal receiving antenna. With a horizontal receiving antenna it is easier to eliminate phase interference, blurring and ghost images, for the antenna then has horizontal directivity and can more readily be positioned to receive signals over only one path. Horizontal television receiving antennas are used exclusively in this country, and all U. S. television transmitters are designed to radiate *horizontally polarized waves* so as to insure good signal pick-up.

Service Range of a Television Station. The longest line-of-sight path from a given television transmitting antenna to a receiving antenna of given height is that along a straight line which joins the two antennas and just grazes the earth's surface somewhere between the antennas. For perfectly level country, this distance depends upon the height of the receiving and transmitting antennas, and can be computed by means of a formula.*



Courtesy Technical Appliance Corp.

When restrictions by the landlord prevent the installation of a television receiving antenna on the roof of an apartment building, the di-pole may be mounted on the wall of the building in the manner shown here. If the television transmitting antenna can be seen from the window, the receiving antenna can be oriented for best pick-up along the line-of-sight path; otherwise you will have to depend upon signal reflections from nearby buildings. Mount the antenna 2 or 3 feet away from the building. Try several different locations, tilting the antenna each time as indicated by the dotted lines, until the best possible pick-up is secured. The antenna in this diagram is a Taco di-pole unit, made by Technical Appliance Corp., 17 East 16th St., New York, N. Y.

* This formula is: Maximum line-of-sight path in miles $= 1.63 \times (\sqrt{h_T} + \sqrt{h_R})$, where h_T is the height of the transmitting antenna in feet and h_R is the height of the receiving antenna in feet.

When the terrain is uneven between the two points or when the receiving antenna is at a different altitude above sea level from the transmitting antenna, any estimate of the service area of a station must be based upon a topographical survey of the locality, showing the heights of all hills which might block signals.

Calculations of maximum path length for television signals should be considered only as rough estimates. Reflection of signals from the ground or from buildings, and refraction of signals in the atmosphere will often increase the theoretical maximum distance. Furthermore, locations within the calculated maximum distance will not always be satisfactory for reception purposes. In thickly populated areas having numerous high buildings, there may be dead areas where the signal has been absorbed by buildings and is consequently too weak for satisfactory reception.

The installation of a television transmitter is generally followed by a field intensity survey, for the owners of a station are anxious to know the extent of their service area. Whenever there is some doubt as to whether a satisfactory television signal is reaching a particular location, it is a good idea to check with the engineers of the local television station. Their field intensity surveys will generally indicate the exact field intensity you can expect with a proper antenna installation at that location.

Single-Station Reception. Although the erection of an antenna for reception of signals from a single television transmitter (a telecaster) is by no means simple, it is still the least involved of the antenna problems which will be encountered by the Teletrician. In this simplest case the problem involves the interception of horizontally polarized waves having a definite 6-megacycle wide channel and arriving at the receiving location over one or more paths. The most suitable path must be utilized; by orienting the antenna to reject signals coming over undesired paths, signal interference resulting in ghosts, blurring or phase interference can be minimized. The transmission line must be properly terminated to avoid similar interference difficulties due to signal reflection in the line, particularly when an open transmission line is employed.

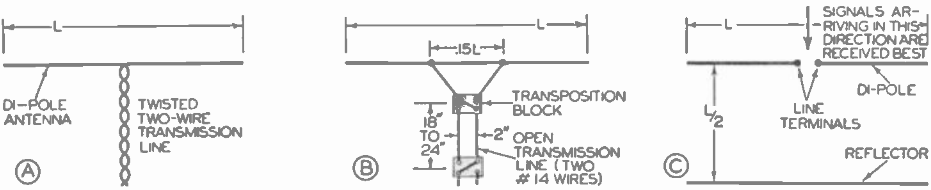


FIG. 2. Antennas for reception of programs from a single television station.

When reception of only one television channel is required, the antenna may be tuned to a frequency within the channel without serious attenuation of any side frequencies. Ordinarily, however, a doublet antenna is employed and its length is so chosen that it tunes to the highest frequency in the desired channel. Under this condition there will be maximum current at the center for all frequencies in the channel, and a current-feed connection can be used.

The di-pole or doublet antenna most commonly used for reception of a single television station is shown in schematic form in Fig. *2A*. The total length *L* of this antenna is equal to one-half wavelength at the frequency to which the antenna is to be tuned.

Values of L for different frequencies are given in table *1*. The resistance at the center of the antenna at resonance depends upon the height above the ground, and is generally about 72 ohms. A satisfactory impedance

FREQ.	L
50 mc.	9 ft., 10 in.
56 mc.	8 ft., 9 in.
72 mc.	6 ft., 10 in.
84 mc.	5 ft., 10 in.
90 mc.	5 ft., 5 in.
102 mc.	4 ft., 10 in.
108 mc.	4 ft., 6 in.

TABLE 1. This table gives the total length of a di-pole television receiving antenna for resonance ($\lambda/2$ operation) at the highest frequency in each of the seven ultra-high-frequency channels now assigned for commercial television purposes. Values of L in feet for other frequencies can be determined by the formula: $L = 490 \div f$, where f is the frequency in megacycles to which the antenna is to be tuned.

match, insuring adequate signal transfer to the transmission line, can be secured by connecting to a transmission line having an impedance of between 70 and 100 ohms. A twisted-pair line like that shown in Fig. *2A* or a coaxial line can be used.

When signal attenuation in a twisted or rubber-insulated coaxial line is too great for satisfactory reception, an open transmission line like that shown in Fig. *2B* can be used. This line will have a surge impedance of about 500 ohms, and consequently a center-fed connection cannot be used. Instead, the voltage or impedance feed shown in Fig. *2B* is employed. The transmission line wires are spread out and connected to two points on the antenna which are about .15L apart and equally spaced on each side of the center of the single half-wavelength long rod which serves as the antenna. The impedance between these two points on the antenna is about 500 ohms, and consequently this connection gives the desired impedance match.

Transposition blocks must always be used with an open-wire transmission line, in order to minimize the effects of noise signals and station signals picked up by the transmission line. Transposing of the line wires at regular intervals also serves to maintain a balanced line and reduce reflection effects in the line. The blocks should be spaced about 18 inches apart.

Although deviations of an inch or so in the length of a di-pole antenna are not particularly important, it is essential to have a support which will prevent both the antenna and the transmission line from swaying in the

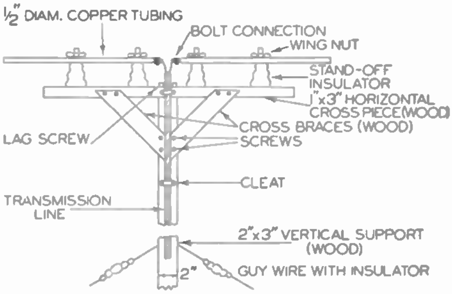


FIG. 3. Constructional details for a simple supporting structure for a di-pole antenna. Holes are drilled through the tubing for the insulator bolts and the bolt connections to the transmission line. Aluminum angle-pieces may be used in place of copper tubing.

wind. A suitable support for a single di-pole antenna is shown in Fig. *3*.

A single di-pole antenna is usually suitable for locations reasonably near the transmitter provided there are no high buildings in the vicinity to create reflection paths. A single doublet may also be suitable for use on the roof of a tall building in a congested area, but in the latter case a directive antenna will generally give better results.

Di-pole with Reflector. A half-wave di-pole antenna which is "backed up" by a wire or rod one-half wavelength long and one-quarter wavelength away, as indicated in Fig. *2C*, will receive best in a direction away from the back rod or reflector. A radio wave arriving at the di-pole antenna induces in it a signal voltage; for convenience, let us consider a positive peak of the wave. If the antenna is properly loaded by the transmission line, this voltage is completely absorbed. Passing the di-pole antenna, the positive peak of the radio wave moves on towards the reflector, where it is reflected right back on itself. If there were no phase reversal at the reflector, we would still have a positive peak arriving back at the di-pole. Since di-pole and reflector are λ/4 apart, this peak travels a total distance of λ/2 in going from the di-pole to the reflector and back again; this distance is equal to 180° of time. In this time the radio wave from the transmitter has changed 180° at the di-pole so that it now has a negative peak. If the radio wave coming from the reflector did have a positive peak, there would be complete cancellation. Actually, however, the reflector changes the phase of the wave 180° at the instant of reflection, so that we have a *negative peak* coming from the reflector. Since both the oncoming wave and the reflected wave now have negative peaks, we have reinforcement of signals which reach the di-pole before they hit the reflector, and signal pick-up is considerably greater than could be secured with a di-pole alone.

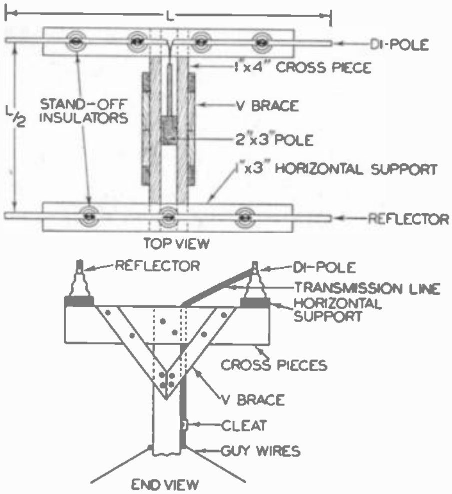


FIG. 4. Constructional details for a supporting structure for a di-pole antenna with reflector. The reflector should be farthest from the desired station.

A similar analysis would show that signals which hit the reflector first are reradiated 180° out of phase with the original signal, so that the direct and reradiated signals cancel each other in the di-pole and give no signal pick-up from this direction.

Since a di-pole gives little pick-up of signals arriving from its ends, a di-pole with reflector constitutes a unidirectional antenna system which can be oriented to pick up maximum energy from the desired television signal path while rejecting energy from other paths. A reflector is therefore used with a di-pole television receiving antenna *to secure increased signal pick-up* and *to give rejection of signals arriving over undesired paths.*

A suitable support for a di-pole with reflector is shown in Fig. 4. This will insure rigidity of the di-pole and reflector in normal wind.

From a practical standpoint, it is sometimes possible to obtain directional characteristics without the use of a reflector. A single di-pole antenna which is properly positioned with respect to nearby metal structures such as rain gutters, roof flashing, metal penthouses, etc., can give highly directional action. Experimentation when installing a single di-pole antenna will indicate the best position.

Long Television Receiving Antennas. On the outskirts of the service area for a television transmitter, the signal picked up by an ordinary di-pole antenna or by a di-pole with reflector may not be sufficient to give a satisfactory image. If only a small amount of additional pick-up is required, the use of an open transmission line or a low-loss coaxial line may prove a solution to the problem. If even this procedure is inadequate, the use of a long antenna with one of these transmission lines should be tried. The length of the antenna may be four wavelengths (8*L*) or more, as indicated in Fig. *5A*.

The polar (vertical) radiation pattern for a long antenna is shown in Fig. *5B*. This indicates that the antenna gives maximum pick-up from its free end, at an angle θ with the antenna. For an antenna four wavelengths long this angle will be about 20°. The free end (*F*) of the antenna should therefore be tilted toward or away from the ground until maximum signal strength is obtained at the receiver.

Strictly speaking, end *F* of a long antenna should be grounded through a resistance, but this is not always convenient in a television receiving antenna installation. There may be sufficient attenuation of signals along the antenna before they are reflected at the free end to make the use of a resistor unnecessary. If the free end is located near a roof flashing, drain pipe, vent pipe or other grounded metal object, this end may be connected to ground through a 600- to 700-ohm carbon resistor. This will prevent reflection of signals from the free end back along the antenna.

Line Terminations. Transmission line terminations are the same for long antennas as for doublet type antennas. The input circuit of the television receiver will probably have leakage inductance along with a resistance of about 100 ohms, since television receivers are generally designed for use with a twisted or coaxial line. If an open type transmission line like that shown in Fig. *5A* is employed, the input impedance of the receiver should be increased to about 500 ohms so as to match the line impedance. This can be done by shunting the receiver end of the line with a trimmer type variable condenser having a maximum value of about 100 mmfd. The condenser is adjusted for maximum signal strength and the clearest possible definition. This tuning will automatically eliminate ghosts or other signal interference defects due to reflection back and forth in the transmission line. The variable capacity and the leakage inductance together form a parallel-resonant circuit which raises the input impedance of the receiver to about 500 ohms. The important fact to remember is that the input impedance of a conventional television receiver can be increased *by connecting a variable*

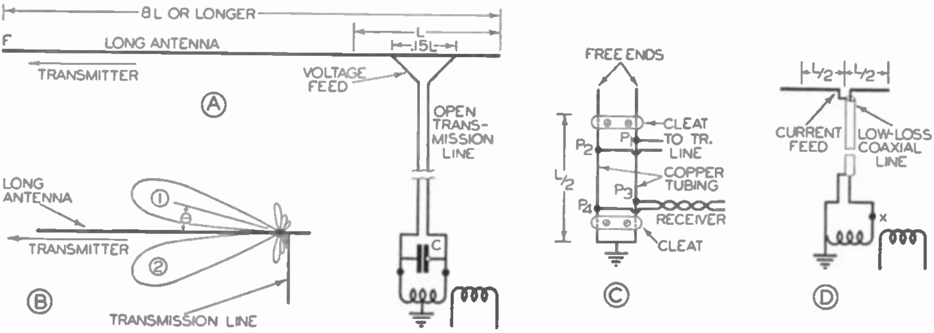


FIG. 5. Design for a long antenna suitable for use at the extreme limits of the service area for a television station. *L* is equal to *one-half* the wavelength to which the antenna is to be tuned.

condenser across the input terminals and tuning for resonance. At the antenna, a voltage-feed connection like that shown in Fig. *5A* would be used.

If the addition of a variable condenser does not give sufficient resonant step-up of signal strength at the receiver end of an open transmission line, try the $\lambda/4$ impedance-matching network shown in Fig. *5C*. Adjust points P_1, P_2, P_3 and P_4 (all points along the transmission line to which connections are made) for maximum signal at the t.c.r. tube. After each adjustment, be sure to readjust the brilliancy and contrast controls on the receiver to get the true effect of each change in the impedance matching.

When a low-loss coaxial line is used with a long antenna, a current-feed connection should be made at a point one-quarter wavelength ($L/2$) away from the end of the line, as shown in Fig. *5D*, for the surge impedance of a coaxial line is approximately the same as that of a twisted line. At the receiver, an ordinary matching transformer is used. The primary terminal which connects to the outer conductor of the coaxial line is grounded. A 200-mmfd. variable condenser may be inserted at point x and tuned for maximum signal strength in order to improve the impedance match.

Reception from Two or More Telecasters. During the experimental days of television, reception in a given area was generally limited to programs from a single telecaster. Now, however, it is quite likely that a number of the larger cities in this country will have anywhere from two up to the maximum of seven television stations, one on each of the present channels assigned to television. The erection of an antenna system which will satisfactorily pick up signals from two or more stations brings new problems, the seriousness of which depend upon existing conditions. If, for example, all the telecasters in a given service area are closely grouped together, it will be possible to use a simple di-pole antenna or a directive antenna which is designed to have a wide frequency response and is oriented in the direction of the group of stations. When the telecasters are widely separated in the metropolitan area, receivers in the center of this area must have antennas which will pick up signals from several desired directions. Many different types of television antennas will undoubtedly be devised to take care of the various conditions encountered.

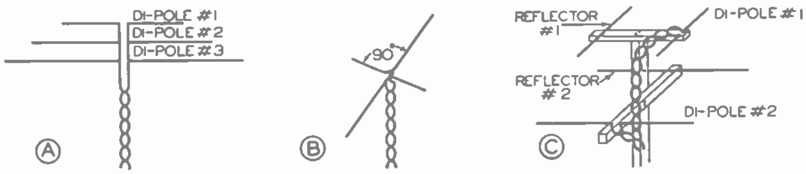


FIG. 6. Antennas for reception of two or more television stations.

When conditions are such that directivity is unimportant, a simple di-pole like that shown in Fig. *2A* will generally be adequate. The length of the antenna can be chosen to make it a $\lambda/2$ doublet at the highest frequency employed by any station in the locality. An antenna like this will have maximum current at its center for all stations. By using a long transmission line (several wavelengths long, which is a normal length), the antenna system will be sufficiently broad for satisfactory reception over two or more bands.

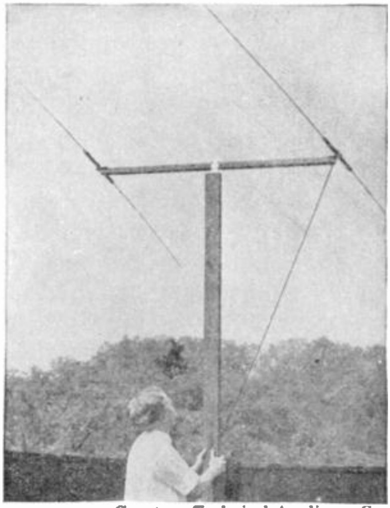
When television reception is desired over the maximum frequency range of from 44 mc. to 108 mc., and conditions are such that directivity is not important, an ordinary doublet antenna which is tuned to the middle of this frequency range will give fairly good response for all stations. A simple doublet which is tuned to 70 mc. gives 60 per cent of resonant pick-up at 44 mc., and about 50 per cent of resonant pick-up at 108 mc., according to experimental tests.

Multiple doublet arrangements such as are used in all-wave aerials for sound program reception may also be satisfactory for television reception. These doublets could be arranged as shown in Fig. *6A*. As long as one doublet does not act as a load on another, the doublets will be more or less independent and each will be resonant to its particular signal frequency. The doublets should be spaced about two inches apart.

When conditions are such that directivity is essential for the receiving antenna, the best procedure would be to erect a separate antenna for each television station, and provide means for switching the receiver from one antenna to another. Each antenna should have a separate transmission line, to permit switching at the input of the receiver.

When there is sufficient separation between the frequencies of the stations to be received (none are on adjacent channels), several di-poles or several di-pole-reflector arrangements may often be connected to the same transmission line with negligible interaction, particularly if the di-poles are approximately at right angles to each other. Simple di-poles of different lengths, at right angles to each other, are shown in Fig. *6B*. Doublet and reflector arrangements of different lengths, one above the other, are shown in Fig. *6C*. One antenna will always act as a reactive load on the other, reducing the effectiveness of the system slightly, but in many cases an arrangement like this will be satisfactory.

Installation Problems. The first requirement of a good receiving antenna installation is a location high above surrounding buildings on a line-of-sight path from the telecaster. Almost equally as important is the requirement that the chosen location be remote from any roads which are traveled by automobiles. In certain cases it may be necessary to locate the antenna as far as one hundred feet from a main highway in order to minimize



Courtesy Technical Appliance Corp.

This television receiving antenna with universal joint mounting, permitting adjustments in all directions, is made by Technical Appliance Corp., 17 E. 16th St., New York City. The di-pole antenna is constructed of heavy duralumin rods held together with a sturdy center insulator. Two extension rods, which can be cut to any desired length, screw into the center rods. Mounting straps are provided for clamping the mast to a convenient support. A reflector is available for providing directivity when needed; in this case, a horizontal cross-arm is used as shown in the illustration. By loosening a nut on the universal joint at the top of the mast, the antenna pick-up structure can be rotated or tilted any desired amount. The nut is tightened when the optimum position is found.

ignition interference, but locations involving transmission lines as long as this should first be tested to make sure that sufficient signal pick-up will be obtained.

When a location has been selected, the antenna should be temporarily mounted, with the transmission line initially quite long, to permit moving the antenna back and forth at the selected location and to permit orientation for maximum signal strength.

In England a special service truck carrying the equivalent of a television receiver is employed to check various possible antenna locations and choose the best one for the final installation. One man watches the results in the service truck while the other tries various positions of the antenna. The purpose of these experiments is to find a location which will receive signals with maximum strength over the direct line-of-sight path without ghosts, blurring or phase interference. If reception of the direct signal proves unsatisfactory, the antenna should be aimed at the ground or at some nearby building in the hope of picking up a suitable reflected signal. The final location chosen should be checked long enough to make sure that ignition interference, which produces prominent "snow storms" (brilliant, moving white spots) on the screen, is not serious.

Preselectors

Review of Preselector Requirements. Assuming a superheterodyne r.f. circuit, as is universal practice in television receivers today, the mixer-first detector stage will be preceded by an r.f. circuit commonly known as the preselector, which has a number of important functions.

First of all, the preselector must be able to tune to the different telecasters from which reception is desired. Tuning will be accomplished with a continuously variable control, with a push-button switch, or with a multiple-position rotary switch. Some sets will have provisions for tuning to any one of the seven television channels, while others will have provisions for tuning in only two, three or four channels.

When the preselector is tuned to any one channel, it must have sufficient selectivity to exclude signals which are above the desired picture carrier by twice the video i.f. value, and exclude signals which are above the desired sound carrier by twice the sound i.f. value. If these undesired higher frequencies came through, they would cause a type of interference corresponding to image interference in an ordinary superheterodyne radio receiver.

The preselector must not have such high selectivity that it seriously attenuates any of the side frequencies in the desired channel. This means that the pass band of the preselector must be about 5 mc., if we neglect the guard band and the undesired side frequencies below the video carrier frequency. To secure this wide pass band, at least one band-pass circuit is generally used in the preselector.

The preselector must be properly coupled to the transmission line, in order to give an impedance match between the surge impedance of the line and the input impedance of the receiver, and a path to ground must be provided for noise signals.

Input circuit noise must be kept at a minimum in order to give a high signal-to-noise ratio. This noise is caused by thermal agitation in the input resonant circuit and by shot effect in the tubes of the first stages. Since the input resonant circuits are heavily loaded with resistance, circuit noises due to thermal agitation get very little resonant step-up, and consequently this source of noise is not particularly troublesome. Shot effect causes fluctuations in plate current flow. These can be minimized by employing for both the r.f. amplifier and the mixer, tubes having a high ratio of transconductance to plate current. A type 1852 tube having a normal plate current value of 10 ma. and a transconductance of 9,000 micromhos is fairly satisfactory. A stage of r.f. amplification tends to offset shot effect noises in the mixer tube.

Simple Preselector Circuit. In the smaller television receivers, employing 3-inch to 5-inch diameter t.c.r. tubes, simple preselector circuits such as that shown in Fig. 7*A* will be employed in order to reduce cost, even though this involves a sacrifice in image definition.

In this circuit, the transmission line is coupled to the first resonant circuit L_2-C_1 through the mutual inductance between coils L_1 and L_2. When this first resonant circuit is at or near resonance, its impedance will be governed essentially by the 1,500-ohm shunt resistance. By using the proper value of mutual inductance between coils L_1 and L_2, the input impedance of the receiver can be made equal to somewhere between 70 and 100 ohms, in order to secure the desired impedance match with the surge impedance of the twisted-pair transmission line. The input transformer (L_1-L_2) will have a very little resonant step-up, since the secondary of this transformer is quite heavily loaded by the 1,500-ohm resistor. Note the grounded center tap on coil L_1; this provides a path to ground for noise signals which are picked up by the transmission line and travel down both wires in the same direction.

In the plate circuit of the r.f. amplifier stage in Fig. 7*A* is parallel-resonant circuit L_3-C_2, loaded with a 1,500-ohm resistor. At or near resonance, the r.f. amplifier tube will therefore have a 1,500-ohm plate load impedance. Since this type 1852 tube has a transconductance of 9,000 micromhos, the stage gain will be 9,000 $\times$ 1,500 $\div$ 1,000,000, or 14. The operating values and maximum ratings for two tubes which can be used in the r.f. amplifier stage of a television receiver are:

	Type 1852	Type 1853
Heater voltage	6.3 volts	6.3 volts
Heater current	.45 ampere	.45 ampere
Plate voltage	300 volts	300 volts
Amplification factor	6,750	3,500
Plate resistance	.75 megohm	.7 megohm
Plate current	10 milliamperes	12.5 ma.
Screen voltage	150 volts	200 volts
Max. cathode resistance	160 ohms	190 ohms
Screen current	2.5 milliamperes	3.2 ma.
Transconductance	9,000 micromhos	5,000 micromhos

Both the screen grid and plate supply voltages are applied through resistance-capacitance filters in order to minimize feed-back through the power supply. Assuming a definite supply voltage of about 350 volts, the series resistor in each filter circuit must reduce the supply voltage the correct amount for the electrode in question. Plate current of 10 ma. (.01 amp.)

Courtesy Stromberg-Carlson Telephone Mfg. Co.

Portable telephone set No. 100, made by Stromberg-Carlson Telephone Manufacturing Co., 100 Carlson Road, Rochester, N. Y., especially for use in installing television receiving antennas. One man moves, tilts or rotates the antenna and describes what he is doing, while the other watches the television receiver screen and reports results. The set includes a headphone and microphone with breast plate for each man and 200 feet of connecting cable. In addition, two 1½-volt dry cells are needed.

through the 5,000-ohm plate circuit resistor gives the 50-volt drop required to give 300 volts on the plate. Screen grid current of 2.5 ma. (.0025 amp.) through the 80,000-ohm resistor produces the 200-volt drop required to give 150 volts on the screen grid.

The 160-ohm cathode resistor in Fig. 7*A* develops a C bias of 160 × .0125, or 2 volts. Any reduction in the cathode resistor value would be unsafe unless plate voltage were correspondingly reduced, for a negative bias of at least 2 volts is required to keep plate current at a safe value.

Note that the value of the grid resistor for the next tube, the mixer-first detector tube, is quite low. Stable operation is highly essential in television circuits, and consequently the value of the grid resistor in a television r.f. stage is kept below .5 megohm in order to prevent gas in the tube from altering the value of the low negative bias.

The response of the r.f. amplifier stage can be broadened to any desired degree by providing sufficient loading. Curve *1* in Fig. 7*B* shows this response when there is no loading and curve *2* gives the response when a 1,500-ohm resistor is connected across each resonant circuit as shown in Fig. 7*A*. Loading impairs the image rejection ability of the preselector; this can be overcome by using less loading and tuning the two resonant circuits to slightly different frequencies so as to get the desired wide pass band.

To cover all seven television channels between 40 mc. and 108 mc., tuning condensers C_1 and C_2 will each have a maximum capacity of 120 mmfd. and a minimum capacity of 12 mmfd. or less. Coils L_1, L_2 and L_3 could be wound with three turns of No. 16 bare or enamel-covered solid copper wire, using a ½-inch diameter coil form and spacing the turns ⅛ inch apart. Coils L_1 and L_2 will be wound close to each other on one form, with L_1 at the grounded end of L_2. The spacing between them is generally adjusted at the factory to provide a satisfactory match between the receiver input and a recommended type of transmission line. The 1,500-ohm shunt resistors for the resonant circuit will be either of the carbon or metallized type, so the reactance they introduce into the tuning circuits is negligible. This data is given to make you familiar with the appearance of typical television receiver parts.

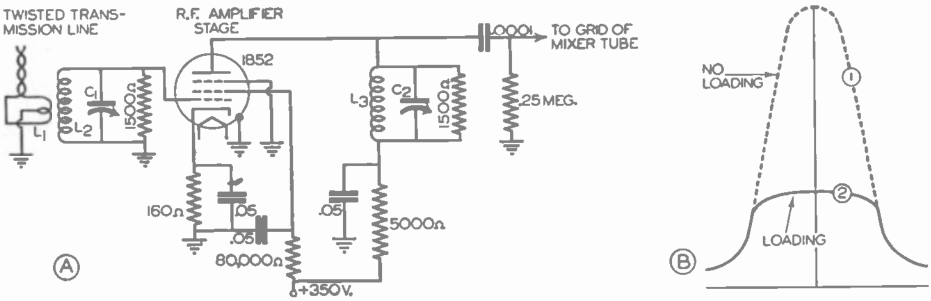


FIG. 7. Simple preselector circuit employing one stage of amplification. The effect of loading on the response curve of the stage is shown at *B*.

Band-Pass Preselectors. A wide pass band in the preselector means high picture definition and good frequency conversion for the sound channel. Theoretically, it should be possible to make a continuously variable band-pass circuit which can be tuned to any frequency in the desired range, but in actual practice the design and construction of such a circuit is by no means a simple task. From a practical viewpoint, it is wiser to use push-button or rotary switches which will introduce separate condenser or coil elements into each resonant circuit for each telecaster. This procedure is gaining widespread popularity among television receiver designers, for it permits preadjustment of each tuning element to give the desired pass band for each station.

A typical circuit employing preadjusted condensers, one for each station, in the resonant circuits is shown in Fig. *8A*. This preselector arrangement employs three tuned circuits, with the first two being tuned to dif-

Considering now the band-pass circuit, observe that coil L_2 is tuned by either C_1, C_2 or C_3, depending upon the setting of the station-selector switch, while coil L_3 is tuned either by C_4, C_5 or C_6. Coils L_2, L_3 and L_4 will usually be identical. Condensers C_1, C_4 and C_7 will be identical 5 to 75 mmfd. trimmer condensers, preferably of the air dielectric type in order to insure stability of adjustment. Condensers C_2, C_5 and C_8 will be 4 to 50 mmfd. units, and C_3, C_6 and C_9 will be 3 to 25 mmfd. units. Different maximum values are employed to eliminate critical adjustments when tuning each condenser in a group to a different station.

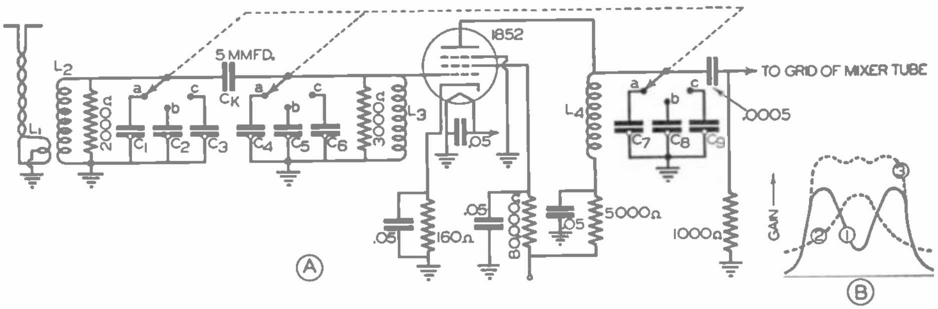


FIG. 8. **Typical band-pass preselector circuit, and response curves for its tuned circuits. Selector-switch tuning is employed to permit the use of preadjusted tuning condensers for each station.**

ferent frequencies to give the double-peak pass-band response represented by curve *1* in Fig. *8B*, and the third being broadly peaked as shown by curve *2*. The over-all response is therefore essentially flat-topped, as shown in curve *3*.

Considering first the resonant plate load circuit in Fig. *8A*, we see that coil L_4 can be tuned to any one of three different television channels by setting the station-selector switch to point *a*, *b* or *c*; this inserts preadjusted condenser C_7, C_8 or C_9 in the resonant circuit. The 1,000-ohm grid resistor in the following mixer stage loads this resonant circuit, thereby broadening the response.

Observe that the first and second tuned circuits in Fig. *8A* are coupled together by a 5-mmfd. fixed condenser C_K. This will ordinarily be the only coupling between the first two tuned circuits, for coils L_2 and L_3 will either be placed in shields or mounted at right angles to each other to avoid mutual inductance. Since these circuits are tuned to ultra-high frequencies, this small capacity is sufficient to give critical or over-critical coupling.

In actual practice, the coupling is usually made greater than the critical value in order to separate the peaks still farther, as indicated by curve *1* in Fig. *8B*. The plate resonant circuit, having response curve *2*, *fills out* the valley between the peaks.*

If we set the station selector switch at setting *a*, and proceed to adjust all circuit components for a flat-top response at the lowest-frequency television channel (44-50 mc.), coupling condenser C_K would not be properly adjusted for higher-frequency channels tuned in at settings *b* and *c*. At higher frequencies, the reactance of C_K would be lower, giving more coupling, a wider pass-band and increased Q factor for each of the first two tuned circuits. As a result, the loading on these resonant circuits would be inadequate at the higher frequencies, and we would have three more or less sharp peaks in the response curve instead of the desired flat-top response. This condition can be partially overcome by adjusting C_K for optimum results at a mid-channel in the frequency range to be received. Unless C_K gives approximately critical coupling for each desired station, the adjustment of the trimmer condensers for that station will be quite difficult.

The real difference between the preselector circuits employed in television and sound receivers lies in the sizes and values of the parts. In television receivers, both the inductance and the capacitance values are quite low; because of this, the parts must be mounted in such a way that stray coupling to the chassis does not appreciably alter the values of the parts. Condenser C_K, particularly, should be mounted away from the chassis and other parts. Leads should be short.

Ideal Band-Pass Preselectors. The necessity for maintaining a flat-top response for each channel tuned in has compelled some designers of high-definition television receivers to employ a separate preselector circuit for each television channel, as shown in Fig. *9*. The only parts of the preselector used in common for all channels are the antenna, the r.f. amplifier tube and the supply and filter components associated with the tube. With this arrangement it is possible to design each preselector circuit for a particular channel, securing optimum coupling and optimum loading for the desired pass-band on that channel. Although only two preselector circuits are shown in Fig. *9*, any number up to seven may be employed in receivers, depending upon the number of stations which are to be received.

The twisted two-wire transmission line is connected to the first section of the station-selecting switch. Center tapped resistor R_1 across the receiver end of the transmission line allows static charges to leak off to ground without unbalancing the antenna. The station-selecting switch connects the transmission line to either L_{1a} or L_{1b} in this two-station arrangement. These input coils have center taps which also shunt noise signals to ground.

Let us analyze this preselector arrangement with the station selector switch at point *a*, as indicated in Fig. *9*. Other preselector circuits will be identical except that circuit constants will be for a different frequency channel.

Signal currents from the transmission line pass through primary winding L_{1a}, inducing a voltage into secondary winding L_{2a} of the first resonant circuit. Condenser C_a tunes this circuit to the center of the desired pass band, and R_a loads this circuit so as to give a broadly peaked response. The mutual inductance between L_{1a} and L_{2a} is adjusted to give a proper

---

* Curve *3* in Fig. *8B* is obtained by multiplying together the values of curves *1* and *2*. Response curves represent gain, and consequently we must take products rather than sums when combining, just as we do when computing the gain of several amplifier stages.

match between the input impedance of the receiver and the transmission line impedance at the desired station frequency.

The electrode supply circuits and the filter circuit for the first r.f. tube are conventional in design, with the single exception that an r.f. choke is employed in the plate lead for the tube to assist by-pass condensers C_3 and C_4 in keeping ultra-high-frequency currents out of the power supply.

After amplification by the type 1852 r.f. amplifier tube, r.f. signals pass through d.c. blocking condenser C_{K2} into a band-pass circuit made up of resonant circuit L_{3a}-C_{1a} and L_{4a}-C_{2a}, which are mutually coupled by coil

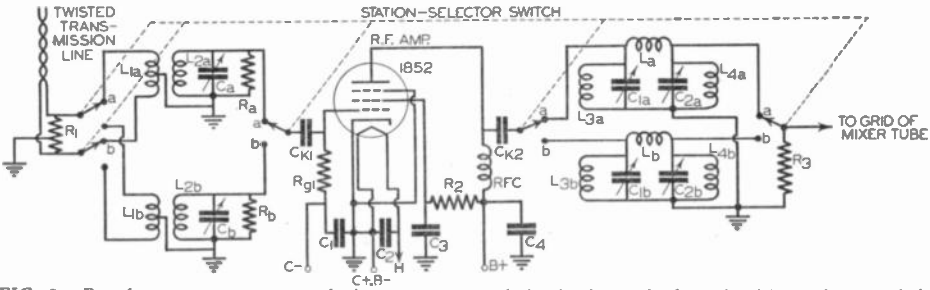


FIG. 9. Preselector arrangement employing separate tuned circuits for each channel, with a selector switch to connect the desired set of preadjusted circuits to the r.f. amplifier stage.

L_a. Grid resistor R_3 for the converter stage loads this band-pass circuit; this resistor is common to all preselector circuits. By selecting the proper value for L_a, it is possible to secure the desired separation of peaks and depth of valley between peaks for a definite load. Note that there is no mutual inductance between coils L_{3a} and L_{4a}; it is simpler to employ a separate coil L_a for coupling together the resonant circuits than to depend upon mutual inductance between the main coils.

Frequency Converters

In any superheterodyne receiver, whether used for television or sound reception, most of the gain and band-pass action is provided by the i.f. amplifier, which normally operates at a much lower frequency than that of the incoming carrier signal. The frequency converter serves to change the incoming carrier frequency to this lower i.f. value. A detector circuit is employed to mix the incoming signal with the r.f. signal from a local oscillator, in order to produce a composite signal which after detection gives the desired beat or difference frequency. This output signal possesses the original modulation if square-law detection is employed or if linear detection is used and the local r.f. oscillator signal is made at least ten times as strong as the incoming carrier signal.

Frequency converter systems for television receivers are fundamentally the same as those for all-wave sound receivers. In each case a local oscillator stage and a mixer-first detector stage are needed. Combination oscillator-detector tubes (pentagrid converters) are not suitable for television receivers, because these tubes are poor oscillators at extremely high frequencies, and their low ratio of transconductance to plate current tends to accentuate noise.

Separate mixer-first detector tubes and oscillator tubes are used in television receivers. The two tubes may be in the same envelope, however. The local r.f. signal at the grid of the oscillator tube may be injected electronically into the mixer tube by a connection to one of the mixer electrodes, or the oscillator circuit may be coupled either capacitively or inductively to the mixer circuit.

Linear detection is invariably employed for the converter in a television receiver, and consequently the oscillator output voltage will be quite high. The mixer-first detector tube in this case will be of the sharp plate current cut-off type, with a linear e_g-i_p characteristic. Automatic gain control can be used to prevent grid current flow on strong signals and to offset the natural drop in the oscillator output at higher frequencies.

The mixer tube should have a high

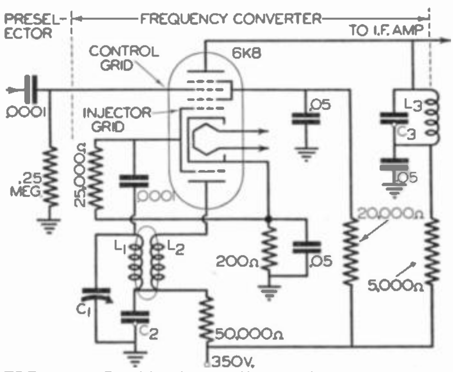


FIG. 10. Combination oscillator-mixer-first detector tube connected into a frequency converter circuit which provides continuously variable tuning.

ratio of conversion conductance to plate current, for otherwise this tube will create an appreciable noise signal which will cause "snow storms" or undesired patterns to move across the reproduced image.

Frequency stability is an important consideration in the oscillator circuit of a television receiver, since excessive deviations in the oscillator frequency can distort or completely block the output of the sound channel. Frequency drift should be a minimum in the oscillator, and the sound i.f. channel should be sufficiently broad to pass the sound i.f. signal despite unavoidable frequency drift.

Frequency Converter with Electronic Mixing. A circuit employing a combination triode and pentode tube as oscillator and mixer-first detector is shown in Fig. *10*. The oscillator output voltage, developed across oscillator tuning condenser C_1, is injected into the pentode mixer tube by means of a direct internal connection between the triode oscillator grid and the first grid (injector grid) of the pentode mixer tube; this arrangement is known as *electronic mixing*. The frequency of the local oscillator in this circuit is continuously variable over the entire range of seven television channels, and hence this circuit is suitable for use with the continuously variable preselector circuit shown in Fig. *7A*.

The oscillator circuit in Fig. *10* is of the tuned grid type, with inductive feed-back from plate to grid through the mutual inductance between coils L_1 and L_2. Additional feed-back is provided by C_2, since this capacity to ground is common to both coils. At high frequencies the reactance to C_2 is quite low, and most of the feed-back is inductively produced; at low frequencies the mutual inductive reactance is reduced, but the mutual capacitive reactance provided by C_2 is a maximum, providing the required additional feed-back to maintain the oscillator output voltage more or less constant.

Rectified grid current produces across the 25,000-ohm resistor the required negative C bias for the oscillator. The combined plate current of the two tube sections, flowing through the 200-ohm cathode resistor, produces an independent C bias for the mixer tube.

Condenser C_2 and the 50,000-ohm resistor serve as the r.f. filter for the oscillator plate circuit. Similar filters are used in the screen grid and plate supply leads of the mixer tube. Resonant circuit L_3-C_3, serving as plate load for the mixer-first detector, is broadly tuned and is loaded by following circuits so as to give uniform response over the entire range of side frequencies associated with the sound and video i.f. carriers.

When using the circuit of Fig. *10* with the preselector shown in Fig. *7A*, oscillator tuning condenser C_1 in Fig. *10* may be variable from 12 mmfd. to 120 mmfd., and padding condenser C_2 may have a maximum value of about 250 mmfd. Oscillator grid coil L_1 may have three turns of No. 16 enameled solid copper wire with the turns spaced ⅛ inch apart on a ½-inch diameter coil form. Feed-back coil L_2 may be of similar construction, placed far enough away from the oscillator grid coil so the circuit will oscillate at the lowest desired frequency.

When combining the preselector and frequency converter sections just discussed, three midget 12-120 mmfd. variable condensers may be ganged together to give single-control tuning. In this case condenser C_2 in Fig. *10* would be adjusted to give proper alignment at the low-frequency end of the tuning range.

Frequency Converter for Switch-Type Tuning. A suitable frequency converter arrangement for use with the preselector circuit in Fig. *8* is given in Fig. *11*. With these two circuits, either a rotary switch or a push-button tuning switch may be employed for instantaneous tuning to a desired television station.

As you can see, the oscillator circuit in Fig. *11* employs a separate 6J5 triode tube connected into a Hartley oscillator circuit. The oscillator plate is shunt-fed through a 5,000-ohm resistor and an r.f. choke coil. Rectified grid current flowing through the 50,000-ohm grid resistor produces the required C bias for the oscillator. Coil L_5 is tuned to the desired oscillator frequency by trimmer condenser C_{10}, C_{11} or C_{12}; these have maximum capacities of 75, 50 and 25 mmfd. respectively. Coil L_5 may consist of five turns of No. 26 enamel wire wound within a space of ½ inch on a ½-inch diameter coil form, with tap T made one turn away from the grounded end of the coil.

A type 1852 pentode tube is used as the mixer-first detector in order to give a high ratio of conversion conductance to plate current. Observe that the first grid (the control grid in this case) of this tube connects to the plate of the r.f. amplifier tube through a .0005-mfd. d.c. blocking condenser. The 1,000-ohm grid resistor thus loads the tuned plate load of the r.f. amplifier, giving the desired broad response to this tuned circuit.

The oscillator output voltage developed across coil L_5 is coupled to the plate of the r.f. amplifier tube through a 1-mmfd. blocking condenser. In this

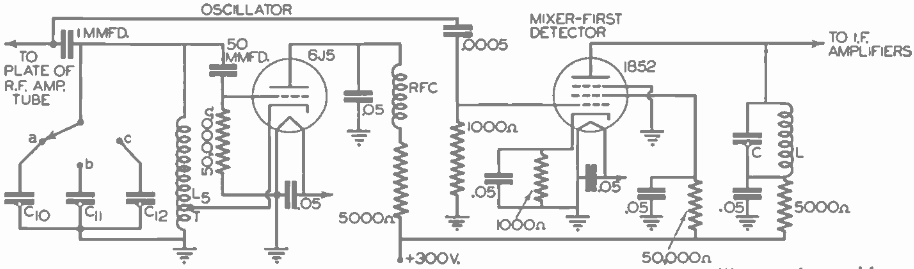


FIG. 11. Frequency converter employing separate mixer-first detector and oscillator tubes, with pre-adjusted oscillator tuning condensers.

way both the amplified incoming signal and the local r.f. oscillator signal are fed simultaneously to the grid of the mixer-first detector tube. The low coupling value of 1 mmfd. prevents the oscillator tuned circuit from having an appreciable effect upon the tuned plate load of the r.f. stage.

Frequency Converter Employing a Tuned Plate Oscillator. Some television receiver designers prefer to use a tuned plate oscillator because it gives better frequency stability than a tuned grid circuit. A preadjusted oscillator circuit with plate circuit tuning and

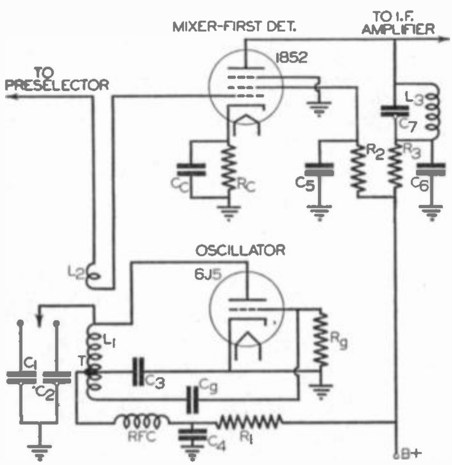


FIG. 12. Frequency converter with tuned plate oscillator and preadjusted tuning.

an inductive form of mixing is shown in Fig. *12*. This circuit was designed for use with the preselector arrangement shown in Fig. *9*, but may be modified for use with any other preselector arrangement.

The mixer-first detector circuit in Fig. *12* is similar to those just described, with the exception that the grid circuit is run through coil L_2, which is inductively coupled to oscillator coil L_1. The current in the oscillator tuned circuit thus induces the required oscillator voltage in the mixer grid circuit.

The oscillator tuning condenser (C_1 or C_2) connects only across the upper or plate portion of L_1, thus giving a tuned plate oscillator. R_g and C_g provide C bias automatically for the 6J5 oscillator tube. The plate supply voltage for the oscillator is fed through r.f. filter R_1-C_4, through choke coil *RFC* and through the upper part of L_1. The choke coil prevents r.f. from feeding back into the plate supply, as also does filter R_1-C_4; as a result, signal currents in the oscillator tuned circuit are forced to take the path through C_3 to ground.

Frequency Converter with Colpitts Oscillator. The Colpitts oscillator circuit is another favorite with television design engineers. This circuit as adapted for television requirements is shown in Fig. *13;* as you can see, it calls for more parts and for a more intricate switching arrangement when switch-type tuning is desired.

With the tuning switches in position *a*, oscillator coil L_1 is in the circuit, with one end connecting to the oscillator grid through C_g and the other end connecting directly to the oscillator plate. The common lead for C_1 and C_2 connects to the cathode through the chassis and through condenser C_C. Condensers C_1 and C_2 would be ganged together to simplify adjustments. Resistors R_1 and R_2 keep r.f. signals out of the power supply lead.

Oscillator Frequency Stability. Assuming an essentially constant supply voltage, the oscillator output frequency depends upon *the resonant frequency of the oscillator tuned circuit* and upon *the constancy of the phase of the feed-back voltage.*

Variations in temperature and humidity can change coil and condenser values, thus changing the resonant frequency of an oscillator tuned circuit. These variations can be minimized by employing air dielectric condensers and by mounting the coil turns rigidly on insulating material which is not affected by temperature or humidity. Rigid connecting wires are equally as important. In fact, all parts used in the oscillator circuit should change the least possible amount with fluctuations in temperature and humidity, and compensating means must be provided for any unavoidable excessive changes.

Fundamentally, the phase of the feed-back voltage depends upon the characteristics of the oscillator tube. The a.c. plate resistance and the a.c. grid resistance of the oscillator tube are the two important tube characteristics which can affect the oscillator frequency. When one of these values changes, a.c. voltages and currents

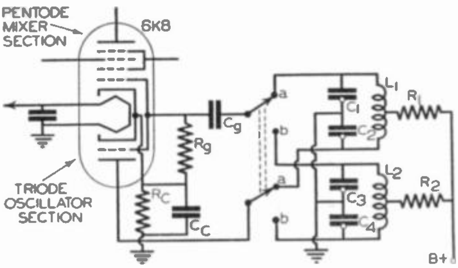


FIG. 13. Colpitts oscillator circuit as adapted for a television receiver.

change correspondingly in order to change the other resistance value and thereby maintain the constant resistance ratio which is a characteristic of all self-excited oscillator circuits. As a result, the phase of the feed-back voltage is altered, and this in turn changes the oscillator output frequency. By careful circuit design, careful choice of part values for the oscillator circuit and good voltage regulation in the power supply, the phase of the feed-back voltage can be kept essentially constant or changes in the phase of the feed-back voltage can be prevented from affecting appreciably the oscillator frequency.

A high Q factor for the oscillator tuned circuit, along with loose coupling between the oscillator circuit and the mixer circuit, contributes to good stability. Inductance or capacitance may be introduced in the oscillator grid or plate leads or in both to offset any circuit changes which might affect the phase of the feed-back voltage. At ultra-high frequencies, the inductance of the plate and grid leads must be considered, and may be utilized to improve frequency stability. Finally, the oscillator tube itself must be carefully chosen, for certain types of tubes are more stable than others.

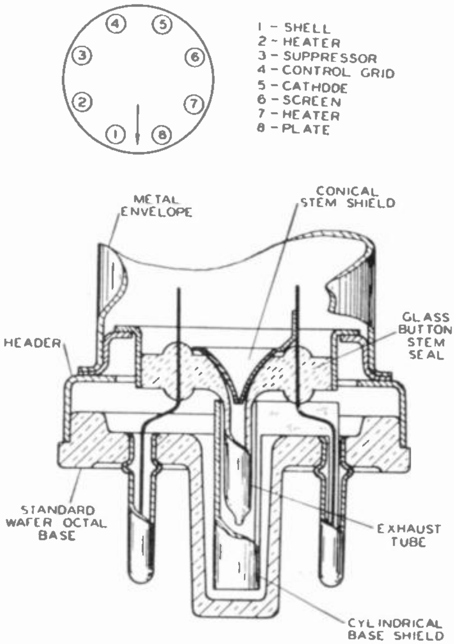
The design of stable oscillators for ultra-high-frequency circuits has been taken up here primarily to show that *indiscriminate interchanging of tubes and parts in the oscillator circuit is likely to create real service problems in television receivers.*

Chassis Layout Problems. In television circuits it is essential that all stray capacities between input and output circuits be reduced to an absolute minimum. There must be no possibility of r.f. signals entering the power supply, for that would cause extremely undesirable regeneration or degeneration. All parts in a television receiver must be extremely rigid, and connecting leads must likewise be short and rigid.

In a television receiver, particular attention must be given to the grid lead when it goes to a top cap type of pentode tube. In sound receivers this lead is more or less flexible and may assume different positions after each tube replacement. At ultra-high frequencies even the slightest shift in in the position of this lead may result in severe undesirable regeneration, particularly if the tube has a high transconductance.

Filter circuits are extremely important in television circuits and are widely used, but at ultra-high frequencies it is wiser to use resistors in place of inductances. Filter condensers must be sufficiently non-inductive to prevent their acting as coils at these high frequencies.

By-pass condensers, particularly the screen grid by-pass condenser, must be located close to the tube socket prongs to which they connect if they are to have maximum effectiveness. High-potential supply leads should be placed close to the chassis, in order that their capacity to the



Courtesy RCA Mfg. Co.

FIG. 14. Structural details of a single-ended amplifier tube designed especially for ultra-high-frequency circuits in order to simplify chassis layout problems.

chassis will provide extra by-passing for leakage r.f. currents and will minimize coupling to other parts.

All leads in a single stage which are shown in the schematic circuit diagram as going to the chassis should be brought to a single point on the chassis, and not to the nearest convenient chassis bolt. A common grounding point eliminates conductive coupling through the chassis.

Short grid and plate leads, separated from each other as much as possible, are essential in u.h.f. circuits to prevent feed-back. Tube manufacturers have recently brought out "single-ended" tubes which have no top caps, *in order to simplify chassis layout problems* for the television receiver designer. The special base construction shown in Fig. *14*, in which the control grid prong (*4*) and plate prong (*8*) are diametrically opposite each other, is required in these tubes to keep the plate-to grid inter-electrode capacity sufficiently low.

The capacitance between the plate and grid leads as they pass through the glass stem is reduced by a conical-shaped metal stem shield inside the glass exhaust tube, and the capacitance between the prongs is reduced by a cylindrical metal shield inside the hollow aligning plug. Both shields are connected to the metal envelope of the tube and to prong No. *1*, which is usually grounded to the chassis through the tube socket.

Wafer type sockets are considered better than molded sockets by television receiver designers, for wafer sockets reduce the capacity between the various socket terminals. To provide *additional shielding between plate and grid leads*, the screen grid by-pass condenser is often mounted directly underneath the socket in such a way that it is between these two leads. Since the outside foil of this condenser is grounded, the action is that of a grounded shield located between the leads.

A typical chassis layout for the preselector and frequency converter sections of a television receiver employing single-ended tubes is shown in Fig. *15*. Grid and plate leads are short, far apart and do not cross each other. The tubes are visible when inserted in their sockets, and are readily removed without taking the chassis out of the cabinet.

The Sound Channel

At the output of the frequency converter in a television receiver we have two new desired carrier currents. The *sound i.f. carrier* is modulated with the audio signal, and the *video i.f. carrier* is modulated with the picture signal. Each carrier is accompanied by its side frequencies. The most satisfactory location at which to separate these two carriers is right at the output of the first detector. The separation can be accomplished here simply by employing separate i.f. am-

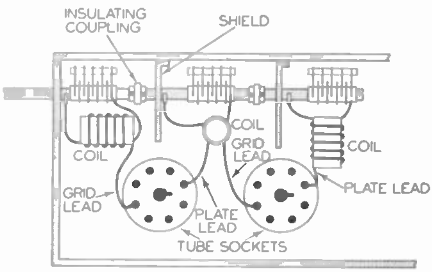


FIG. 15. Bottom view of chassis for ultra-high-frequency stages employing single-ended tubes. The coils, tuning condensers and all leads are under the chassis.

plifiers, each designed to accept only one type of signal. This permits a minimum width for the pass band of the video i.f. amplifier, greatly simplifying the design of the i.f. transformers. Each i.f. channel can be designed to give maximum rejection of the other signal. This is necessary because video i.f. signals which are not completely rejected by the sound i.f. amplifier will reach the audio demodulator stage and cause *chattering noises* along with the sound program. Likewise, any sound i.f. signals in the picture channel will produce distortion of the image.

The input circuit of each i.f. channel must be so connected to the mixer-first detector that there is no adverse action between the sections. We will consider first the connections to the first detector, then study the entire sound channel from the first detector to the loudspeaker.

Since it is standard practice to radiate the sound programs on a carrier frequency which is above the video carrier by 4.5 mc., and since the local oscillator in a television receiver is always operated at a frequency *above* the incoming video carrier frequency, the i.f. sound carrier in a television receiver will always be 4.5 mc. below the video i.f. carrier. For example, if the video i.f. carrier is 13 mc., the sound i.f. carrier will be 8.5 mc.

Video Sets. Some television receivers do not have a complete sound channel; instead, the output of the sound i.f. amplifier is fed into the existing all-wave receiver in the home. When tuned to 8.5 mc., the all-wave receiver completes the sound channel section of the television receiver. This gives a material reduction in the cost of the television receiver.

Every precaution must be taken to prevent the oscillator in the all-wave receiver from reacting back on the television frequency converter. For example, if the all-wave receiver has a .46-mc. (460 kc.) intermediate frequency and its preselector is tuned to 8.5 mc., its oscillator will operate at 8.96 mc., which is right at the edge of the pass band for the video i.f. amplifier. Since a 9-mc. video i.f. side frequency corresponds to the highest video frequency, any 8.96-mc. oscillator signal which enters the video channel can introduce an undesired pattern and impair the definition of the image on the screen.

Any harmonics of the oscillator in the all-wave receiver must likewise be prevented from entering the mixer-first detector of the television receiver, for these harmonics might beat with signals in the lower-frequency television channels to give undesired patterns on the image. To prevent any interaction like this between an all-wave receiver and a television receiver, an extra stage known as a *sound buffer stage* is invariably inserted between the output of the television frequency converter and the input of the all-wave receiver.

Combination All-Wave-Television Receiver. When a receiver is to serve for both television and all-wave sound reception, the regular sound channel of the television receiver may be so designed that it can be switched either to the television frequency converter section or to an extra preselector and frequency converter section of the all-wave type. In this way, all-wave reception can be incorporated in a television receiver at a minimum cost.

A number of other arrangements are possible in a combination all-wave television receiver. The sound i.f. channel can be designed to operate at .46 mc. (460 kc.), and a conventional all-wave preselector and frequency converter is provided. An extra frequency converter is then needed to change the 8.5-mc. sound i.f. signal at the television converter output to .46 mc. for the sound i.f. channel, and this extra frequency converter must be preceded by a sound buffer stage. The local oscillator for this second television frequency converter would operate either at 8.96 mc. or 8.04 mc. Either the all-wave converter or the second television converter can then be switched to the input of the sound i.f. channel.

Another possible arrangement is that where the television receiver is of conventional design, and an all-wave preselector, frequency converter and i.f. amplifier are added. The audio demodulator, along with the audio amplifier and loudspeaker, are switched either to the all-wave i.f. channel or to the regular television sound i.f. channel.

Whenever the sound portion of a television program is sent through a .46 mc. i.f. channel, it is highly essential that the oscillator associated with the television mixer-first detector have unusually good frequency stability. A .46-mc. i.f. channel is normally quite selective, so that any frequency drift would cause audio distortion and even complete fade-out of the sound program. Automatic frequency control would be highly desirable for the sound channel in a case like this. Furthermore, whenever an extra frequency converter is employed, the oscillator associated with this converter must have a minimum frequency drift for the same reason; otherwise, it will be necessary to retune quite often to correct for audio distortion due to side-band cutting in the .46-mc. i.f. channel. Loading of the .46-mc. tuning circuits with 10,000- to 50,000-ohm resistors will broaden their response and minimize the effects of frequency drift.

Let us consider the sound channels of a few typical television receivers. Only the unique features will be pointed out, for you are already familiar with conventional sound receivers.

Using an All-Wave Receiver as the Sound Channel. A typical buffer stage for linking the frequency converter of a television receiver to the input of an all-wave receiver is shown in Fig. *16*. Resonant circuit L_1-C_1 is broadly tuned to the video i.f. carrier, and the video i.f. voltage developed across it is fed into the video i.f. channel through d.c. blocking condenser C_K. In shunt with this resonant circuit (between the plate of the first detector and chassis) is a combination rejector-acceptor circuit, with L_2-C_2

tuned to the low-frequency end of the video i.f. band width in order to reject that part of the picture signal which might interfere with the sound channel, and with L_3-C_3 tuned to the sound i.f. carrier so that maximum sound i.f. voltage will be developed across it. Condenser *C* is placed between these two resonant circuits to block the flow of d.c. plate current to ground, and 15,000-ohm resistor *R* is employed to minimize the loading effect of this rejector-acceptor circuit upon the first detector. Without *R*, this circuit would act almost as a direct short for the 13-mc. video i.f. carrier, impairing the pass action of the first detector load.

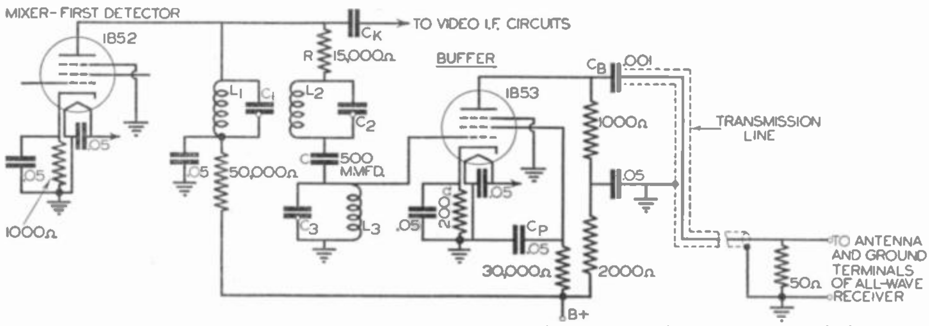


FIG. 16. Circuit for a typical buffer stage intended for use between an all-wave receiver and the output of the mixer-first detector of a television receiver.

A type 1853 tube, having a high transconductance at ultra-high frequencies, is employed in the buffer stage in order to give as high gain as possible. The voltage supply connections to this tube are conventional. Screen grid by-pass condenser C_P should be placed as close as possible to the screen grid terminal on the tube socket. Plate and control grid leads should be kept far apart so as not to destroy the natural feed-back-eliminating characteristic which is inherent in tubes having screen grids; the screen grid in this tube thus provides the desired buffer feature.

The plate load in the buffer stage is a 1,000-ohm resistor. The plate supply is fed to this load through a 2,000-ohm resistor and .05-mfd. condenser acting as an r.f. filter. The final connection to the all-wave receiver is made with a 50- to 100-ohm transmission line which is grounded both to the chassis of the television receiver and to the chassis of the all-wave receiver. A 50- to 100-ohm resistor is placed across the all-wave receiver end of this transmission line to give proper loading. A well shielded transmission line is essential, in order to prevent signals from being radiated by this line and picked up directly again by parts in the television receiver.

Sound Channel in a Conventional Television Receiver. The sound i.f. amplifier in a conventional sight-sound television receiver will be tuned to approximately 8.5 mc. At this frequency, the sound i.f. channel can be properly balanced to give stable operation, simple tuning and sufficient pass-band width to allow for reasonable oscillator frequency drift.

Highly selective circuits at ultra-high frequencies such as 8.5 mc. will have high Q factors, and hence these circuits may force even pentode tubes into oscillation. The solution lies in loading the i.f. circuits sufficiently. In receivers employing continuously variable tuning, the receiver owner will tune in a telecaster by tuning for clearest sound reception. If the sound i.f. channel is too selective, this will be an extremely critical adjustment and difficult to make. A *100-kc. pass band* for the 8.5-mc. sound i.f. amplifier is generally suitable for television requirements.

Loading of the tuning circuit in an 8.5-mc. sound i.f. amplifier reduces the selectivity of the circuit. Enough tuned circuits must therefore be employed to give the required selectivity for rejecting video signals and for giving the required sensitivity for amplifying the sound signals. A simple and complete sound channel employing these features is shown in Fig. *17*.

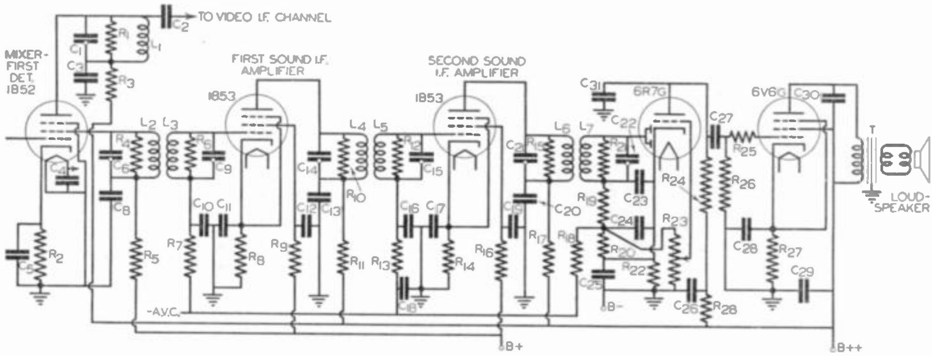


FIG. 17. **Conventional sound i.f. channel for a sight-sound television receiver. The sound i.f. value is about 8.5 mc.**

The method employed for feeding the sound and video i.f. signals from the mixer-first detector into their respective channels is of particular interest. The video i.f. signal enters parallel-resonant circuit L_1-C_1, which is connected between the plate and cathode of the mixer tube, developing across this circuit the desired high video i.f. voltage for transfer through d.c. blocking condenser C_2 into the video i.f. amplifier.

The sound i.f. signal is fed into parallel-resonant acceptor circuit L_2-C_6, which is connected between the screen grid and the cathode of the mixer tube. Sound signal currents in this circuit are transferred inductively into resonant circuit L_3-C_9 in the input of the sound i.f. channel. The suppressor grid of the mixer tube effectively shields one channel from the other. Two stages of sound i.f. amplification are employed, along with three i.f. transformers. Each transformer is heavily loaded with resistance across both the primary and secondary to give broad tuning to the selected high sound i.f. value (about 8.5 mc.) and the coupling between primary and secondary is adjusted in each case to give the desired 100-kc. pass band. The remainder of this circuit is of conventional design.

The stability of any of the sound channels so far mentioned depends essentially upon the ability of the adjustable condensers to maintain their capacity values despite variations in temperature and humidity. This stability can be obtained only with adjustable condensers employing air as a dielectric. Because air condensers occupy valuable space, it is often preferable to use fixed mica condensers and variable inductances in the tuning circuits. A sound channel incorporating inductance tuning is shown in Fig. *18*. The audio stages between the second detector and the loudspeaker are omitted since they are of conventional form.

Starting at the output of the first

sound i.f. amplifier tube, we find here a tuned-plate, tuned-grid i.f. transformer of unusual form, but the action of this circuit is more or less like that of the conventional double-tuned i.f. transformer. To understand how this circuit operates, we must first consider the conventional double-tuned i.f. transformer circuit in Fig. *19A* and its equivalent electrical circuit in Fig. *19B*. The mutual inductance M in Fig. *19A* becomes the common coupling inductance in Fig. *19B*.

ductance. Condenser C_{11} merely reduces the inductance of L_4, and C_{14} reduces the inductance of L_5. The primary resonant circuit in Fig. *18* is therefore made up of the net inductance of L_4 in series with the common inductance L_8, tuned by the plate-to-cathode capacity of the first type 1853 sound i.f. tube. The secondary resonant circuit is made up of the net inductance of L_5 in series with common coupling inductance L_8, tuned by the grid-to-cathode capacity

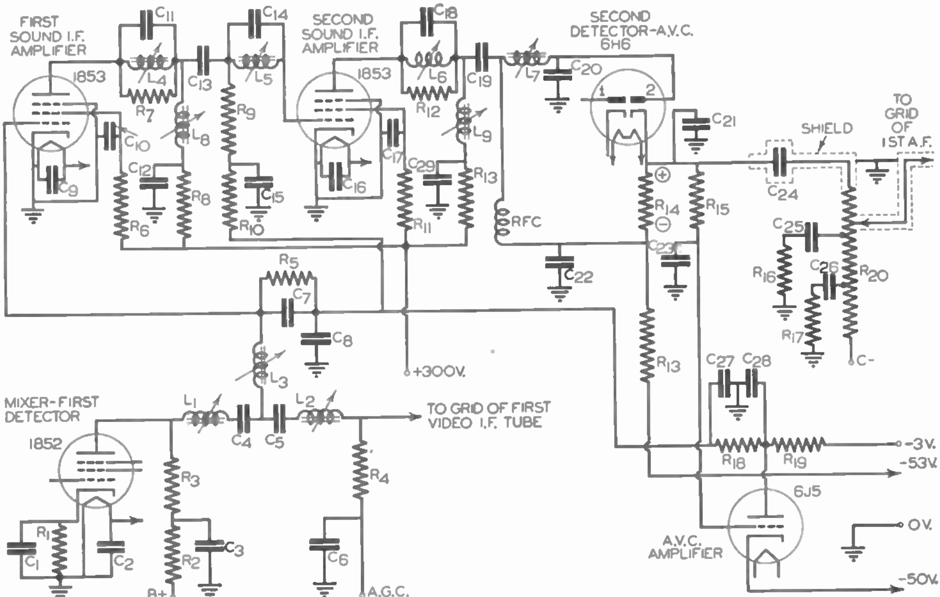


FIG. 18. Circuit diagram for the sound i.f. amplifier, second detector and a.v.c. amplifier of a television receiver employing inductance tuning for the 8.5-mc. sound i.f. channel. Each variable inductance has a fixed winding with a movable plug-type core made of pulverized soft steel particles.

The primary of our equivalent circuit is tuned by the primary leakage inductance (L_1-M), and the secondary circuit is tuned by the secondary leakage inductance (L_2-M).

Returning to the sound i.f. transformer under consideration in Fig. *18*, we recognize variable inductance L_8 as corresponding to the common coupling inductance M in Fig. *19B*. L_4 corresponds to the primary circuit inductance in Fig. *19B* and L_5 corresponds to the secondary circuit in-

of the second type 1853 sound i.f. tube. Condenser C_{13} has a very low reactance at sound i.f. frequencies, and serves essentially for blocking d.c. plate current. This condenser can therefore be considered as short-circuited when analyzing this circuit.

By properly proportioning the values of L_4 and C_{11}, the net inductance in the primary circuit can be made correct for resonance at the desired sound i.f. value, and L_4-C_{11} can at the same time act together as a parallel-resonant circuit which is tuned to the lowest side frequencies of the video i.f. carrier, thereby rejecting picture signals. The same action can be secured in the secondary circuit by proper choice of values for C_{14} and L_5.

If the picture signal rejection feature is unnecessary in the secondary circuit, a coil alone can be used here; thus, coil L_7 in the final i.f. transformer is not shunted by a condenser. Just as in conventional i.f. transformers, the primary and secondary circuits will be tuned to slightly different frequencies in order to give the desired wide pass band. Resistor R_7 in the first i.f. transformer and resistor R_{12} in the last i.f. transformer broaden the circuit actions and thus smooth out the double peaks in the response curve.

Resistor R_9 in the first i.f. transformer in Fig. *18* will have a high ohmic value, for it serves only to complete the d.c. circuit from the a.v.c. and C bias sources through L_5 to the grid of the second sound i.f. amplifier tube. All other elements associated with the first sound i.f. transformer circuit are for filtering and bypassing purposes. If two stages in the sound i.f. channel do not give sufficient gain, another type 1853 tube and another i.f. transformer network similar to that associated with L_4, L_8 and L_5 may be used.

The second detector in the circuit of Fig. *18* also furnishes the a.v.c. voltage. The sound i.f. amplifier output voltage across C_{20} sends electrons through R_{14} and then from the cathode to the plate of one of the diodes of the 6H6 tube, thereby developing a rectified voltage across R_{14}. Condenser C_{21} serves to filter this voltage; this condenser may be omitted if the capacity between the following shielded cable and ground is adequate for filtering purposes. The a.f. voltage across R_{14} is fed through coupling condenser C_{24} to tapped potentiometer R_{20}, which serves as a combination volume control and automatic bass compensator. R_{16}-C_{25} and R_{17}-C_{26} are the two automatic bass compensation networks.

In order to secure a more positive a.v.c. action, the d.c. voltage developed across R_{14} is amplified by the type 6J5 triode before being applied to the a.v.c.-controlled tubes. Since this triode reverses the polarity of the a.v.c. voltage, it is essential that the grid of the triode be fed with a positive potential. This is accomplished by connecting diode load R_{14} into the cathode lead of the diode, and tapping off the detector output voltage from

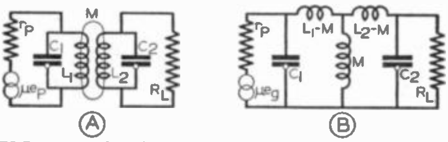


FIG. 19. Double-tuned i.f. transformer and its equivalent electrical circuit.

the positive end of R_{14} through resistor R_{15}.

R_{19} serves as a load for the plate circuit of the 6J5 tube; positive voltage swings on the grid of this tube make the plate end of R_{19} swing negatively with respect to the other end of this resistor. The plate receives d.c. power from a —3 volt terminal, while the cathode of this tube is connected to a —50 volt terminal; this indicates that the plate has a net positive supply voltage of 47 volts. The grid of this triode, being connected to a —53 volt terminal through R_{15}, R_{14} and R_{13}, has a fixed negative bias of 3 volts with respect to the cathode. Since no current flows in the grid circuit, there is no delay in the a.v.c. action. The amplified a.v.c. voltage in series with the —3 volt bias is supplied to the grids of all i.f. amplifier tubes through time delay network R_{18}-C_{27}-C_{28}.

Considering now the connection of this sound channel to the output of the frequency converter, we find that coils L_1, L_2 and L_3, acting with the plate-to-cathode capacity in the 1852 first detector tube and with the grid-to-cathode capacity in the 1853 first sound i.f. tube, form a double-tuned band-pass circuit. It will be easier to understand the action of this circuit if you short out condensers C_3, C_4, C_5, C_6 and C_8 on the diagram with a pencil; these condensers all have negligible reactance at signal frequencies.

L_3 and C_7 form a series-resonant circuit which is tuned to the sound i.f. frequency; a large sound i.f. voltage is therefore developed across C_7 for application to the grid of the first sound i.f. amplifier tube. R_5 loads this resonant circuit and at the same time provides a path for the negative bias for the sound i.f. tube. L_1 has a low reactance to sound i.f. signals and hence does not block them.

At video i.f. frequencies, the reactance of C_7 is less than that of L_3, hence series-resonant circuit L_3-C_7 becomes inductive and serves as the common coupling inductance between the primary and secondary tuned circuits for the video channel. L_1 and the net inductive reactance of L_3 tune the plate-cathode capacity of the mixer tube to the video i.f. carrier, while L_2 and the net inductive reactance of L_3 tune the grid-cathode capacity of the first video i.f. tube to the same frequency. Resistors R_3 and R_4 broaden the response of the primary and secondary tuned circuits for video i.f. currents.

TEST QUESTIONS

Be sure to number your Answer Sheet with the *number* appearing on the front cover underneath the title of this text.

Place your Student Number on every Answer Sheet.

Send in your answers for this lesson immediately after you finish them. Doing this insures that the graded answers will reach you while the subject matter is still fresh in your mind, and you will get the greatest possible benefit from our speedy personal grading service. *Never hold up a set of lesson answers.*

1. What is the line-of-sight path between two points?
2. What three troubles can occur when a television receiving antenna accepts video carrier signals coming from a given station over two or more paths which differ in length?
3. How are ghosts eliminated?
4. Will a vertical television receiving antenna pick up more man-made interference noise than a horizontal antenna?
5. Why is a reflector sometimes used with a di-pole television receiving antenna?
6. How can the input impedance of a television receiver be increased?
7. Why are single-ended tubes used in television receivers?
8. Why is the screen grid by-pass condenser sometimes mounted below the socket of a single-ended tube in such a way that it is between plate and grid leads?
9. What is heard along with the sound program when video i.f. signals are not completely rejected by the sound i.f. amplifier?
10. What is the normal pass band width for an 8.5-mc. sound i.f. channel?

NATIONAL RADIO INSTITUTE
16TH & U STS., N. W. WASHINGTON, D. C.

MODEL ANSWERS

Antennas, Preselectors, Frequency Converters and Sound Channels for Television Receivers. No. 61 RH-1

1. The shortest and most direct route through space. It is always a straight line.
2. Phase interference, blurring and ghosts.
3. By designing and positioning the television receiving antenna so it will accept signals arriving over only one path.
4. Yes.
5. To secure increased signal pick-up and to give rejection of signals arriving over undesired paths.
6. By connecting a variable condenser across the input terminals and tuning for resonance.
7. To simplify chassis layout problems (for example, to simplify the elimination of undesirable feedback).
8. To provide additional shielding between plate and grid leads.
9. Chattering noises.
10. About 100 kc.

VIDEO I. F. AMPLIFIERS, VIDEO DETECTORS AND AUTOMATIC GAIN CONTROLS

62RH-1

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

Why Do You Want To Succeed?

There are several answers to this question. You may want to succeed for the very human reason that you want more money with which to enjoy life, or you may have a family for whom you want to provide those comforts they so well deserve—a home, a new car, good clothes, life insurance and financial security.

Your ambition to succeed may be prompted by the desire to bring happiness to an aged father, mother or relative whose chief hope in life is to see you enjoy prosperity and prestige, to see you on the pinnacle of success.

Pause for just a minute and think—*what is your reason for wanting success?* With this reason in mind, resolve firmly that you will never allow your ambition to weaken. Resolve that you will never swerve from the direct path to your goal. Make this resolution now and keep it, so the years to come will be happier and more prosperous for you.

J. E. Smith.

NATIONAL RADIO INSTITUTE

WASHINGTON, D. C.

1942 Edition

A LESSON TEXT OF THE N. R. I. COURSE
WHICH TRAINS YOU TO BECOME A
RADIOTRICIAN & TELETRICIAN
(REGISTERED U. S. PATENT OFFICE) (REGISTERED U. S. PATENT OFFICE)

NCP2M242 Printed in U. S. A.

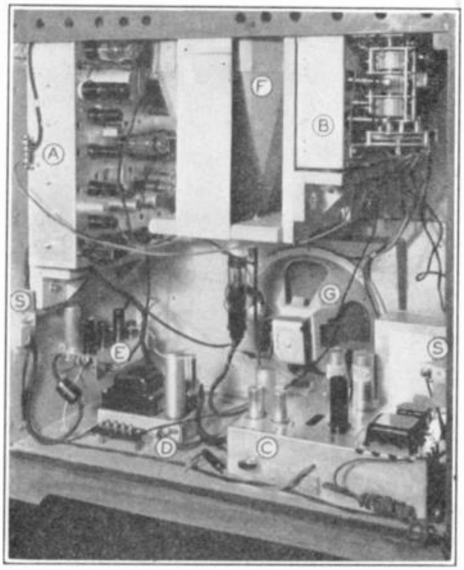
Video I. F. Amplifiers, Video Detectors and Automatic Gain Controls

Video I.F. Amplifiers

CHOICE *of Video I.F. Value.* In setting up the present standards for television signals, engineers gave considerable attention to the problem of securing a satisfactory video i.f. value. A number of factors influenced the decision of television engineers to use a low video i.f. value, in the vicinity of 13 mc., in modern television receivers.

Although a high i.f. value (a value approaching the lowest television carrier frequency, which is 45.25 mc.) gives highly desirable image rejection and greatly simplifies the task of getting a flat, wide response characteristic, there are a number of important drawbacks which prevent its use. First of all, with a high i.f. value it is difficult to secure the required high gain. Furthermore, a high i.f. value calls for extremely small values of inductance and capacitance, and the adjustment of these values for proper tuning and for optimum coupling is considerably more critical than when larger part values are used.

We must not overlook the fact that when a single local oscillator is used for both sight and sound channels, the video i.f. value definitely determines the sound i.f. value. With the sound carrier frequency 4.5 mc. higher than the picture carrier frequency, and with a local oscillator frequency higher than either of these values, the sound i.f. value will be *4.5 mc. lower* than the video i.f. value. One factor to consider here is that too low a sound i.f. value makes it difficult to secure a wide pass-band for the sound i.f. amplifier. Too narrow a pass-band (less than 50 kc.) makes tuning of the receiver highly critical and emphasizes the effects of frequency drift in the local oscillator.



RCA Victor Photo

Rear view of an RCA Victor combination all-wave and television receiver employing a 12"-diameter television cathode ray tube mounted vertically. The image is viewed on a mirror attached to the underside of the cabinet cover, with the cover propped up at a 45-degree angle for viewing. The various sections shown in this photo are:

- *A.* **Television receiver chassis, including the entire video channel and part of the sound channel.**
- *B.* **All-wave sound receiver chassis.**
- *C.* **High-voltage and low-voltage power packs for television chassis.**
- *D.* **Power pack for all-wave radio chassis.**
- *E.* **Special video chassis unit for demonstration purposes. Not used in regular production models.**
- *F.* **Television cathode ray tube in its protective housing.**
- *G.* **Loudspeaker.**
- *S.* **Safety inter-lock switches.**

The final important requirement is that neither the sound nor the video i.f. value be in a channel which is used extensively in radio communication, for undesired station signals at either i.f. value can oftentimes ride through the preselector and cause serious interference with reception of a desired program. Since there are many amateur stations near 7 mc. and near 14 mc., a logical choice for i.f. values would be between these frequencies (values above 14 mc. would not give enough i.f. gain, and values below 7 mc. would make wide band-passing of the video i.f. amplifier rather difficult). Some engineers have standardized on 13 mc. for the video i.f. value, with the side frequencies extending down to about 9 mc.; in this case the sound i.f. value becomes 8.5 mc. Another common choice is 12.75 mc. for the video i.f. value and 8.25 mc. for the sound i.f. value.*

Single Side-Band Reception. Double side-band transmission and reception calls for a pass-band which is twice the value of the highest picture frequency to be transmitted. If this highest frequency is 4 mc., the pass-band for double side-band transmission would be 8 mc. It is a real task to design an i.f. amplifier which will give uniform response over a band width of 8 mc. and still provide sufficient gain. The wider the pass-band, the lower is the gain which can be expected. These factors placed a definite limit upon the maximum picture frequency, even before the present high standards were accepted. In the early days of cathode ray television, a maximum picture frequency of 2 mc. was considered satisfactory; with double side-band transmission, this required a 4-mc. pass-band.

It was found that when tuning in a double side-band transmission, better image definition could sometimes be secured by detuning the television receiver. This immediately suggested to engineers that one side-band of the picture carrier could be removed without loss of detail. This would cut the pass-band requirement for the video i.f. amplifier almost in half, greatly simplifying its design and adjustment problems. Actually, however, when changing to single side-band transmission the engineers kept the same pass-band of about 4 mc. and increased the maximum picture frequency in order to give improved image definition.

If two video i.f. stages each provide a gain of 20, both together will deliver a gain of 20 times 20, or 400. Doubling of the pass-band width cuts the gain per stage in half; thus, doubling the band width in this example would lower the gain per stage to 10, and two stages would provide an amplification of only 100. (This low amplification may necessitate a third video i.f. stage.) With present picture standards and single side-band transmission, three i.f. stages are generally required to provide sufficient gain while handling all picture frequencies up to the highest now being transmitted.

Before a shift was made to single side-band transmission and reception, careful studies and comparisons were made of both systems. A brief re-

---

* One television receiver, the Du Mont type 180, employs 7.4 mc. as the video i.f. value and 2.9 mc. as the sound i.f. value. This indicates that there are no fixed limitations to the choice of i.f. values.

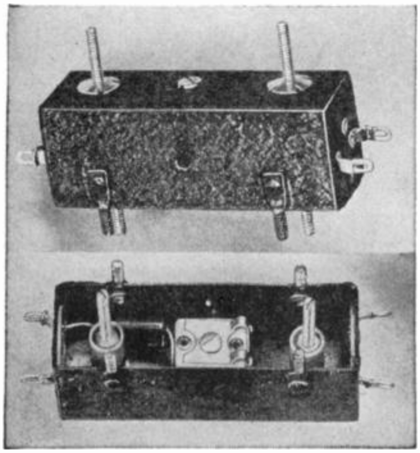
view of the factors which were considered will be of value at this time.

Phase Delay Considerations. Engineers recognized that any tuned circuit was resistive at resonance, but became reactive off the resonant frequency. The parallel-resonant circuits which are widely used in i.f. amplifiers become *inductive* below the resonant frequency and become *capacitive* above the resonant frequency. In the first case the current fed into the resonant circuit lags the applied voltage, and in the second the current leads the voltage; the phase difference between the two values increases for frequencies farther away from the resonant frequency in both cases.

In double side-band transmission, each video frequency was represented by two side frequencies; the one above the video carrier had a leading current, while that below the video carrier had a lagging current. When recombining the side frequencies in the video detector, the differences in phase cancelled each other, with the result that there was no phase delay.

When single side-band transmission is used, there is only one side frequency for each frequency component in the video frequency signal, and all side frequencies are below the video i.f. carrier value. This means that with single side-band transmission, the desired side frequencies will encounter, in the video i.f. amplifier, impedances ranging from a pure resistance to an almost pure inductance, and each side frequency has a different phase delay with respect to the video carrier signal. Fortunately, however, it was found that the shift produced by this phase delay was negligible in the case of the present 441-line images. Distortion due to phase delay in the video i.f. amplifier can therefore be neglected completely as long as the present television standards are maintained.

Removing One Side-Band. Having proved that single side-band transmission did not introduce distortion, engineers next tackled the problem of removing one band of side frequencies at the transmitter. Highly selective band-eliminating circuits are extremely difficult to design and build for ultra-high frequencies, but a satisfactory equivalent to single side-band transmission and reception can be obtained with conventional band-pass



Courtesy F. W. Sickles Co.

Front and rear views of an i.f. transformer (also known as a coupling unit) designed especially for use in the video i.f. channels of television receivers. There are two adjustable permeability-tuned inductances, one for the grid-cathode capacity and one for the plate-cathode capacity. In addition, there is a trimmer condenser; in the particular unit shown, it serves to tune a wave trap (rejection) circuit to the sound i.f. value. A fixed condenser provides coupling between the two tuned circuits. In some coupling units the wave trap is omitted, and the trimmer is connected to provide adjustable coupling. Varying the coupling varies the pass-band of the unit. These units are designed for mounting under the chassis, to permit the shortest possible connections to single-ended tubes.

circuits if they are employed at both the transmitter and receiver and are properly adjusted.

With single side-band transmission, the carrier frequency is generated in the usual manner at the transmitter, and is modulated normally so that both side frequencies are produced at the output of the modulated stage. Thus, if the carrier frequency is 55 mc. and it is modulated with a 4-mc. video signal, the signal frequencies at the output of the modulated stage will range from 51 mc. to 59 mc. If the lower side-band is to be removed, the following amplifiers must be designed to have a flat response only from 55 to 59 mc. Even with several tuned stages, complete suppression of the side frequencies below 55 mc. is not as yet practical. For this reason, the proposed television standards are as shown in Fig. *1A*, in which a 1.25-mc. portion of the television channel is reserved for unsuppressed lower side frequencies.

Suppressing the Undesired Side-Band in the Receiver. The passage of a single side-band transmission through the frequency converter in a receiver having a 13-mc. i.f. value gives a video i.f. carrier frequency of 13 mc. and side frequencies ranging from this value down to about 9 mc.* (Because the local oscillator frequency is *above* the radiated picture carrier frequency, the higher side frequencies in the radiated carrier transmission become the *lower* side frequencies in the video i.f. stage.) Thus, if a video i.f. amplifier having a pass-band of 4 mc. is to handle a 13-mc. video i.f. carrier in a standard single side-band television system, it should be aligned *between 13 mc. and 9 mc.* Under this condition, unsuppressed side frequencies above 13 mc. can be partially rejected.

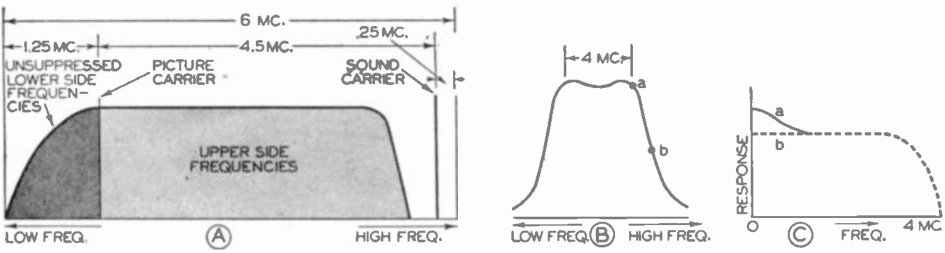


FIG. 1. Arrangement of carrier and side frequencies in a standard television channel (*A*), response curve for a typical video i.f. amplifier (*B*), and effect of video i.f. carrier location upon over-all video response of receiver (*C*).

Since the ideal rectangular response characteristic for an i.f. amplifier is practically impossible to obtain, some of the side frequencies between 13 mc. and 14.25 mc. will get through the i.f. amplifier stages. The result is that we will have the action of a double side-band system for side frequencies nearest the carrier frequency (corresponding to low picture fre-

* In the remainder of this textbook, a video i.f. value of 13 mc. and a sound i.f. value of 8.5 mc. will be used for illustrative purposes.

quencies). Since the amplitudes of corresponding side frequencies on each side of the carrier act together in the demodulator to give increased output, lining up of the video i.f. carrier with point *a* on the response curve in Fig. *1B* would give abnormally high video detector output at the low picture frequencies, as indicated by curve *a* in Fig. *1C*. This is obviously an undesirable condition.

If the video i.f. carrier frequency is lined up with point *b* on the i.f. amplifier response curve in Fig. *1B*, so that the carrier is amplified only about one-half as much as the desired side frequencies, practically uniform response can be secured over the entire desired range of side frequencies, as indicated by dotted-line curve *b* in Fig. *1C*. Side frequencies which are equal amounts above and below the video i.f. carrier now act together to give a video detector output which is essentially the same for all video frequencies.

Ordinarily, the video i.f. carrier is aligned with point *b*, about halfway down from the top of the response curve for the video i.f. amplifier. When increased output at the low video frequencies is desired, however, the video i.f. carrier may be lined up somewhere between points *a* and *b* in Fig. *1B*.

Video I.F. Amplifier Design Problems. Aside from providing the required amount of gain (an amplification of about 1,000 is quite common for the entire amplifier), the video i.f. amplifier can contribute materially to high picture definition. The video frequency amplifier (which follows the video detector) should provide a flat response from about 10 cycles to about 4 mc., but most v.f. amplifiers have a gradually lowered response at the higher video frequencies, as indicated at the right in Fig. *1C*. This would result in a loss in definition between adjacent elemental areas of the image unless it were compensated for by the video i.f. amplifier. This means that the resonant response of the video i.f. amplifier should ordinarily be peaked at about 9 mc. A practical response curve which produces this desired result is shown in Fig. *2A*. This type of response can

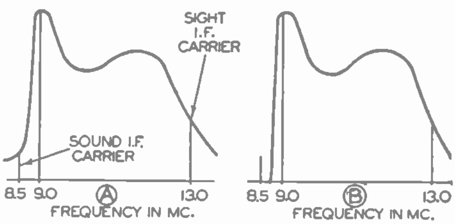


FIG. 2. Video i.f. amplifier response curves having increased gain at about 9 mc. to compensate for high-frequency attenuation in the v.f. amplifier. A sound i.f. rejection circuit was used in the circuit corresponding to curve *B* to bring the gain of the video i.f. amplifier to zero at the 8.5-mc. sound i.f. carrier value.

be secured by employing a suitable tuned network for inter-stage coupling in the video i.f. amplifier and adjusting the coupling values properly.

Separating Sight and Sound I.F. Signals. Both sight and sound i.f. signals are present at the input of the video i.f. amplifier. It is highly important that sound signals be kept out of the video detector. If both the 13-mc. and 8.5-mc. carriers exist at the video detector, they will beat together to produce a 4.5-mc. beat frequency. Even though the response of the v.f. amplifier is quite low at this frequency, the original carrier signals are so strong in comparison with the side frequencies that the undesired 4.5-mc. signal may act on the t.c.r. tube. Although the individual spots due to this 4.5-mc. signal are so small that they will not be resolved by the eye, this signal will affect background brilliancy as well as contrast between elemental areas. When a strong 4.5-mc. beat signal is present, it may be extremely difficult to secure a total white or total black background regardless of how the receiver controls are adjusted.

The 8.5-mc. sound i.f. signal can, if it gets into the video i.f. channel, beat with any picture i.f. side frequencies to produce undesired beat signals ranging in frequency from .5 mc. to 4.5 mc. If, for example, there is a prominent 10-mc. video i.f. side frequency, this can beat with the 8.5-mc. sound i.f. carrier to give an undesired 1.5-mc. beat signal at the t.c.r. tube. This undesired frequency will cause blurring of the entire image.

For the above reasons, *rejector circuits which are tuned to the sound i.f. value are used in the video i.f. channel to keep sound i.f. signals out of the video detector.* These rejector circuits would, in the example being considered, produce a sharp cut-off below 9 mc. in the response characteristic of the video i.f. amplifier. Without rejector circuits, the response might be as shown in Fig. *2A*, where there is still appreciable response at the sound i.f. carrier value of 8.5 mc. When rejector circuits are used, the response drops sharply below 9 mc., giving complete rejection of 8.5-mc. sound signals.

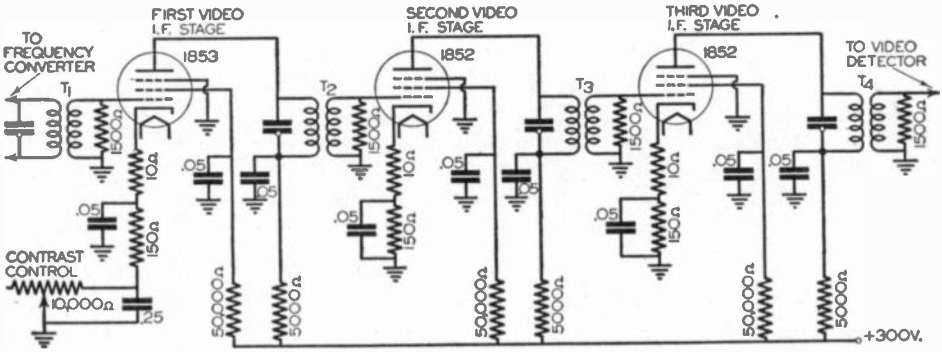


FIG. 3. Simple video i.f. amplifier circuit. This is not a high-definition arrangement, but does give satisfactory performance in television receivers using 3" and 5" t.c.r. tubes.

Typical Video I.F. Circuits

Having covered in detail the various problems involved in the design, construction and adjustment of video i.f. amplifiers, we are now ready to take up typical circuits.

Simple Video I.F. Amplifier. In inexpensive television receivers and kits where no attempt is made by the designer to secure high image definition, simple i.f. amplifier circuits like that shown in Fig. *3* are generally used. These sets usually employ either 3-inch or 5-inch t.c.r. tubes, and the resulting images are so small that lack of definition is ordinarily not noticeable.

Three stages of i.f. amplification, each providing a gain of about 10, are used in the circuit of Fig. *3* to give an over-all gain of 1,000. Video i.f. transformers T_1, T_2, T_3 and T_4 are identical. Each has a tuned primary which acts as a parallel resonant plate load, and an untuned, closely coupled secondary which is loaded with a 1,500-ohm resistor. The voltage across the secondary in each case is fed directly to the input of the following tube. There being only one tuned circuit per transformer, each transformer has a single-peak response which is flattened by the loading resistance to give the desired wide pass-band.

If a reasonable amount of loading does not give sufficient band width, the i.f. transformers may be tuned to slightly different frequencies to broaden the pass-band. To insure adequate amplification when this is done, an additional i.f. amplifier tube is often used, giving four video i.f. stages in all.

The tubes employed in the circuit of Fig. *3* are all of the single-ended type, permitting a simple chassis layout. Each tube is provided with self-bias by means of a 150-ohm resistor and a 10-ohm resistor in series, connected between cathode and chassis. Note, however, that the 10-ohm resistor is not by-passed to ground. This arrangement provides a small amount of degeneration, *stabilizing the circuit and at the same time preventing amplitude distortion.**

Automatic gain control is not employed in this simple i.f. amplifier. Overloading of the amplifier is prevented by a C bias control on the first tube, which varies the gain of a video i.f. amplifier stage and thus serves also as the *contrast control.* This control is shunted by a large condenser to prevent noise when the control is adjusted. The first tube must be of the remote cut-off type such as the type 1853, in order to secure satisfactory contrast control

---

* The action of the 10-ohm resistor in providing degeneration is as follows: A positive swing in the signal voltage on the grid causes plate current to increase. Increased plate current through the 10-ohm cathode resistor causes a corresponding increase in the voltage across this resistor, making the ground end of the resistor more negative than before with respect to the cathode. (The voltage drop across the 10-ohm resistor follows plate current variations because there is no smoothing condenser across it; the drop across the 150-ohm resistor remains essentially constant despite variations in plate current, since this resistor is by-passed to ground.)

A positive swing in grid voltage thus causes a negative swing in the potential of the ground end of the 10-ohm resistor; this potential is applied to the grid through the chassis, and since it is out of phase with the original applied grid voltage, we have degeneration.

Since the feed-back voltage cancels a part of the input grid voltage, this degeneration gives some loss in gain; this loss is more than compensated for by the advantages of degeneration. Any tendency for the circuit to regenerate increases the out-of-phase feed-back voltage produced by the 10-ohm resistor, decreasing the gain of the stage and thus stabilizing the circuit. Distortion due to a non-linear e_g-i_p tube characteristic (amplitude distortion, also called modulation distortion) is smoothed out by the degenerative action. Furthermore, noise and hum ripple currents in the plate circuits produce a grid feed-back voltage which partially cancels the noise and hum currents in the plate circuit.

action. All other features in the circuit are conventional.

Band-Pass Video I.F. with Condenser Tuning. An i.f. transformer arrangement which gives a suitable pass-band for high image definition, along with adequate rejection of the sound i.f. carrier, a peak response at the lowest i.f. side frequency and gradual attenuation of unsuppressed side frequencies above the video i.f. carrier, is shown in Fig. *4*; when properly adjusted, this i.f. transformer will give the response characteristic shown in Fig. *2B*.

Parallel resonant circuit L_3-C_3 in Fig. *4* is normally made resonant to the 8.5-mc. sound i.f. value; it therefore acts as a high resistance at this frequency, preventing any sound i.f. signals from passing through the sight channel. (L_3-C_3 and L_2-C_2 act as a voltage divider. Most of the voltage at the sound i.f. frequency is developed across L_3-C_3, and very little is developed across L_2-C_2 for application to the following tube.)

At video i.f. frequencies, parallel resonant circuit L_3-C_3 acts as a condenser, and its value will naturally be less than 20 mmfd. This circuit is, therefore, a high capacitive reactance to video i.f. signals, and serves as the *mutual coupling* between the grid and plate tuned circuits. Since the resultant capacity in this circuit controls the coupling, L_3 and C_3 are sometimes adjusted to correct values at the factory. In other cases, one of them is made variable; when the receiver is realigned, this must be adjusted by the Teletrician to resonate at the rejection frequency.

A 2,500-ohm resistor loads L_2-C_2, broadening its response. At the video i.f. carrier frequency, L_3-C_3 might assume a value of 5 mmfd., giving it a capacitive reactance of about 3,000 ohms; the 2,500-ohm load on the grid tuned circuit acts through this 3,000-ohm reactance to broaden plate resonant circuit L_1-C_1.

Plate resonant circuit L_1-C_1 and grid resonant circuit L_2-C_2 in Fig. *4* are tuned to different frequencies in the 9-13 mc. pass-band in order to provide the separation between peaks which is required for a 4-mc. pass-band. Since sharpest cut-off is desired at the low-frequency end of the video i.f. pass-band, L_1-C_1 (being loaded less than L_2-C_2) is tuned near this end of the band; L_2-C_2 is tuned to about 12.5 mc. There is considerable interaction between the two circuits when tuning; for example, when L_1-C_1 is tuned to 9.5 mc., and L_2-C_2 to 12.5 mc., L_2-C_2 will act as an inductive load on L_1-C_1, while L_1-C_1 will act as a capacitive load on L_2-C_2. The amount of the interaction depends upon the mutual coupling reactance provided by L_3-C_3.

The design of the coupling circuit in Fig. *4* is such that two more or less pronounced peaks are produced, with their outer sides separated by about 4 mc. The peak at the low-frequency end of the pass-band is quite sharp, and its sides very steep, while that at the high-frequency end is broad, with its sides dropping gradually. The signal rejection characteristics of L_3-C_3 at sound i.f. frequencies make the slope at the low i.f. side of the response even more sharp.

Automatic gain control is used in this i.f. stage. The negative a.g.c. voltage is applied to the control grid through a 20,000-ohm resistor and through coil L_2. The .01-mfd. condenser and 20,000-ohm resistor together act as an a.g.c. filter having a negligible time delay. Whenever variable gain is employed in an i.f. stage, a.g.c. action must not affect the width of the pass-band. A change in C bias due to a.g.c. action will change the plate-to-cathode tube resistance; in this circuit, however, the change in resistance will be negligible in comparison with the load on the plate resonant circuit, and a.g.c. will have only a negligible effect upon the pass-band characteristics.

The cathode resistor value is made low in this circuit in order to provide maximum gain, but a.g.c. action normally raises the C bias to a value dependent upon the pedestal voltage in the incoming television signal. Shunt condensers across the cathode resistors are omitted in order to take advantage of degeneration.

All parts enclosed by the dotted-line box in Fig. *4* are mounted in a single shield can, and constitute the video i.f. transformer or coupling unit. The inclusion of the .01-mfd. r.f. by-pass condensers inside this shield can in the manner shown serves to place one terminal of the trimmer condenser and one coil terminal in each tuned circuit at r.f. ground potential, greatly simplifying adjustment of the trimmer condensers and giving a far more satisfactory arrangement than with conventional external by-pass condenser connections.

To simplify the presentation, only one i.f. transformer is shown in Fig. *4*. Remember that about three i.f. amplifier stages are normally used, and these will require four similar transformers. Each transformer or coupler improves sound signal rejection, boosts gain and improves response.

Video I.F. Amplifier with Inductance Tuning. Three different types of i.f. coupling circuits employing inductance tuning are shown in Fig. *5*. The first, which connects the plate of the mixer-first detector tube with the first video i.f. amplifier stage, will not be considered here since it has been discussed elsewhere.

The second video i.f. coupling unit operates much like the coupling unit

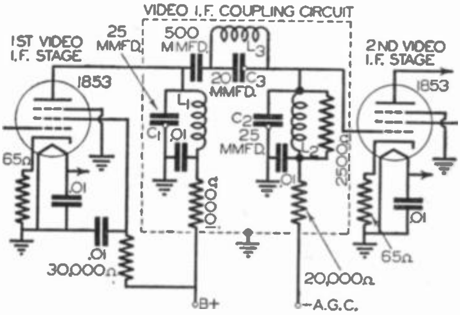


FIG. 4. Typical high-definition video i.f. coupling unit (in dotted lines) as used between the first and second video i.f. stages. This coupling unit employs capacitive tuning, with an extra resonant circuit (L_3-C_3) serving a dual role as sound i.f. rejector and coupling capacitance.

shown in Fig. *4*. The chief difference is in the coils, which have adjustable pulverized iron cores. The grid and plate coils are tuned by the plate-cathode and grid-cathode inter-electrode capacities respectively. Both the grid and plate resonant circuits are loaded by resistor *R*. L_3-C_3 acts simultaneously as the sound i.f. rejector and the mutual coupling for video i.f. signals.

The third video i.f. coupling unit is a conventional band-pass network. The plate-to-cathode capacity of VT_2 acts with coils L_4 and L_5 in series to make up the plate parallel resonant circuit, which is loaded by resistor R_7. The grid-cathode capacity of VT_3 acts with L_6 and L_5 to form the grid parallel resonant circuit, with R_9 providing the loading. Condenser C_2 is simply a d.c. blocking condenser. Coil L_5 serves as the mutual coupling inductance; if adjusted for optimum coupling, it gives an essentially flat-top response curve with practically no peaks. There is no sound i.f. rejector in this stage, since adequate rejection is provided in prior stages.

A video i.f. amplifier employing inductance tuning will generally have three or four i.f. stages. Two of the coupling circuits will be like the second video i.f. coupling unit in Fig. *5*, while the remainder will be like the third unit. In this way sufficient gain, sufficient sound i.f. rejection and sufficiently broad pass-band characteristics can be obtained.

Video Detectors

Problems of Single Side-Band Detection. With ordinary double side-band reception, the two side frequencies for each modulation frequency must be equal in strength in order to prevent amplitude distortion. If this condition is maintained up to the detector, a linear detector will provide distortionless detection.

In a television system, modulation is accomplished at the transmitter by varying the amplitude of the carrier. This produces a carrier and two side frequencies for each modulation frequency. If the modulation signal is sine wave in form, the envelope of the resultant modulated carrier will likewise have a sine wave form.

If we start with a 51-mc. carrier and modulate it with a 2-mc. picture signal (using conventional amplitude modulation), we secure three signal components, namely 49 mc., 51 mc. and 53 mc. With single side-band transmission, the 49-mc. side frequency is suppressed, leaving us with two sine wave signals having frequencies of 51 mc. and 53 mc. respectively. Let us first assume that these signals have equal amplitudes, as shown in Figs. *6A* and *6B*. When these are combined in the first detector of the television receiver, the resultant composite signal as shown in Fig. *6C* has an envelope which is obviously not a sine wave. Instead,

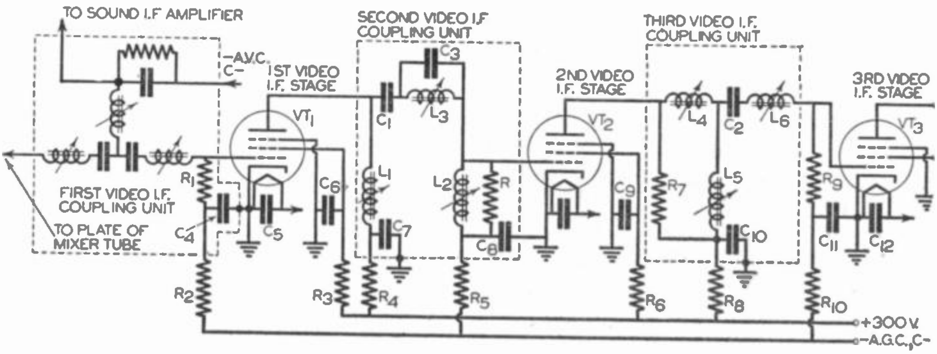


FIG. 5. High-definition video i.f. coupling units of three different types, all employing inductance tuning.

it has rounded peaks as at *a*, and V-shaped troughs as at *b*. The envelope frequency will be the difference between the original two frequencies, and hence will be 2 mc.

When one signal is weaker than the other, as indicated in Figs. *6F* and *6G*, the resultant signal at the output of the first detector will have more or less a sine wave envelope, as shown at Fig. *6H*. These facts about detection are well known, and apply to both radio and television circuits.

Figure *6C* corresponds to 100 per cent modulation of one signal with another, whereas Fig. *6H* corresponds to a low percentage of modulation. Making the amplitudes of the two original signals more nearly equal increases the percentage of modulation, and at the same time increases the deviation of the envelope from a true sine wave form. In other words, increasing the percentage of modulation increases the amount of amplitude distortion in the envelope of the resultant signal.

When the resultant signal shown in Fig. *6C* is fed into a linear detector and the rectified high-frequency components are removed, we secure an output signal like that shown in Fig. *6D*. This is clearly a distorted modulation signal, and not at all like the sine wave signal which produced our original single side frequency at the transmitter. If a square-law detector is used, however, the detector out-

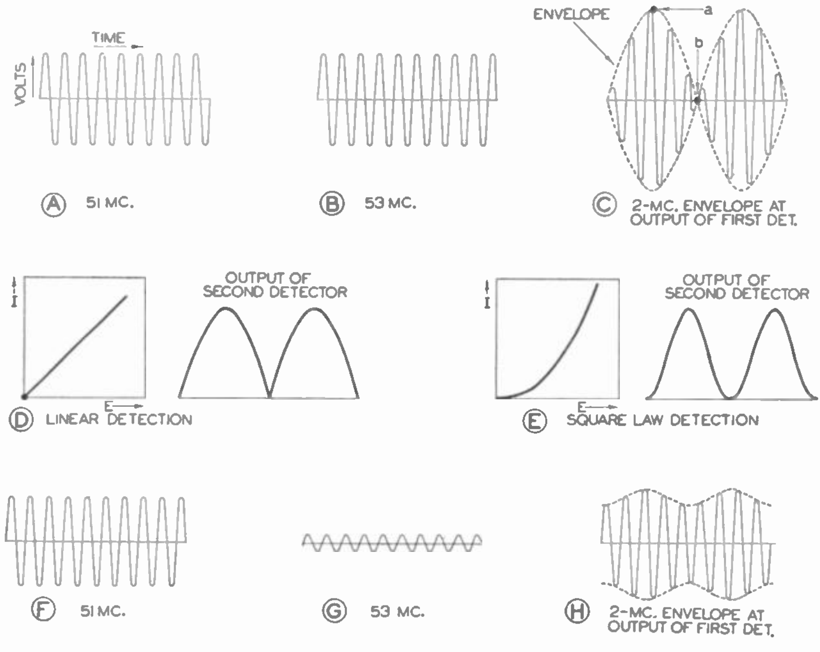


FIG. 6. Action of linear and square-law detectors in the case of single side-band transmission. If a 51-mc. video carrier is modulated with a 2-mc. sine wave signal and the lower side frequency is suppressed, the two constant-amplitude signals which remain will be those shown at *A* and *B*.

put signal assumes its true sine wave characteristics as shown in Fig. *6E*. One distortion balances another in this case.

Amplitude Distortion. A linear detector is invariably used in the video section of a television receiver, for square-law detectors cannot ordinarily handle large r.f. voltage swings. When a linear detector is used to handle modulated r.f. voltages higher than about 5 volts, second harmonic distortion resulting from detection will increase more or less uniformly up to a maximum of about 12 per cent at 100 per cent modulation, while third harmonic distortion will reach a maximum of about 3 per cent. In a sound receiver this would be appreciable amplitude distortion, but in television reception experience has shown that amplitude distortion as great as this is not objectionable.

At low percentages of modulation, corresponding to a dark portion of a scene, there will be a maximum difference between the amplitudes of the two signals (corresponding to Figs. *6F* and *6G*), and the detector will therefore be almost entirely free from distortion (Fig. *6H*). At high percentages of modulation, corresponding to a bright portion of a scene, there will be practically no difference in the amplitudes of the signals. The resulting severe amplitude distortion will not be noticeable, however, because the human eye tends to be attracted to bright portions of a scene, overlooking defects in smaller details of the scene. These facts indicate that with single side-band transmission and negative modulation, distortion due to the video detector will not be noticeable in the reproduced image. We are thus able to obtain satisfactory image definition with a considerably narrower frequency channel than would be required for conventional double side-band transmission. *It is far more important to prevent frequency distortion and unequal time delay of signal components in the video detector than it is to prevent amplitude distortion.*

Frequency Distortion. Attenuation of certain picture frequencies in the demodulated television signal is known as *frequency distortion.* This attenuation occurs only at the higher picture frequencies in the case of a diode video detector, and may be due to undesired capacity shunted across the load resistor. Referring to diode load resistor R_L in the typical television video detector circuit shown in Fig. *7A*, an increase in the picture frequency will lower the reactance of any capacity across this load, thereby by-passing the higher picture frequencies to ground. Stray capacities do exist across the detector load in an actual circuit, even though they are not shown in circuit diagrams; let us consider what they are.

One undesirable shunt capacity is that which exists between the cathode and the grounded filament of the diode detector tube. Another is the plate-to-cathode inter-electrode capacity of the tube, for the plate is grounded through video i.f. amplifier output coil (L_3 in Fig. *7A*). Any capacity between the cathode lead and the chassis also shunts R_L. Finally, condenser C_1 in low-pass filter L_1-L_2-C_1 and the grid-cathode capacity of the first v.f. stage are in effect shunted across R_L because the reactance of L_1 is quite low at picture frequencies. These five undesired capacities across R_L exist in any diode detector circuit, but good detector design minimizes the resultant frequency distortion.

By making diode load resistor R_L low in ohmic value, around 2,000 ohms, any shunt reactance across this resistor *will have less effect upon high picture frequencies.* The use of a low load resistance is therefore the most effective way to minimize frequency distortion in the detector. Of course, a low load resistance will prevent true linear detection, but any justable from about 3 to 30 mmfd. If full-wave detection is employed, it is possible to make the capacity of C_1 quite low, for in this case the lowest frequency in the rectified i.f. voltage will be two times 9 mc., or 18 mc. The low-pass filter then has only to suppress frequencies above 18 mc. The lower the values of L_1, L_2 and C_1, the less is the attenuation of the higher picture frequencies. (L_1, L_2 and C_1 may also be used to boost the gain at high picture frequencies, as explained elsewhere in this lesson.)

Modulation Envelope. Up to the video detector in a television receiver,

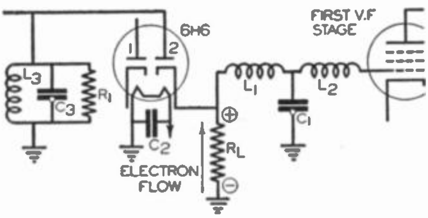


FIG. 7A. Fundamental circuit for a diode video detector which provides a demodulated signal having a *negative* picture phase.

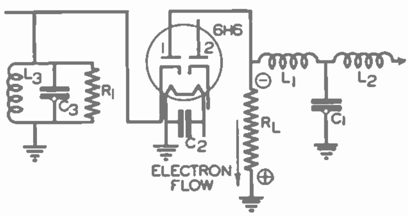


FIG. 7B. Fundamental circuit for a diode video detector which provides a demodulated signal having a *positive* picture phase.

tendency toward square-law detection is actually beneficial in that it reduces amplitude distortion.

Another precaution involves the use of a diode tube having low interelectrode capacities. A type 6H6 double-diode is quite satisfactory. Note that only one diode is used in Fig. *7A;* this eliminates the capacity of the other diode.

Low-pass filter circuit L_1-C_1-L_2 in Fig. *7A* should begin its suppressing action at the lowest video i.f. side frequency, which is 9 mc., and should suppress all signal frequencies above this value. Condenser C_1 in this filter should have a low capacity, ad-

a television signal has essentially the same form and phase as the signal radiated by the transmitting antenna. This modulated carrier signal is shown in Fig. *8A,* and consists of a carrier having peak values which vary in accordance with the picture signal and the synchronizing impulses. The peaks of the carrier therefore follow the dash-dash line, which is known as the *modulation envelope.*

Removal of the lower side-band from a modulated carrier signal does not alter the shape of the modulation envelope except for changing the depth of modulation; it merely removes r.f. components lower than the carrier frequency. Passage of the resulting signals through the frequency converter likewise has no effect upon the shape of the modulation envelope; it merely changes the carrier frequency from the original r.f. value to the video i.f. value and amplifies the carrier signal. The number of stages in either the preselector or the i.f. amplifier has no effect whatsoever upon the shape of the television signal; insertion of extra stages only increases the amplitudes of the signals, providing these stages have no frequency and amplitude distortion.

Negative Modulation. The black level in Fig. *8A* corresponds to the carrier level when there is no modulation, and the bright level corresponds approximately to zero carrier level. This gives what is known as *negative modulation,* and is standard for television transmissions in the United States. (Positive modulation of the carrier is being used in some foreign countries; in this case, the bright level corresponds to the peak modulated value of the radiated carrier. The black level still corresponds to the carrier level without modulation, and is equal to about 30% of the peak value.)

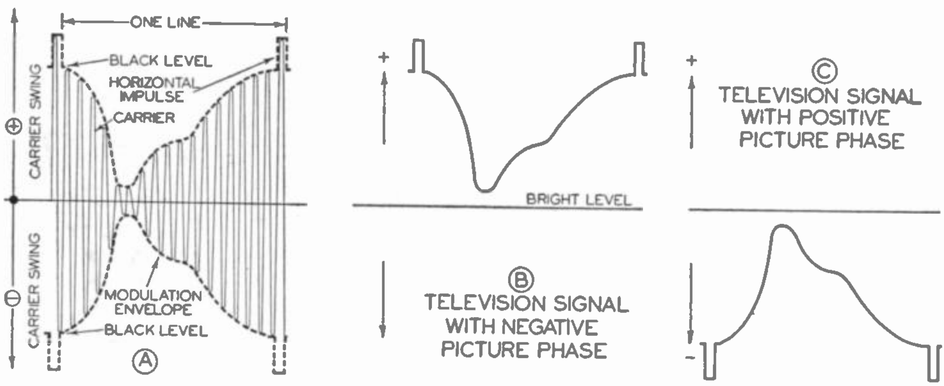


FIG. 8. A modulated video carrier signal with negative modulation is shown at *A*. The same signal after demodulation appears at *B* and *C*.

Negative Picture Phase. If a modulated television signal like that in Fig. *8A* is rectified in such a way that the negative portions of each r.f. cycle are rejected, the resulting demodulated signal will follow the positive peaks of modulation, and we secure a television signal like that shown in Fig. *8B*. Since this signal swings in a *negative* direction for bright elements of a picture, we say that it has a *negative picture phase.*

Positive Picture Phase. On the other hand, if the positive peaks of the r.f. cycles are rejected during rectification by the video detector, the resulting signal will be as shown in Fig. *8C*. This signal swings in a positive direction for bright picture elements, and hence has a *positive picture phase.*

The television signal which is applied to the t.c.r. tube must have a positive picture phase, for we want positive voltage swings to increase the electron beam current, giving a bright spot. Negative voltage swings will then cut off beam current almost completely, and retraces will not show during the transmission of synchronizing impulses.

Choosing the Correct Picture Phase for the Video Detector. The television signal at the output of the video detector is seldom sufficiently strong for direct application to the t.c.r. tube. This means that additional video frequency (v.f.) amplification must be used. Since each v.f. amplifier reverses the picture phase, we can have any phase at the video detector in so far as the t.c.r. tube is concerned, as long as we send the v.f. signal through the correct number of stages to give a positive phase at the input of the t.c.r. tube.

The connections to the a.g.c. circuit and to the impulse separator must also be considered when choosing the picture phase for the signal at the output of the video detector. These are problems for the television receiver designer, but Teletricians should know the picture phase in each section of a television receiver, particularly in the stages following the video detector.

Securing the Desired Picture Phase. When a diode tube is connected into a video detector circuit in the manner shown in Fig. *7A*, only positive carrier peaks across L_3-C_3 will cause electron flow through detector load R_L, and consequently we have a *negative picture phase* at the detector output. (Carrier peaks which make the ungrounded end of L_3 positive with respect to the grounded end are considered to be *positive peaks.*) When the cathode of the diode is connected to the ungrounded end of L_3, as shown in Fig. *7B*, only the negative peaks of the carrier signal in Fig. *8A* can cause electron flow through R_L. Under this condition, the detector output signal across R_L has a *positive picture phase*, as shown in Fig. *8C*. Low-pass filter L_1-L_2-C_1 in Figs. *7A* and *7B* removes i.f. components from the detector output signal.

The voltage across the diode load follows the peaks of modulation. The resultant demodulated signal will then have all pedestals lined up at the same voltage level and all synchronizing impulse peaks will be lined up at a higher level.

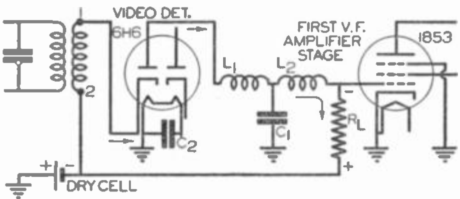


FIG. 9. This simple diode video detector circuit, which provides a signal having a positive picture phase, is used in some lower-priced television receivers. Arrows indicate direction of electron flow.

Typical Diode Video Detector Circuit. A simple diode video detector circuit as used in an inexpensive television receiver is shown in Fig. *9*. The positive end of diode load resistor R_L in this circuit is grounded through a small dry cell. Electrons flow in the directions indicated by arrows when the i.f. carrier swings in a direction which makes point *1* negative with respect to point *2*. The resulting current through R_L produces across this resistor a video signal having a positive picture phase, for a signal for a bright element reduces the current through this resistor and thus makes the negative end of R_L less negative (more positive) with respect to ground.

The grid of the first v.f. amplifier tube is connected to the negative terminal of the load resistor, and the dry cell is connected to *increase* the negative potential of this terminal with respect to ground. Under this condition the grid always remains negative with respect to ground. This small-sized flashlight cell thus provides the minimum negative bias for the grid of the following v.f. amplifier. Since this grid is negatively biased, it draws no current from the battery, and consequently one battery will last a long time. There is no other C bias on the grid of the v.f. amplifier tube. The v.f. amplifier tube can be operated very nearly at zero bias, in order to give high gain on weak signals, for with this circuit all signals drive the grid in a negative direction, and the grid never swings positive.

Low-pass filter L_1-L_2-C_1 in Fig. *9* prevents i.f. currents from flowing through the diode load. In this circuit the filtering of i.f. currents takes place simultaneously with rectification, whereas in the conventional diode video detector circuit of Fig. 7 the r.f. currents are suppressed after rectification. Both methods are equally satisfactory.

Variation of Simple Diode Detector Circuit. Another simple video detector circuit is shown in Fig. *10*. Diode D_1 in this circuit has a low ohmic resistance when conducting current, but acts simply as a low-capacity condenser when not conducting. When the video i.f. voltage makes point *1* positive with respect to point *2*, diode D_1 will be conducting and will have a much lower resistance than R_1. We thus have a voltage divider which passes only a negligibly low voltage to the grid of the first v.f. amplifier tube. When point *1* is negative with respect to point *2*, diode D_1 is an open circuit, and the complete negative half cycle of the video i.f. signal across L_1 is applied through R_1 to the grid and cathode of the following tube. Thus, only the negative alternations at the ungrounded i.f. output terminal act upon the grid of the v.f. amplifier tube; this means that we are obtaining a positive picture phase from the video detector.

When the negative alternation of the i.f. signal is being applied to the grid of the v.f. amplifier tube, the combined capacity between this tube and ground (the capacity of C_1 in parallel with the plate-cathode capacity of diode D_1 and the grid-cathode capacity of the first v.f. amplifier tube) is being charged and discharged through resistor R_1. This action makes the net voltage on the grid of the v.f. tube follow the desired modulation envelope, and at the same time removes i.f. components more or less completely. Resistor R_1 also serves to limit the current through diode D_1 to a safe value during positive carrier peaks at point *1*.

Low-pass Filter Circuit Problems. In any superheterodyne receiver, it is essential that some means be provided for removing i.f. signals from the output of the second detector. In a sound receiver this task is fairly simple, for the i.f. currents have about 50 times the frequency of the highest audio signal. For example, the highest audio frequency in a high-fidelity sound receiver may be 8.5 kc., and the i.f. value may be 460 kc., which gives a ratio of about 54.

In a television receiver the filtering job is considerably more difficult, for the highest picture frequency in a high-definition receiver is about 4 mc., and the lowest i.f. component is about 9 mc., giving a ratio of only about 2.3 between the frequencies. Ordinary capacitance filters which will satisfactorily by-pass 9-mc. i.f. components are bound to attenuate the higher-frequency picture components as well.

In the circuit of Fig. *10*, condenser C_1 has a capacity of about 5 mmfd. This acts in parallel with the plate-cathode and grid-cathode inter-electrode capacities of the two tubes to form an i.f. by-pass condenser, but at the same time the total capacity will by-pass the high picture frequencies. Obviously, this detector circuit is hardly suitable for use in a high-definition television receiver.

The low-pass filter networks L_1-C_1-L_2 in Figs. *7A, 7B* and *9* are more suitable for i.f. rejection purposes in high-definition television receivers. These filters can be designed to have fairly sharp attenuation at the cut-off frequency (the frequency at which the circuit begins to reject signals.) Furthermore, these circuits can be designed to have very little effect upon those frequencies which are to be passed, and can be made to boost the high-frequency response of the video detector.

The design of suitable low-pass filter networks involves considerable knowledge of wave filter design, which need not be taken up here. From the Teletrician's viewpoint it is sufficient to realize that at the higher frequencies (approaching i.f. values), the filter coils choke the currents and the condenser by-passes them, thereby giving a voltage divider which provides the desired attenuation of i.f. signals.

High-Frequency Compensation by Filter Networks. In the circuit of Fig. *9*, combination L_1-C_1 is made to resonate at some frequency below that at which the filter network begins to attenuate signals. If the values of these parts are so chosen that they resonate slightly above the highest video frequency, L_1-C_1 will form a series resonant circuit which gives resonant step-up of the higher video frequency signals, thereby compensating for high-frequency attenuation in

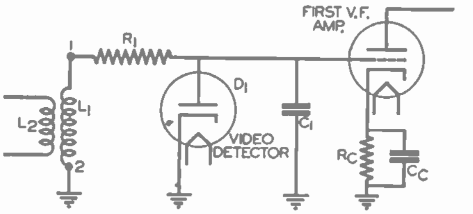


FIG. 10. A somewhat unconventional video detector circuit which delivers a signal having a negative picture phase.

the v.f. amplifier. At or near resonance, the voltage across either the coil or the condenser will be much greater than the supply voltage.

Coil L_2 and the grid-cathode capacity of the first v.f. tube form a series resonant circuit which acts in a similar manner. Although maximum step-up occurs at resonance, there is appreciable step-up for a considerable range of frequencies before and after resonance if the circuit is sufficiently broad (has a low Q factor).

Equivalent Circuit of Detector Filter Network. The tube inter-electrode capacities in the conventional diode detector circuit of Fig. *7A* have an important effect upon the low-pass filter action. The filter circuit can be redrawn as shown in Fig. *11* to show this effect more clearly. The plate-to-cathode capacity and filament-to-cathode capacity of the diode are combined as C_D, and the grid-cathode capacity of the v.f. amplifier tube is shown as C_{GK}. The circuit can now be recognized as a double π (pi) type filter. Capacity C_1 is usually made twice the capacity of either C_D or C_{GK}; this is a characteristic of pi filters in cascade. C_1 may include the input capacity of other circuits, such as the a.g.c. circuit or the amplitude separator circuit, and hence this is an ideal place to make a connection

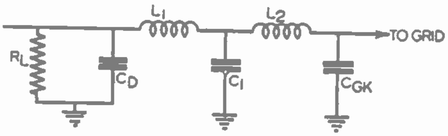


FIG. 11. Filter networks L_1-C_1-L_2 in the video detector circuits of Figs. *7A*, *7B* and *9* actually have three capacities as shown here, making them double pi filters.

without loading the detector circuit adversely.

R_L in Fig. *11* is shunted by capacity C_D, and consequently the higher picture frequencies are by-passed. To offset this, the series circuit consisting of L_1 and C_1 is adjusted to resonate slightly above the highest picture frequency, in order to give resonant step-up of the higher picture frequencies. Condenser C_1 is usually made semi-adjustable.

When properly adjusted, circuit L_1-C_1 in Fig. *11* also serves to maintain a constant time delay for all picture frequencies. This delay cannot be avoided in a detector circuit, but by delaying all components of a picture the same amount, the result will simply be a shift of the entire picture a small amount on the screen. C_{GK} acts with L_2 to provide normal filtering of i.f. signals. Be on the lookout for these combination low-pass filters and frequency-response compensators, as they are widely used in the video detectors of television receivers.

Full-Wave Video Detectors. Many designers of television receivers prefer the use of full-wave detection for high-definition picture channels. Full-wave detection automatically *doubles the frequencies of the undesired i.f. pulses, making it easier to separate them from desired video signals in the detector output.* Thus, half-wave rectification of a 9- to 13-mc. i.f. signal will give these frequencies and their harmonics in the detector output along with the picture signal, but full-wave rectification will double these undesired i.f. components, making them 18 to 26 mc. With these higher frequencies it is easier to secure satisfactory rejection of i.f. components and compensation for high-frequency attenuation, for simple filter networks like that shown in Fig. *11* give increasingly greater signal attenuation as frequency increases.

A typical full-wave video detector circuit is shown in Fig. *12*. Inductance L_1 acts with plate-cathode interelectrode capacity C_{PK} of the final video i.f. amplifier tube VT_1 to form a parallel resonant circuit which is broadened by resistor R_2 in series with the coil. The value of L_1 is chosen to give resonance at the video i.f. value.

At resonance, an appreciable circulating current flows through L_1 and R_2, and the resulting voltage drop across R_2 is transferred to coil L_2 through d.c. blocking condenser C_K. The mid-point of L_2 is grounded through condenser C_4, and the voltage supply end of R_2 is grounded through C_1. The voltage across R_2 is therefore applied between points P and $C.T.$ of coil L_2. This induces voltages on each side of this center section of L_2, and consequently the ends of this coil are opposite in polarity (have potentials 180° out of phase with each other).

Each end of coil L_2 is connected to one of the plates of double-diode tube VT_2, and consequently the diode sections alternate in sending electrons in the indicated direction through the detector load resistor R_L. Since an end of coil L_2 must be *positive* with respect to the grounded center tap before the corresponding diode can become conductive, we see that the *positive pulses* of the i.f. signal are utilized in this circuit. This means that the picture signal across R_L will have a *negative picture phase*. By interchanging connections *a* and *b* and interchanging connections *c* and *d*, a positive picture phase can be secured with this circuit.

Filtering and frequency compensation at high picture frequencies occur simultaneously with rectification in the circuit of Fig. *12*. The plate-cathode and cathode-filament capacities of the diodes are combined as a single capacitance C_D in the circuit diagram. The grid-cathode capacity of the following v.f. amplifier tube is shown as C_{GK}, for its effect is felt across R_L. Parts C_D, L_3, C_5, L_4 and C_{GK} thus form a double-cascade π filter. Semi-adjustable condenser C_5 in this circuit may include also the input capacities of the a.g.c. and amplitude separator sections of the receiver. C_5 is adjusted to give the desired resonant step-up at higher picture frequencies.

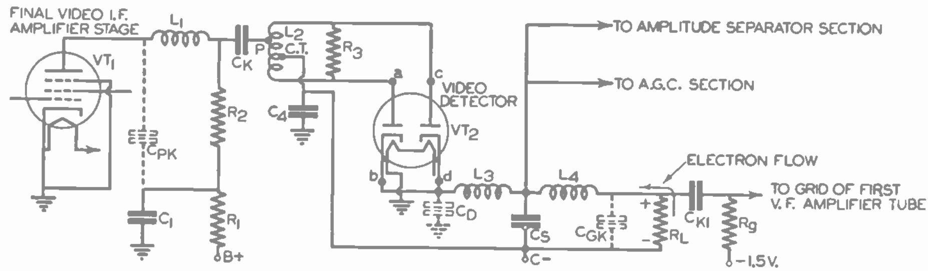


FIG. 12. Full-wave video detector circuit having a low-pass output filter which also provides frequency compensation. The demodulated output signal has a negative picture phase.

Automatic Gain Control

Why A.G.C. Is Needed. In a sound all-wave receiver, automatic volume control minimizes fading due to interaction between ground and sky waves, and eliminates blasting when tuning from a weak to a strong station. We do not have this particular type of fading in the picture channel of a television receiver, but we do have fading due to swaying antennas and transmission lines, to objects crossing the signal path in space, and to sudden increases in signal strength when tuning from a weak to a strong television station. Automatic gain control (the equivalent of a.v.c.) is employed in the picture channel of a television receiver to counteract these two effects.

Phase interference is always present to a certain extent in any antenna installation. Swaying of the antenna or transmission line in the wind will change the phase relationship between the signals arriving over different paths, thus changing signal pick-up. Rigid antenna supports and proper anchoring of the transmission line can prevent most of this movement during normal winds, but it is generally not practical to make the antenna sufficiently rigid to withstand movement in strong winds.

Swaying trees and power lines which are in the path of desired television signals can cause fading. When a wave which is reflected from the ground is utilized for reception, an object crossing this path on the ground can attenuate the signal and produce momentary fading. Furthermore, the signals may be reflected from the moving object (such as from an automobile or truck) instead of from the ground, thereby changing the length of the reflection path. If there are originally two signals arriving over different paths, this will change the phase relationship between them, giving fluctuations in signal strength.

There are a number of circuits in a television receiver which must be adjusted according to the amplitude (strength) of the received signal. The contrast control (gain control) must be set to give the proper contrast between light and dark portions of the image, and the brilliancy control must be set to give proper background brilliancy and complete cut-off of the back traces. The correct settings of these controls are dependent entirely upon signal amplitude, and consequently both controls must be adjusted each time there is a change in signal strength such as occurs when tuning from a weak telecaster to a strong telecaster.

Automatic gain control can hold the signal amplitude at the t.c.r. tube essentially constant over a wide range of input signal amplitudes, thus eliminating the need for readjustment of contrast and brilliancy controls when tuning to a new station. The most important function of a.g.c. is, however, the elimination of temporary fading, for receiver controls cannot be adjusted fast enough to compensate for this.

The importance of having the television transmitter maintain continuous control over the sweep circuits in the receiver has already been stressed. Without a.g.c. in the receiver, fading or the tuning in of a new station with different signal strength might result in loss of this control, necessitating readjustments in the receiver.

Somewhere after the video detector, the demodulated picture signal along with the synchronizing impulses is sent through a biased diode or triode tube which separates the impulses from the picture signal. The bias value on this amplitude separator tube will be correct only for signals within a limited range of amplitude variations. If the picture signal amplitude is too low, a lower bias value will be needed; if the picture signal amplitude is too high, a higher bias value will be needed to give proper separation. By keeping the amplitude essentially constant, a.g.c. eliminates the need for frequent readjustments of the bias on the amplitude separator tube to compensate for fading or for the tuning in of a different station. Field tests have shown that a.g.c. is highly desirable in high-definition receivers, where it greatly simplifies the adjustments needed to maintain high definition.

Effect of Carrier Level upon Average D.C. Voltage. In sound all-wave receivers employing diode detectors, the d.c. voltage across the diode load varies with carrier level and is therefore suitable for a.v.c. purposes. This condition exists because most sounds, particularly musical tones, vary equal amounts in positive and negative directions about their zero-intensity value; regardless of the amplitude of the sound signal, the average rectified d.c. voltage is dependent upon carrier intensity.

In the picture channel of a television receiver, the d.c. voltage developed across the diode load of the video detector does not depend entirely upon carrier intensity, but rather upon the brilliancy of the line being scanned. Under certain conditions we can, in fact, actually have a higher d.c. load voltage for a low carrier level than for a high carrier level. Let us see how this is possible.

A television signal corresponding to a bright line with a short dark element is shown in Fig. *13A* as it exists across the diode video detector load resistor after demodulation and filtering. The corresponding signal for a dark line having a short bright element is shown in Fig. *13B*. These diagrams assume that the video detector provides a negative picture phase.

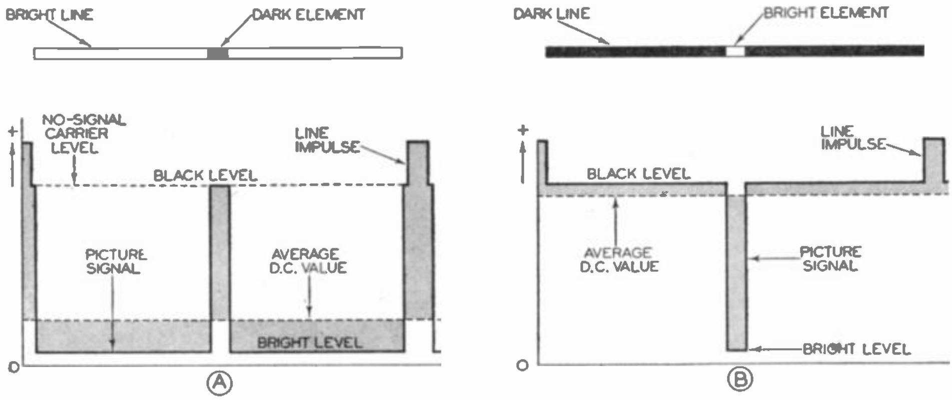


FIG. 13. Effect of line brilliancy upon the average d.c. value of a demodulated television signal.

In the case of Fig. *13A*, a high voltage exists only for the durations of the line impulses and the duration of the dark element, and consequently the average d.c. voltage for a bright line having only a small dark element is quite low. For a dark line having a short bright element, a high voltage exists at all times except for the short interval during which the bright part of the line is transmitted, and consequently we have a high average d.c. voltage here. The longer a voltage exists across the load, the higher will be the average d.c. voltage.

Increasing the carrier level in Fig. *13A* will merely increase the heights of the impulses and the dark-element signal. Since these occupy only a negligible portion of the time of one line, a large increase in carrier level is necessary in order to make the average d.c. voltage equal to the average value provided by the dark line in Fig. *13B*. Obviously the average d.c. voltage across the diode load resistor in the video detector has no direct relation to carrier level; this voltage is therefore *not suitable for a.g.c. purposes.*

Relation of Impulses to Carrier Level. The impulses in Figs. *13A* and *13B* are at the same level despite the differences in line brightness. Furthermore, the height of the impulses above carrier level is always proportional to carrier level; in other words, doubling the carrier level value will double the height of the impulses above the carrier level. If the impulses alone can be fed into a resistance-capacitance filter having a low time constant, a voltage can be secured which follows the peaks of the impulses and is therefore proportional to carrier level. This is how an a.g.c. voltage is secured in a television receiver.

A.G.C. Connection. The direct shunting of a suitable filter circuit across the diode load would by-pass higher picture frequencies, thereby impairing picture definition. For this reason, special attention must be given to the method of connecting the a.g.c. system to the video detector.

Assume that resistor R_L in Fig. *14A* is the load resistor for a diode video detector. A varying voltage which includes the picture signal and the impulses will be developed across this resistor; for illustrative purposes, let us say that it has the form of curve *1* in Fig. *14B*. When R_L is shunted with a.g.c. filter R_F-C_F, the voltage across this filter will follow increases in voltage across R_L. When the voltage across R_L reaches a peak and starts to decrease in amplitude, we would

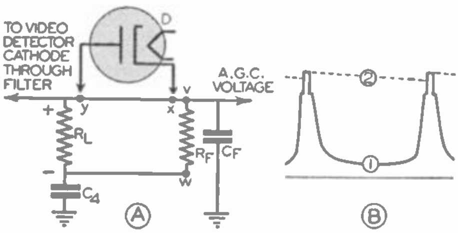


FIG. 14. Use of a diode tube to make an a.g.c. filter circuit follow the peaks of a television signal.

normally expect condenser C_F to discharge slowly through R_F if the latter has a high ohmic value. Unfortunately, however, load resistor R_L has a low ohmic value and consequently discharges the condenser. This is unsatisfactory, for we desire to secure across R_F a voltage which follows only the impulses.

Diode A.G.C. Tube. A diode tube like *D* in Fig. *14A* can be used *to prevent a.g.c. filter condenser C_F from discharging through diode load resistor R_L.* By breaking the connection between points *x* and *y* in Fig. *14A* and inserting between them the diode tube D, R_L can be prevented from shunting C_F during the time when the voltage across R_L is dropping. The voltage across R_F will then follow the peaks of the impulses. The plate of the diode must be connected to the positive terminal of R_L.

When the voltage across R_L is at its peak value, the diode plate is positive with respect to its cathode, and maximum current flows through the diode to charge up C_F. When the voltage across R_L drops, C_F tends to maintain its maximum voltage, making the diode plate (point y) negative with respect to the cathode (point x). The diode then acts as an open circuit, preventing C_F from discharging through R_L. The discharge of C_F is now controlled essentially by the time constant of C_F-R_F. If this constant is greater than the time for one line of the picture, the voltage across R_F will stay essentially at the peak charging value. In this way the voltage across R_F can be made to follow curve *2* in Fig. *14B*, maintaining itself essentially at the peaks of the impulses as is desired for a.g.c. purposes.

In the circuit of Fig. *14A*, diode load R_L is in effect shunted by the plate-cathode capacity of diode D, and consequently there is some attenuation of the higher picture frequencies. If the a.g.c. connection is made as shown in Fig. *12*, so that this added capacity is shunted across condenser C_5, we have a connection which is satisfactory for a.g.c. purposes and at the same time provides compensation for higher picture frequencies. Figure *15* illustrates how this a.g.c. connection is made.

D.C. Amplification of A.G.C. Voltage. In Fig. *14A* you will observe that terminal v is positive, while terminal w is negative. If we wanted to connect terminal w to the grids of the a.g.c.-controlled tubes, in order to utilize its negative potential with respect to v, it would be necessary to ground terminal v. This is obviously not permissible, for it would prevent application of the detector output voltage to the grid of the first v.f. amplifier tube. By inserting a d.c. amplifier stage between R_F and the a.g.c.-controlled tubes, we can reverse the polarity of the a.g.c. voltage and

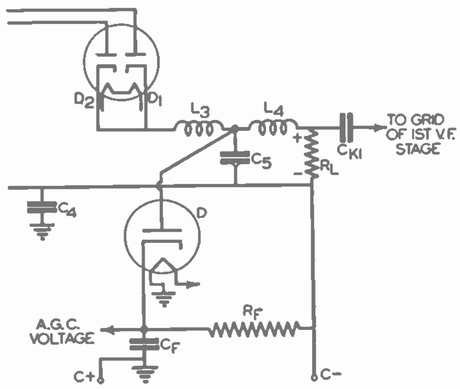


FIG. 15. Satisfactory a.g.c. connection to the filter circuit of a diode video detector. This arrangement also provides a fixed negative C bias for the a.g.c.-controlled tubes. Note that the filament-to-cathode capacity of a.g.c. diode *D* is in parallel with C_F.

at the same time amplify the a.g.c. voltage across R_F so it will have a more positive control over the video i.f. amplifier tubes.

A typical circuit employing a triode as a.g.c. amplifier tube is shown in Fig. *16*. The a.g.c. voltage developed across resistor R_F in the a.g.c. diode circuit is applied to the grid and cathode of the a.g.c. amplifier tube in series with a negative bias voltage of 3 volts (the voltage drop between the -50 and -53 volt terminals on the power supply voltage divider). Plate current of the a.g.c. amplifier tube flows through load resistor R_{F_1} to the -3 volt terminal on the voltage divider, developing across R_{F_1} the desired negative a.g.c. voltage for the video i.f. tubes. The plate voltage on the amplifier tube is thus 47 volts. The connection of the plate to the -3 volt terminal instead of to ground provides a fixed bias of -3 volts in series with the varying negative voltage developed across R_{F_1}, and this serves as the fixed negative bias for the a.g.c.-controlled tubes.

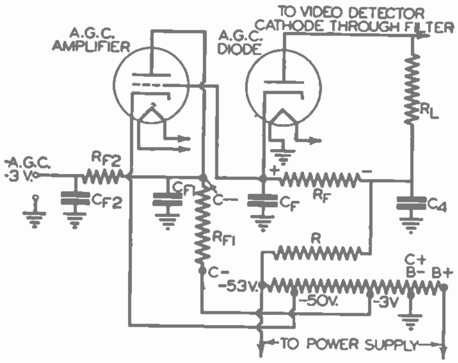


FIG. 16. This triode a.g.c. amplifier stage for a television receiver serves to increase the swing of the a.g.c. voltage developed across *R* and at the same time reverse its potential.

An increase in the level of the incoming carrier signal results in an increased d.c. voltage across R_F, making the grid of the a.g.c. amplifier tube more positive than before with respect to its cathode. As a result, plate current through R_{F_1} increases, making the plate end of R_{F_1} more negative than before with respect to ground and thus providing the desired higher negative bias to offset the increase in the level of the incoming carrier. In this way the a.g.c. amplifier tube provides both amplification and reversal of polarity.

Resistor R in Fig. *16* has a high ohmic value, so that it acts with C_4 as a power supply filter. R_{F_1}-C_{F_1} and R_{F_2}-C_{F_2} serve to filter the output voltage of the a.g.c. amplifier, for it is highly important that no a.c. ripple voltages enter the video i.f. amplifier. These filters also act as an a.g.c. time delay.

A.G.C. Circuit with A.C. Amplification. An automatic gain control circuit like that in Fig. *15* or Fig. *16* is highly desirable in a television receiver, as it utilizes the television signal in its d.c. form, with the pedestals lined up. This arrangement complicates somewhat the video detector, a.g.c. and power supply circuits, however, increasing the cost of the receiver.

When receiver cost is to be kept low, a less complicated a.g.c. circuit can be used. Although the simpler arrangements will not be completely effective in varying receiver gain in accordance with carrier level, they will give far better results than would be obtained without an a.g.c. circuit.

A simplified a.g.c. circuit which utilizes the a.c. form of the television signal and which provides a.c. amplification of the a.g.c. voltage is shown in Fig. *17*. Triode a.g.c. amplifier tube VT_2 is connected through d.c. blocking condenser C to a point in the resistance - capacitance - coupled v.f. amplifier at which the television signal exists in its a.c. form. The amplified output voltage of this a.g.c. amplifier tube is then rectified by diode VT_3 (plate and grid are tied together to give a diode). The positive or cathode terminal of diode load resistor R_4 is grounded, and the negative terminal of this resistor is utilized as the a.g.c. source terminal.

Electron flow in Fig. *17* is from the cathode to the plate of VT_3, then through R_2, R_3 and R_4 back to the cathode. The pulsating voltage developed across R_4 is smoothed out and time delayed by shunt condenser C_2, and consequently the voltage across R_4 tends to follow the peaks of the signal. Resistor R_3 serves to prevent condenser C_2 from by-passing v.f. amplifier tube having a positive picture phase. If the video detector delivers a negative picture phase, then the plate circuit of the first v.f. amplifier stage will have a positive picture phase, and can be connected to the a.g.c. amplifier tube.

Resistor R in Fig. *17* serves to limit the amount condenser C and the grid-cathode capacity of VT_2 can attenuate the higher picture frequencies. The automatic C bias developed by R_C and C_C is applied through R_g to

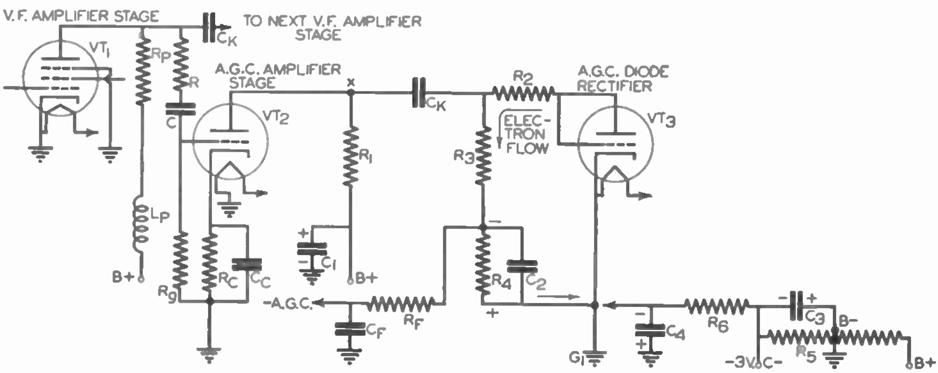


FIG. 17. A.G.C. amplifier stage which amplifies only the a.c. components of a picture signal prior to rectification.

the signal voltage across plate load resistor R_1. Resistor R_2 merely serves to limit current through diode VT_3.

VT_3 will conduct current only when terminal x of R_1 is driven positive with respect to the chassis. This means that the phase of the picture signal at the input of VT_3 must be negative. Since a.g.c. amplifier tube VT_2 reverses the phase of the picture signal, it is necessary to feed into this tube an a.c. signal having a *positive* picture phase. For this reason, the a.g.c. connection must be made to a the grid of VT_2. Condensers C_K are simply d.c. blocking condensers.

The a.g.c. voltage developed across R_4 is fed to the grids of the controlled tubes through time delay and filter circuit R_F-C_F. If C bias is to be provided for these tubes along with the a.g.c. voltage, ground G_1 may be removed and a connection made instead from the cathode of VT_3 through resistor R_6 to the C- terminal on the main voltage divider, as indicated at the right in Fig. *17*. R_5-C_3 and R_6-C_4 act as ripple filters, keeping power supply ripple currents out of the a.g.c.-controlled tubes. Condensers C_4 and C_8 in these filters should have high capacities, about 50 mfd.; dry electrolytic condensers can be used, since a voltage rating of about 25 volts is entirely adequate.

A.G.C. - Controlled Tubes. Video i.f. amplifier tubes which obtain part or all of their bias from the a.g.c. system are referred to as a.g.c.-controlled tubes. One requirement of an a.g.c.-controlled tube is that it have a remote cut-off on its grid voltage-plate current characteristic, for increases in the negative C bias voltage must never cut off the plate current completely. Furthermore, the e_g-i_p characteristic of the tube must be essentially linear for normal grid voltage variations, in order to keep amplitude distortion at a minimum. Any distortion which does occur due to non-linearity of the tube may be reduced by using a cathode resistor without by-pass condenser in order to produce degeneration.

The tuning circuits of the video i.f. amplifier are all heavily loaded with resistance in order to secure the required wide pass-band. The net plate load resistance for a video i.f. tube at the video i.f. frequencies is usually about 1,500 ohms. This means that the a.c. plate resistance of the tube will always be very much greater than the plate load impedance, and most of the a.c. plate voltage ($\mu \times e_g$) is dropped between the plate and cathode of the tube rather than across the load.

High Transconductance Is Needed. Since a video i.f. amplifier tube acts like a constant-current generator, it is simpler to consider its amplification as the product of mutual conductance (transconductance) and plate load resistance. With this thought in mind, we can readily see that a video amplifier tube must have a high transconductance value if it is to give reasonable gain with a low-resistance load.

One way to secure a high transconductance in a tube is to use a cathode which emits a large number of electrons, use a high d.c. plate voltage, and place the grid closer than usual to the cathode in order to secure an effective control over the resulting high plate current. Tubes designed especially for television purposes will therefore require far more cathode heating power than tubes used in all-wave receivers. For example, a type 1853 television pentode tube has a filament voltage of 6.3 volts and a current of .45 ampere, giving a total filament power of about 2.8 watts; this tube, when operated with a d.c. plate voltage of 300 volts, has a transconductance of 9,000 micromhos. A type 6D6 tube such as is widely used in the r.f. and i.f. sections of all-wave receivers requires 6.3 volts and draws .3 ampere, so that the total filament power is only about 1.9 watts. With a plate voltage of 250 volts, this tube has a transconductance of 1,600 micromhos.

Gain Per Stage. When a television tube having a transconductance of 9,000 micromhos is used with a 1,500-ohm load, the gain per stage will be .009 x 1,500 or 13.5 (divide micromhos by 1,000,000 to get mhos, then multiply by the load resistance in ohms). A type 6D6 tube used with the same load would only give a gain of 2.4 for the stage.

Special Television Tubes. Special

high-transconductance tubes such as the 1851, 1852 and 1853, all of which are pentode amplifiers, have been developed for television purposes. The 1851 has a conventional control grid connection to a top cap, but the 1852 and 1853 are of the single-ended type. All three are metal tubes, for shielding against stray electric fields is highly important at ultra-high frequencies.

Although the type 1853 tube is best suited for control with an a.g.c. voltage, all three tubes can be made to have a remote cut-off characteristic by choosing the proper value of screen grid voltage and by applying this voltage to the screen grid through a resistor of suitable value, connected between the B+ terminal and the screen grid.

Tube Characteristic Curves. Grid voltage-plate current characteristic curves showing the effects of different values of screen grid voltage upon the location of the cut-off point are shown in Fig. *18.* These curves are for a fixed plate voltage of 300 volts, as indicated on the circuit diagram above the curves. Note that as the screen grid voltage is increased from 50 volts to 200 volts (curves *1, 2, 3* and *4*) without resistance in the screen grid lead, the plate current cut-off bias increases correspondingly. The bends in these e_g-i_p characteristics are rather sharp, and are undesirable for linear amplification.

By inserting a resistance between the screen grid and the high-voltage supply, it is possible to keep the screen grid voltage near the plate voltage and at the same time secure high plate current values for large negative control grid voltages, as shown by curve *5* in Fig. *18.* The characteristic curve is now more linear (there is no sharp bend in the curve). A.G.C.-controlled tubes are almost invariably operated with a high screen grid voltage applied through a resistor in this manner.

The a.g.c. voltage is applied to the grid of an a.g.c.-controlled tube in a conventional manner. When the cathode of the tube is grounded, as is

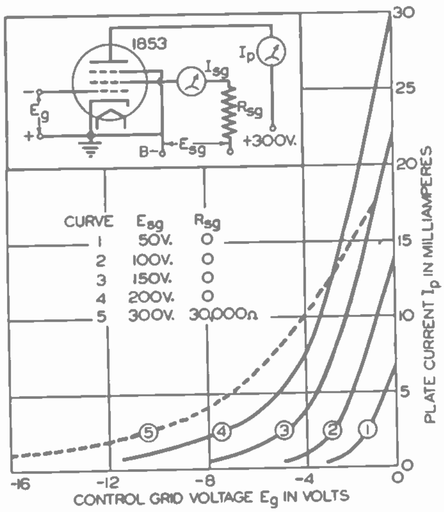


FIG. 18. Characteristics of a pentode television amplifier tube.

the case in Fig. *5,* the a.g.c. circuit must also supply the minimum fixed C bias for the tube. In this case the a.g.c. supply will be as shown in Fig. *16.*

When the a.g.c.-controlled tube is to supply its own minimum C bias, it will have a cathode resistor; Fig. *4* is an example of this case.

A study of the circuit in Fig. *4* would lead one to believe that the minimum C bias is produced here by the 65-ohm cathode resistor. With a normal cathode current of 12 ma., this value of cathode resistance would only give a self-bias of about .8 volts, which is clearly insufficient for satisfactory operation. Additional minimum C bias must be supplied to the circuit of Fig. 4 through the a.g.c. circuit. The resistor is used in the cathode lead primarily to provide degeneration, for its by-pass condenser is omitted.

TEST QUESTIONS

Be sure to number your Answer Sheet with the *number* appearing on the front cover underneath the title of this text.

Place your Student Number on every Answer Sheet.

Send in your answers for this lesson immediately after you finish them. Doing this insures that the graded answers will reach you while the subject matter is still fresh in your mind, and you will get the greatest possible benefit from our speedy personal grading service. *Never hold up a set of lesson answers.*

1. If a video i.f. amplifier having a pass-band of 4 mc. is to handle the 13-mc. video i.f. carrier of a typical single side-band television system, between what two frequencies should the amplifier be aligned?

2. How is the sound i.f. signal kept out of the video detector in a sight-sound television receiver?

3. Why is part or all of the cathode-to-chassis resistor in a video i.f. stage sometimes used without a by-pass condenser?

4. In the video i.f. circuit of Fig. *4*, what serves as the mutual coupling between the plate and grid tuned circuits?

5. Is the prevention of amplitude distortion in the video detector as important as the prevention of frequency distortion and unequal time delay?

6. Why is it necessary to use a low ohmic value for the load resistor of a diode video detector?

7. What picture phase will be obtained if the video detector is designed to reject the positive peaks of the r.f. cycles?

8. Why does a full-wave video detector simplify filtering problems?

9. Is the d.c. voltage which is developed across the diode load resistor of the video detector suitable for a.g.c. purposes?

10. What is the purpose of diode *D* in Fig. *14A?*

1. Between 9 mc. and 13 mc.

2. By using, in the video i.f. channel, rejector circuits which are tuned to the sound i.f. value.

3. To provide a small amount of degeneration in order to stabilize the circuit and prevent amplitude distortion.

4. Parallel resonant circuit L_S-C_S.

5. No.

6. So that any shunt reactance across this resistor will have less effect upon high frequencies, thus reducing frequency distortion.

7. A positive picture phase.

8. Because it doubles the frequencies of undesired i.f. pulses, making it easier to separate them from the desired video signals in the detector output.

9. No.

10. It prevents a.g.c. filter condenser C_F from discharging through diode load resistor R_L.

VIDEO FREQUENCY AMPLIFIERS AND D. C. RESTORING CIRCUITS

63RH-1

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

A WARNING!

"It becomes more and more true that those who break off education as a continuous process rapidly become uneducated. Not only does what they once knew become rusty and useless, but the growth of new knowledge passes them by and leaves them adrift in a world which they are not qualified to understand."

NEWTON D. BAKER,
Former Secretary of War.

NATIONAL RADIO INSTITUTE

WASHINGTON, D. C.

1941 Edition

A LESSON TEXT OF THE N. R. I. COURSE
WHICH TRAINS YOU TO BECOME A
RADIOTRICIAN & TELETRICIAN
(REGISTERED U. S. PATENT OFFICE) (REGISTERED U. S. PATENT OFFICE)

NCP2M841

Printed in U. S. A.

Video Frequency Amplifiers and D. C. Restoring Circuits

V. F. Amplifier Requirements

WHEN the demodulated television signal at the output of the video detector does not have sufficient amplitude to meet the input requirements of the t.c.r. tube, a video frequency (v.f.) amplifier must be employed to boost signal strength. The design of a satisfactory v.f. amplifier for a high-definition television receiver is a highly important task involving a consideration of the characteristics of the amplifier tube along with the values of the various parts, for all affect the performance of the amplifier.

Frequency Response Requirements. First of all, a satisfactory v.f. amplifier must provide flat response over the desired range of video frequencies. This means that in the case of a high-definition television receiver, the v.f. amplifier must amplify and pass equally well all signals from about 10 cycles to about 4 megacycles.

As a general rule, the face diameter of the t.c.r. tube is a guide to the amount of image definition which can be provided by the receiver. A properly designed 12-inch t.c.r. tube is capable of showing all of the details in a 441-line picture signal; this means that with receivers having t.c.r. tubes of this size or larger, the range of uniform frequency response for the v.f. amplifier should extend up to about 4 mc. if maximum image detail is to be obtained. With 3-inch or 5-inch t.c.r. tubes, however, it would be useless to maintain uniform frequency response over the maximum frequency range simply because these tubes as made today cannot produce a sufficiently small and sharp spot on the screen to show fine elemental differences in the image.

Assuming standard 441-line pictures, there is an optimum viewing distance for each t.c.r. tube face diameter. The smaller the face diameter of the tube, the closer is this ideal viewing position to the screen. When a viewer is closer than the optimum distance, the lines of the image will become apparent. When farther away than the optimum distance, the eye will not be able to perceive the fine details which exist in the image. If a small t.c.r. tube is to be viewed from a point farther away than the ideal position (as is usually the case in the average home), the fine details in the image will not be apparent, and consequently there will be no need to provide the wide frequency response required to give this fine detail in the image. In other words, a receiver using a 3-inch or 5-inch t.c.r. tube can and generally will have poorer image definition than television receivers employing larger tubes.

Good response at low frequencies is equally as important in a video frequency amplifier as good high-frequency response. The average briliancy varies from line to line in the image and from frame to frame; if the t.c.r. tube is to reproduce these changes in average brilliancy and maintain the proper background brilliancy, it is essential that low frequencies down to about 10 cycles per second be amplified equally as well as the higher frequencies up to about 4 mc.

Desirability of D. C. Amplifiers. We must not overlook the fact that the picture signal at the output of the video detector is actually a pulsating d.c. signal in which the pedestals are all lined up at one definite voltage level. It is essential that this condition also exist at the input of the t.c.r. tube if a high-definition image is to be secured. Pulsating d.c. signals both at the input and output of the v.f. amplifier indicate the need for a d.c. amplifier, in which there is no condenser coupling between stages to block the d.c. components of the signal.

Drawbacks of D.C. Amplifiers. It is not impossible to build a direct current amplifier which is capable of passing d.c. along with video frequency signals up to 4 megacycles, but when two or more amplifier stages are required, a number of major problems arise. First of all, a high-voltage power supply is required, for the maximum voltage required from the source will generally be the sum of the maximum voltages required for each stage. This requirement in itself would not be an objection if it were not for the fact that high-transconductance tubes are needed to give the desired gain with the desired wide frequency response. These tubes draw high plate currents, and consequently a d.c. amplifier requires a costly heavy-duty power pack to supply the high-voltage and high-current requirements for two or more d.c. stages.

Another serious drawback to the use of d.c. amplifiers is the fact that these amplifier stages, when connected in cascade, are subject to low-frequency oscillation (corresponding to motorboating in a sound receiver). Even resistance-capacitance-coupled amplifiers which are capable of passing low frequencies will have this trouble, as we will shortly see, but it is far more serious in d.c. amplifiers.

In addition to the drawbacks of a *costly heavy-duty power pack* and *undesirable low-frequency oscillation,* a multi-stage d.c. amplifier has an *excessively high cathode-to-heater voltage in the final stage.* This last drawback may be difficult to overcome with ordinary tubes, for these will break down when the cathode-to-heater voltage exceeds a certain value. A separate filament winding would therefore be needed for each d.c. stage, thereby increasing the cost and complexity of the receiver.

A.C. Amplification. Since the d.c. component of the picture signal can be blocked out at the output of the video detector simply by inserting a blocking condenser in the signal path, and since it is possible to restore the d.c. component in a manner which will make the pedestals line up again, it is common practice to amplify only the a.c. components of the picture signal when more than one v.f. stage is used. With this arrangement, the v.f. amplifier circuits are far more stable than they would be if d.c. amplification were employed, and yet are equally as effective. When only one v.f. amplifier stage is required, direct coupling will invariably be used. For this reason, we will consider circuits for both d.c. and a.c. types of v.f. amplifiers in this lesson.

R-C Coupling Networks. Theoretically, a resistance - capacitance (r-c) coupling network between two v.f. amplifier stages would pass equally well all frequencies from the line frequency (13,230 cycles) to infinity if it were not for the plate-cathode tube capacity at the input of the coupling circuit, the grid-cathode tube capacity at the output of the coupling circuit, and the stray capacities to chassis which exist at the sockets, parts and connecting wires. *These capacities limit the upper frequency range of an r-c coupled v.f. amplifier,* for they act together to become an increasingly more effective shunt on the plate load resistance as frequency increases. It is possible to extend the high-frequency end of the pass-band considerably in an r-c coupled v.f. amplifier by employing plate load resistors having low ohmic values.

R-C coupling essentially means the introduction of a blocking condenser between the plate of one v.f. amplifier tube and the grid of the following tube, with the grid return to the C bias voltage supply for the following tube being made through a resistor of high ohmic value. This arrangement in effect constitutes a voltage divider which is connected across the plate load resistance and which reduces the response at lower video frequencies.

By properly proportioning the electrical values of the blocking condenser and the grid resistor, response at the lower frequencies can be improved considerably. The position of the blocking condenser is likewise highly important, for the condenser plates constitute a metal object which has a capacity to the chassis and which therefore serves to shunt the higher picture frequencies to ground. Another important requirement for a wide frequency range in the video frequency amplifier is the use of compensating circuits.

Phase Delay and Time Delay

The presence of the blocking and coupling condenser, tube capacities and stray lead capacities in an r-c coupling network not only affects frequency response, but also affects the phase of the signal voltage which is fed to the following tube. Phase delay and its effect upon picture components is a very important consideration in video frequency amplifier design, and the factors controlling phase delay must be kept clearly in mind by the Teletrician whenever making changes or replacements of parts in the video frequency amplifier. Let us first see what is meant by phase delay and time delay, then consider how they can occur in an r-c coupled amplifier.

Representing Voltages with Vectors. Suppose that a definite signal voltage *V* is applied to the grid of a vacuum tube. For simplicity, we can represent this voltage as a vector rotating in a counter-clockwise direction, like vector *V* in Fig. *1A*.* This diagram tells us that the value of voltage *V* is zero at the instant corresponding

* The use of rotating vectors to represent a.c. voltages and currents has been considered throughout your entire course, starting with the fundamental lessons. A review of the sections on vectors in these earlier lessons will help you to understand this discussion of video frequency amplifiers.

to the vector position shown. Furthermore, this voltage will have its maximum positive value after the vector has rotated ¼ cycle (90°) in its counter-clockwise direction.

If a signal encounters no reactance whatsoever as it passes through a coupling network, the input and output signal voltages will be *in phase* with each other, and will be zero at exactly the same instant of time. If, however, the coupling network has a reactance which delays the signal voltage, the voltage vector at the output of the coupling network may correspond to vector *V'* in Fig. *1B*, and the output voltage vector will have to

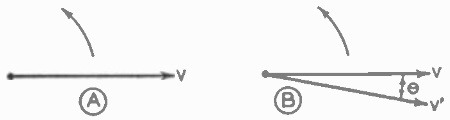


FIG. 1. Vector diagrams representing a signal voltage *V* which undergoes a phase delay corresponding to the angle *θ* while passing through a reactive coupling network.

rotate through the angle *θ*, before it will be back to zero. This angle corresponds to the *phase delay*, and the length of time required for the output voltage to "catch up" with the phase existing at the input is called the *time delay*.

Phase Delay Angles. In a particular coupling network we may find that signal frequencies from 10 cycles up to about 150 cycles are delayed or advanced in phase by a large angle, with the angle of delay being greatest at the lowest frequencies (the output voltage can either be delayed or advanced, depending upon whether the reactance in the coupling network is inductive or capacitive). Furthermore, some other part of the coupling network may cause the higher picture frequencies to be delayed, with the angle of delay increasing with frequency in this case. To understand how this delay at different frequencies affects image definition, we must learn the true significance of phase delay and time delay.

Up to the present time, we have used *angles* to specify the phase of a voltage. Thus, we would say that vector *V* in Fig. *2* undergoes a phase shift of 90° when it is rotated counter-clockwise from position *1* to position *2*. In a similar manner, we would say that vector *V* has been rotated 180°, 270° and 360° when it is at positions *3*, *4* and *5* respectively.

One complete 360° rotation of a vector corresponds to one cycle. For a 1,000-cycle-per-second voltage, a vector would make 1,000 complete revolutions per second. To get the number of degrees of rotation per second for this frequency, we would multiply 1,000 by 360. Engineers, however, do not ordinarily deal with degrees when making certain computations involving the rotation of vectors; instead they use *radians* to express angular movements of vectors.

Radians. You will recall that the circumference of a circle is equal to 2π times the radius of the circle, where π is the number 3.14. One-half the circumference will therefore be equal to π times the radius. One-fourth the circumference will be $\pi/2$ times the radius ($\pi/2$ is the same as $\pi \div 2$).

When vector *V* in Fig. *2* is rotating, its arrow end will trace a perfect circle. We can express an angular movement of this vector in terms of the length of the circular path which its end traces. For an angular movement of 90°, the length of the circular path will be $\pi/2$ times the radius. Engineers express this simply as $\pi/2$ radians, thereby eliminating the need for computing the length. Likewise, an angular movement of 180° would be expressed as π radians, 270° as $3\pi/2$ radians, and 360° as 2π radians.

Angular movements of a vector can thus be expressed either in terms of *length in radians* along the circumference of a circle or *in degrees*. The circumference of any circle, regardless of its size, is always 2π radians. Since there are 360° in a circle, 1° will be equal to $2\pi \div 360$ radians, which is .0175 radian. Any angle θ will therefore be $\theta \times 2\pi \div 360$ radians, or $\theta \times .0175$ radian. Thus, to change degrees to radians, simply multiply the number of degrees by .0175; the answer will then be in radians.

One cycle thus corresponds to 2π radians. For a frequency of 1,000 cycles per second, a vector will therefore rotate $2\pi \times 1{,}000$ radians per second.

Angular Velocity. For any frequency f, the velocity of the corresponding rotating vector can be designated as so many radians per second. Since one complete cycle corresponds to 2π radians, the angular velocity for any frequency f (any number of cycles per second) will be $2\pi f$ radians. The expression $2\pi f$ is often designated by the symbol ω (this same symbol is used in radio to represent ohms, but invariably the nature of the associated text will indicate to you which meaning is intended). You have undoubtedly seen the expression $2\pi f$ many times, for the reactance of a coil in ohms is equal to $2\pi fL$, and the reactance of a condenser is equal to $1/2\pi fC$.

Relation Between Phase Delay and Time Delay. Returning to Fig. *1B*, we now know that the angle θ by which vector V' has been delayed can be expressed in radians. If this vector is rotating at a velocity equal to $2\pi f$ radians per second, we can determine the time required for the vector to rotate through the angle θ and return to its original position quite easily; simply divide θ in radians by $2\pi f$ radians, and the result will be

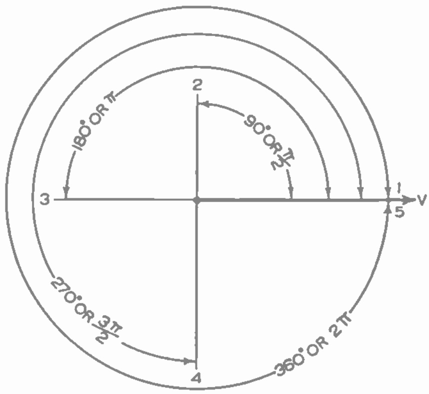


FIG. 2. Relationship between phase angles in degrees and radians. Note that one complete circle or 360° is equal to 2π radians. Half a circle or 180° is thus equal to π radians. The value of π is 3.14 in all cases.

the time in seconds required for the vector to return to its original zero position. (This computation corresponds exactly to the simple case of an automobile having a distance of 5 miles to go and having a speed (velocity) of 20 miles per hour. The time required to travel this 5 miles will be $5 \div 20$, or .25 hour.)

Now we can see that if a 60-cycle signal is delayed by the same angle that a 4-megacycle signal is delayed, it will take a longer time for the 60-cycle signal to catch up; this means that *the 60-cycle signal will have the greater time delay.* (The vector for the 4-megacycle signal is rotating over 50,000 times as fast as the vector for the 60-cycle signal.) This shows that even though two signals have the same phase delay, they may have widely different time delay values. This difference in the time delay for different frequencies can be a serious matter in a high-definition television receiver.

Effect of Time Delay on Image. The spot on the fluorescent screen of a 12-inch t.c.r. tube travels one inch along a line in approximately 7 micro-seconds. This means that a time delay of one micro-second (one millionth of a second) for any one frequency will cause a shift of .14 inch in the detail corresponding to that frequency on the screen. Let us see what effect a delay like this would have upon the reconstructed image.

Suppose we were transmitting a simple scene which was half solid black and half white, the dividing line being vertical. If standard 441-line scanning is employed, with 30 complete frames being transmitted per second, each line of the image will be represented by one complete cycle of a square-top wave. The fundamental frequency of this square-top wave will therefore be the line frequency of 13,230 cycles per second. Such a square wave will have many odd harmonics; the 15th harmonic will be 1/15 as strong as the 13,230-cycle fundamental frequency; the 125th harmonic will be 1/125 as strong as the fundamental, and the 299th harmonic (about 4 mc.) will be 1/299 as strong as the fundamental.

A scene which is all white on one side and all black on the other, with the vertical dividing line right in the center, will thus require a video signal containing all frequency components up to the maximum frequency of the system. In order to reproduce the sharp change from white to black properly, all of the harmonics in this square-top wave must be amplified equally well, with no time delay or with a constant time delay for all frequencies.

Effect of Constant Phase Delay. In a video frequency amplifier where the phase delay angle is constant for all frequencies in the range from 13 kc. to 4 mc., the lower-frequency components (near 13 kc.) will be time delayed more than the higher frequencies. The result will be a wide band of gray separating the black and white areas. We lose the sharp demarcation or change between the two areas.

Although we have considered a simple black and white view in this analysis, a constant phase delay (a constant phase angle between the input and output signals of a stage or section) for all video frequencies will result in blurring of the image. This effect is relatively unimportant when t.c.r. tubes having small face diameters are viewed directly, but is a real problem in large-diameter t.c.r. tubes and in projection type t.c.r. tubes. Picture details corresponding to the lower-frequency components in the video signal (those near 13 kc.) are moved to one side of their correct position due to the unequal time delay period, giving the effect of blurring.

Securing a Constant Time Delay. Although phase delay cannot readily be eliminated from a v.f. amplifier, its objectionable effects can be minimized. It was pointed out that for a constant phase delay, the time delay increases as frequency decreases. This means that the lower video frequencies are time delayed more than the higher frequencies. In a v.f. amplifier, the shunting capacities in the coupling network have the effect of making the phase delay increase as frequency increases. If this increase in phase delay with frequency can be made uniform, we can secure a constant time delay for all frequencies. A *constant time delay is desirable* in a v.f. amplifier, for it merely shifts the entire image to one side a small amount, and this can easily be compensated for by adjusting the image-centering controls.

Time Delay at Low Frequencies. Although we have so far considered phase delay and time delay only for those picture frequencies from 13 kc. to 4 mc. which contribute to detail *along* a line, these troubles can also exist at the lower frequencies. For example, suppose that we are transmitting a half-black, half-white field in which the dividing line is horizontal. If we neglect the synchronizing impulses, this will give us a square-top wave having one complete cycle for each vertical sweep of the picture; in other words, the fundamental frequency of this square-top wave will be the field frequency of 60 cycles per second, and there will be many harmonics extending up to the maximum picture frequency of 4 mc. A phase delay of even a small amount at 60 cycles will result in a very large time delay, and the sharpness of the separation between black and white areas will be lost. The problem is further complicated by the fact that with conventional r-c coupling circuits, the phase angle is not constant with frequency, but actually increases at the lower frequencies. This means even greater time delays for the lower frequencies, and it is a real problem to reproduce properly scenes which have slowly changing background brilliancy.

In the designing and testing of v.f. amplifiers, signal generators which actually produce square-top waves are used in conjunction with cathode ray oscilloscopes to check frequency

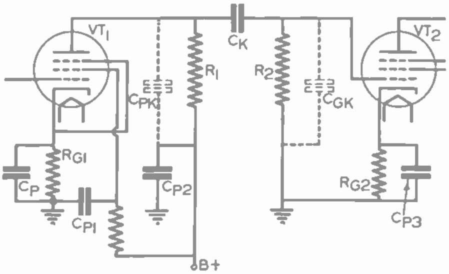


FIG. 3. Typical r-c coupled v.f. amplifier circuit.

response and phase delay. Any departure from a square top in the output signal as reproduced on the oscilloscope screen is interpreted as frequency distortion and time delay.

How Phase Delay Occurs. Let us see how phase delay can occur in a resistance-capacitance coupled v.f. amplifier like that shown in Fig. *3*. Vacuum tube VT_1 develops across plate load resistor R_1 a signal voltage which is impressed upon the control grid of tube VT_2 after passing through the voltage divider made up of C_K and R_2. The capacitive reactance of coupling condenser C_K varies with frequency, so that this condenser affects the output voltage across R_2 and at the same time introduces phase delay. At the higher video frequencies, the reactance of C_K becomes so small that its phase delay and its effect upon frequency response can be neglected. The plate-to-grid coupling condenser in an r-c coupled v.f. amplifier thus affects phase delay and frequency response only *at the low frequencies*.

By redrawing only the voltage divider portion of our coupling network in the manner shown in Fig. *4A*, we can study the phase relationship between the input voltage E_i to this voltage divider and the output voltage E_o. First of all, observe that we have a series circuit. Current i is therefore common to both elements in the circuit, and can be used as the reference vector in our vector diagram for this circuit (Fig. *4B*). The voltage across R_2 will be in phase with this current, and consequently voltage vector E_o coincides with current vector i. The voltage across C_K will lag the current by 90°, and consequently voltage vector E_{CK} is drawn 90° clockwise from vector i.

According to Kirchhoff's laws, the input voltage E_i must be equal to the vector sum of voltage drops E_{CK} and E_o. We add these vectorially in Fig. *4B* by completing the parallelogram as shown in dotted lines, securing E_i as the resultant. This input voltage E_i lags the output voltage E_o by the phase angle θ, which means that the output voltage E_o is speeded up by the angle θ. "Strange as it may seem," the lower video frequencies reach their maximum values in the *output* of this coupling circuit an appreciable time before they do in the *input*.

Analyzing the circuit in Fig. *4A* more closely, we observe that at high frequencies C_K has a very small reactance, much smaller than the resistance of R_2. Under this condition most of the applied input voltage is dropped across R_2, and we secure a maximum output voltage E_o. The higher the frequency, the smaller is the voltage drop across C_K. If we make vector E_{CK} quite small with relation to vector E_o in Fig. *4B*, to correspond to this condition, we find that the resultant voltage vector E_i will now almost coincide with the output voltage vector E_o and be almost equal to it in magnitude. The phase angle between input and output voltages reduces to zero as frequency is increased, and practically the entire input voltage becomes available at the output.

As we reduce the frequency, the reactance of C_K becomes larger and larger; in fact, it may be many times greater than the resistance of R_2 at

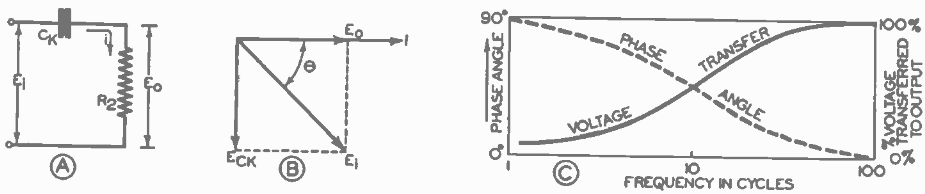


FIG. 4. Effect of coupling condenser upon the phase angle and the per cent voltage transferred from the input to the output at low video frequencies when the r-c coupling network shown in Fig. *3* is employed in a v.f. amplifier.

extremely low video frequencies. In this case, most of the input voltage will be dropped across C_K, and there will be very little available across the output resistor R_2. If we make vector E_{CK} in Fig. *4B* very much larger than vector E_o, we find that the resultant vector E_i tends to coincide with E_{CK} and become equal to it in magnitude; in other words, the phase angle θ between input and output voltages approaches 90° as frequency is lowered.

All these facts about the circuit in Fig. *4A* are summarized graphically in Fig. *4C*. This graph shows at a glance that as frequency increases, the phase angle decreases and the amount of voltage transferred to the output circuit increases.

Computing Effect of Phase Delay. Let us see how serious the effects of phase delay can be at low frequencies. If the phase delay at 10 cycles is 45°, this will be $\pi/4$ radians, which is 3.14/4, or .785 radian. We divide .785 by $2\pi f$ to find the time delay (in a capacitive circuit like that in Figs. *3* and *4A*, it is really a time *advance* or, as engineers say, a *negative time delay*). The expression $2\pi f$ will in this case be equal to $2 \times 3.14 \times 10$, which is 62.8; dividing .785 by 62.8 gives .0125 second, which is equal to 12,500 micro-seconds. This is almost equal to the time required for one scanning of the entire field (the time for half a frame, equal to 1/60 second or 16,700 micro-seconds). Obviously, the delaying of 10-cycle components of a picture this long will quite seriously impair the definition of the image.

Equivalent Coupling Circuit at High Frequencies. For the higher picture frequencies (above about 13 kc.), the reactance of C_K in Fig. *3* is negligibly low, and hence we may neglect this condenser. At these high frequencies, however, the tube interelectrode capacities and the stray lead and part capacities to the chassis are effectively shunting plate load resistor R_1. The equivalent circuit for this condition is shown in Fig. *5A*, where E_i is the voltage developed by tube VT_1, r is the a.c. plate resistance of this tube, and C represents the total capacity shunting plate load resistor R_1. This circuit indicates that the input voltage E_i for the circuit is divided between the plate load resistance and the a.c. plate resistance.

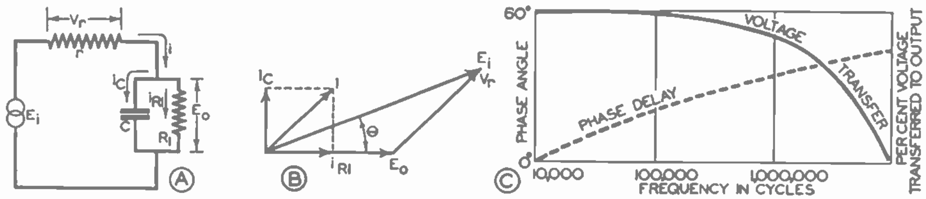


FIG. 5. Effect of tube capacities and stray shunt capacities upon the phase angle and the per cent voltage transferred from the input to the output at high video frequencies when the r-c coupling network shown in Fig. *3* is employed in a v.f. amplifier.

In the circuit of Fig. *5A*, we are concerned with the magnitude of the output voltage E_o across R_1 and with the phase relationship of this voltage to the input voltage E_i for various frequencies. Because of the shunting effect of condenser C upon R_1, we can say immediately that voltage E_o will decrease as frequency increases. The larger the value of C, the greater will be its shunting effect at the higher picture frequencies and the less will be the value of E_o. Capacity C will also cause the phase angle to vary with frequency, but to determine the exact nature of this variation we must use a vector diagram.

Since R_1 and C are in parallel, the same voltage exists across each, and we can use E_o as the reference vector. Current i_{R1} through resistor R_1 will be in phase with reference vector E_o, as shown in Fig. *5B*, but current i_C through condenser C will lead voltage E_o by 90°. Adding these two currents together vectorially as shown by the dotted lines gives us vector i for the current through r. The voltage drop V_r across r will be in phase with current vector i, and the vectorial sum of V_r and E_o will be equal to the input voltage E_i. We add these voltages vectorially by drawing V_r at the end of E_o, in the same direction as i, then complete the third side of this triangle to get E_i.

Our vector diagram in Fig. *5B* now shows that the output voltage E_o lags the input voltage E_i by the angle θ. We actually have a phase *delay* in this case, for E_o will reach its maximum value later than E_i.

Now we can see what effect frequency will have upon the phase angle θ between E_o and E_i. As frequency increases, the reactance of C decreases, and consequently more current flows through the condenser. If vector i_C in Fig. *5B* is much longer than i_{R1}, the resultant vector i will tend to approach i_C, V_r will increase in magnitude and will tilt upward correspondingly, and the net result will be an increase in the angle θ. We can therefore say that an increase in frequency increases the phase delay angle between the input and output voltages.

Time Delay Computations. The facts just discussed are presented graphically in Fig. *5C*. This graph shows at a glance that *the phase delay angle increases with frequency,* while the amount of voltage transferred to the output circuit *decreases* as frequency increases. The phase delay angle may be as much as 45° at 4 mc. This angle corresponds to $\pi/4$ radians or .785 radian. Dividing .785 by $2\pi f$ (dividing by $2 \times 3.14 \times 4{,}000{,}000$), we get a value of about .000000031 second or .031 micro-second for the time delay per stage.

Now let us assume that the phase delay at 10,000 cycles is 2°, which corresponds to .035 radian. This phase delay will produce a time delay of .055 micro-second ($.035 \div 6.28 \times 10{,}000 = .000000055$ second, or .055 micro-second). If these time delay values existed in an actual circuit, we would either have to decrease the .055-micro-second time delay at 10,000 cycles or increase the .031-micro-second time delay at 4 mc. in order to secure a constant time delay for all frequencies. When this time delay is made approximately constant by proper design, the entire picture on the screen will be moved to one side a small amount, which is perfectly acceptable. Of course, the means employed for securing a constant time delay must not affect the frequency response of the v.f. amplifier, for a flat response between 10 cycles and 4 mc. is just as important for high-definition reproduction as a uniform time delay.

Phase-Shifting Networks in Cascade. You already know that when amplifier stages are connected in cascade (connected together), the total gain is the product of the gains per stage. Thus, if a stage having a gain of 10 is connected to a stage having a gain of 20, the total gain will be 10×20 or 200. If, however, the phase delay angle for one stage is 2° and the angle for another stage which is connected in cascade is 4°, the total phase delay will be the *sum* of the individual phase delay angles. In this case, then, the total phase delay angle will be $2° + 4° = 6°$. The usual 180° phase shift which each r-c coupled amplifier stage produces does not enter into these calculations, for this shift can easily be corrected in the detector circuit or by changing the number of v.f. amplifier stages.

It is by no means a simple task to make the phase delay in a v.f. amplifier increase linearly with frequency. Any compensation introduced into the circuit for this purpose will give only an approximation to the desired results. According to some experts, however, the time delay values for the various video frequencies may vary within .1 micro-second for the entire video amplifier without seriously impairing the image.

Typical V. F. Amplifier Circuits

Now that we have outlined the basic requirements of a v.f. amplifier and have analyzed some of the design problems involved, we are ready to study typical amplifier circuits. Since any r-c coupled amplifier which is designed to give a flat response extending above 1.5 m.c. will have negligible frequency attenuation and negligible phase delay in the frequency range from 1,000 cycles to 500,000 cycles, we need only consider v.f. amplifier circuit action in two main frequency groups: *1.* The low picture frequencies, below about 1,000 cycles; *2.* The high picture frequencies, above about 500,000 cycles.

Amplification at High Picture Frequencies. Having seen how the shunt capacities indicated as C_{PK} and C_{GK} in the typical r-c video amplifier circuit of Fig. *3* reduce the amount of voltage transferred from the input to the output and cause a phase delay which increases with frequency, let

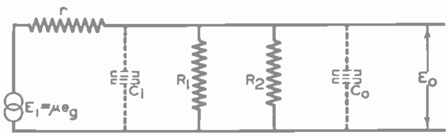


FIG. 6. At high video frequencies, the r-c coupling network of Fig. 3 becomes equivalent to this.

us now consider what these capacities are and how their effects can be minimized without too great a sacrifice of gain.

Since we are dealing only with the *high* picture frequencies, we can neglect C_K; the equivalent circuit then takes the form shown in Fig. *6*. The input voltage E_1 in this equivalent circuit is equal to μe_g (the grid voltage acting on VT_1 in Fig. *3* multiplied by the amplification factor of this tube). This input voltage E_1 will send current through a.c. plate resistance r and the network made up of the combined input shunt capacity C_1, plate load resistor R_1, grid resistor R_2 for the following stage and the combined output shunt capacity C_o, all in parallel.

Assuming a constant input voltage E_1, the output voltage E_o across R_2 would be the same at all frequencies if it were not for the presence of C_1 and C_o, which act as increasingly lower reactance shunt paths as signal frequency increases. The ohmic values of R_1 and R_2 should be made as high as is practical without increasing the d.c. plate supply voltage requirements too greatly, in order that most of the input voltage E_1 will be developed across R_2.

The combined impedance of C_1, R_1, R_2 and C_o in parallel will decrease as frequency increases. Since the tube is of the pentode type, its a.c. plate resistance r will be many times higher than the combined impedance of its load at any frequency, and we can consider this circuit as equivalent to a constant-current generator. This means that with the same current flowing through lower and lower values of combined load impedance, less and less output voltage will be developed across R_2 as frequency increases.

Shunt Capacities. One way to reduce this attenuation of higher-frequency picture signals is to reduce the capacities of C_1 and C_o in Fig. *6*. It is apparent from Fig. *3* that these capacities are not actual condensers connected into the circuit. C_1 represents the plate-cathode capacity of the tube which is feeding a signal into the coupling network (VT_1 in Fig. *3*) plus stray capacities to the chassis which are inherent in resistor R_1, plus any capacity to chassis provided by the lead which connects the plate of the tube to resistor R_1 (this includes the capacity to chassis of the plate terminal of the tube socket). Capacity C_o includes the grid-cathode capacity of tube VT_2 plus the capacity to chassis inherent in R_2, the capacity between the grid lead and the chassis, the socket capacity and the capacity existing between the chassis and coupling condenser C_K. All of these stray capacities are of vital importance in the design of a v.f. amplifier having a wide passband.

Reducing the Shunt Capacities. Shunt capacities due to the grid and plate leads can be reduced by keeping the leads as short as possible and locating them as far away from the chassis as possible. The capacity between coupling condenser C_K and the chassis may be reduced by employing a compact, small-sized unit and mounting it away from the chassis. The use of wafer type tube sockets having small terminals and small prong grips which are well separated from each other will also reduce the values of C_1 and C_o. These mechanical and chassis layout problems are of great practical importance to the Teletrician, for improper replacement of connecting leads and improper positioning of replacement parts can seriously affect the performance of the v.f. amplifier in a television receiver.

Tube Capacities Should Be Low. The tubes used in v.f. amplifier stages must have low inter-electrode capacities. The capacity which VT_2 places across R_2 is not merely the grid-cathode capacity of this tube, but also an additional capacity which is occasionally referred to as the *Miller effect*. This effect exists because the a.c. plate voltage of tube VT_2 is fed back to the input of VT_2 through the grid-plate capacity in such a way as to increase the input capacity. Actually, the added capacity is equal to the grid-plate capacity plus a value equal to the grid-plate capacity multiplied by the actual signal gain of the stage. The use of pentode tubes in v.f. amplifier stages naturally reduces the grid-plate capacity, but if the gain of a stage is fairly high, this added capacity may have an appreciable value.

Even after the shunt capacities C_1 and C_o have been reduced to their lowest possible values, they may still be too large to make possible the desired uniform response over a wide frequency range. In this case, the next step is usually a reduction in the ohmic value of R_1 (for amplification at the higher picture frequencies, the ohmic value of R_2 is of little importance). Lowering the resistance of plate load resistor R_1 makes the shunt reactance of C_1 and that of C_o less effective, thereby *extending the upper frequency limit,* but at the same time this procedure *lowers the gain* of the amplifier at all frequencies.

Effect of Reducing Plate Load Resistance. The effect of a reduction in plate resistance can best be visualized by considering the simplified circuit in Fig. *5A*. In this circuit, condenser C replaces capacities C_1 and C_o of Fig. *6*; since R_2 is unimportant at high frequencies, it is neglected in Fig. *5A*. By using a value of about 50,000 ohms for R_1, it is possible to secure a flat response up to about 100 kc. in the average v.f. amplifier, but the gain will gradually drop for frequencies above this value, and will be down considerably at 4,000 kc. (4 mc.). Reducing R_1 below 50,000 ohms improves the flatness of the response characteristic, as indicated by the curves for 10,000, 5,000 and 1,000-ohm values of R_1 in Fig. 7. Observe, however, that each reduction in the value of R_1 reduces the gain per stage.

Gain Computations. The value of the combined shunt capacity affects the choice of a plate load resistance value. Here is an interesting fact which is worth keeping in mind: If

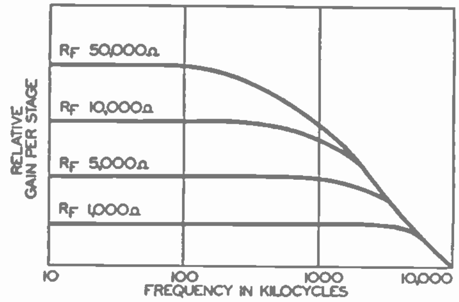


FIG. 7. These curves show that a reduction in the plate load resistance of an r-c coupled v.f. stage improves frequency response at a sacrifice in gain.

the ohmic value of the plate load resistor R_1 in Fig. *3* is chosen to be equal to the reactance of the combined shunt capacity at the highest frequency which is to be passed, a reasonably flat frequency response up to this frequency will be obtained, and the gain at this highest frequency will be down only to 70% of the gain at the medium video frequencies.

An example will show how the load resistance can be computed for this condition. A typical value for the combined shunt capacity in a practical v.f. amplifier circuit is 25 mmfd. For this example, let us say that the highest frequency we wish to pass is 3.5 mc. The reactance of the combined shunt capacity at this frequency will be: $X_C = 1 \div 2\pi fC$, where

X_C is in ohms, f is in megacycles and C is in microfarads. In this case, then $X_C = 1 \div 6.28 \times 3.5 \times .000025$ or 1,820 ohms. The use of a plate load resistance as low as 1,820 ohms naturally results in low gain. Since pentode tubes are invariably used in v.f. amplifier stages, and since these tubes can be considered as constant-current generators, we can readily determine the true gain per stage by multiplying the transconductance in mi-

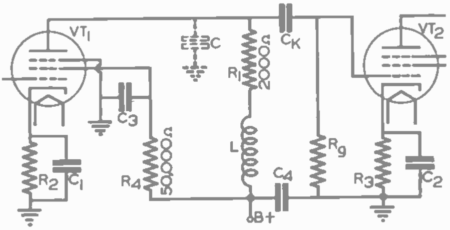


FIG. 8. Coil *L* in this r-c coupled v.f. amplifier circuit provides shunt compensation to offset attenuation of high picture frequencies by *C*.

cromhos by the load resistance in megohms. If a type 1851 tube having a transconductance of 9,000 micromhos is used with a 1,820-ohm load, the gain will be $9{,}000 \times 1{,}820 \div 1{,}000{,}000$ (we divide by 1,000,000 in order to change ohms to megohms). This gives us a value of about 16.4 for the gain per stage, if the response is to be fairly flat up to 3.5 mc.

The foregoing discussion shows that even lower gain per stage will be secured if the response is made flat up to 4 mc. Furthermore, if two identical stages are used, the response at the maximum frequency being passed will be down to 50% at the output of the v.f. amplifier; if there are three identical stages; the response at the highest frequency will be down even more to about 35%.

Shunt Compensation. One way to compensate for the gradual drop in response at higher frequencies is to insert an inductance L in series with the plate load resistor in the manner shown in Fig. *8*. Since this coil shunts the undesired capacity C, it is sometimes referred to as a shunt compensator or shunt connection. The parallel-resonant circuit in Fig. *8* is completed by by-pass condenser C_4, which is in effect a short circuit at the high picture frequencies.

By making parallel-resonant circuit L-C in Fig. *8* resonate at or above the highest picture frequency to be passed, the net plate load impedance is increased at the higher frequencies, thereby offsetting the drop in gain at these frequencies. At the same time, the introduction of L in this manner will reduce the amount of phase delay. The effects of various values of L upon frequency response and phase delay are shown graphically in Fig. *9*, where curves L_0 correspond to zero inductance (no coil in the circuit), curves L_1 are for a small value of inductance, and curves L_2 are for a large value of inductance.

By choosing a value of L which will give resonance at the highest frequency to be passed, the coil will be adding reactance in series with R_1 long before we reach this maximum frequency. In this way a compensating coil increases the load impedance gradually as we approach the maximum frequencies. This increase in load impedance gives a corresponding increase in the gain per stage. As resonance is approached, the shunt capacity acts with coil L to give a parallel-resonant circuit having a high impedance; this increases the load impedance by the Q factor of the circuit. Since R_1 is a large load (has an appreciable ohmic value), the Q factor is low and sharp resonance is not obtained. A larger value of L increases the Q factor, and consequently makes resonance much sharper, as indicated by frequency response curve L_2 in Fig. *9*.

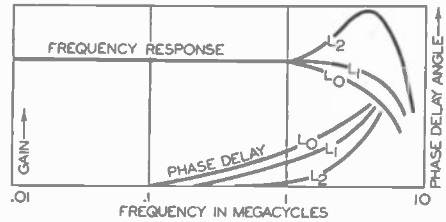


FIG. 9. Effect of inductance *L* upon phase delay and frequency response in the shunt-compensated v.f. amplifier circuit of Fig. *8*.

The introduction of inductance L in Fig. *8* not only gives *flatter frequency response*, but also serves to nullify partially the shunt capacity C, *thereby lessening the amount of phase delay*. Figure *9* shows that this delay is least for the largest value of inductance. Too great a value of L, however, will reduce the phase delay too much, making it impossible to secure a constant time delay for all frequencies. By choosing a value for coil L which will give resonance at a frequency slightly higher than the maximum picture frequency to be reproduced, and by using the proper ohmic value for load resistor R_1, the desired flat frequency response along with essentially constant time delay for all frequencies can be obtained without too great a sacrifice in total gain.

Series Compensation. In the equivalent circuit of Fig. *6* we divided the undesired shunt capacity into two parts, the capacity C_1 at the input of the coupling network and the capacity C_o at the output of the coupling network. In a practical circuit C_o is considerably larger than C_1, for C_o is increased due to the Miller effect. By adding coil L in the manner shown in Fig. *10*, to give what is known as a series compensating circuit, it is possible to isolate C_o from C_1 in an actual circuit. This permits making the ohmic value of R_1 larger, thereby giving more gain per stage. With this arrangement, any signal attenuation due to C_1 can be compensated for during design of the stage by making C_o either larger or smaller according to circuit requirements.

First let us consider Fig. *10* under the condition where L is shorted and C_o is omitted. Now, since the shunt reactance of C_1 alone is considerably higher than the combined reactance of C_1 plus C_o, it is possible to use a higher ohmic value for R_1 in order to secure higher gain with the same limited pass-band, or use the same ohmic value for R_1 and secure a wider pass-band.

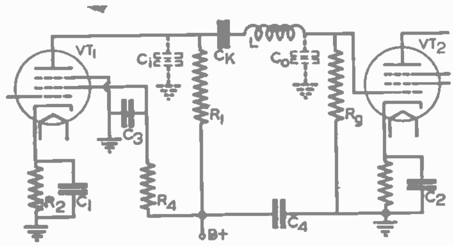


FIG. 10. Coil *L* provides series compensation at high picture frequencies in this r-c coupled v.f. amplifier circuit.

C_1 will naturally have an attenuating effect upon the voltage across R_1 at the higher frequencies, but when we restore L and C_o to the circuit we secure a series-resonant circuit which has voltage-boosting ability for a considerable range around its resonant frequency. By properly choosing the value of L, we can secure resonance at the highest picture frequency and thus compensate for attenuation at these frequencies. At resonance, the voltage across C_o (or across R_g) will be greater than the voltage across R_1 by the Q factor of series-resonant circuit L-C_o.

The presence of C_o in Fig. *10* increases the phase delay of the circuit at frequencies below the resonant frequency of L and C_o, but experience has shown that this increase in phase delay is not serious. In practice, C_o

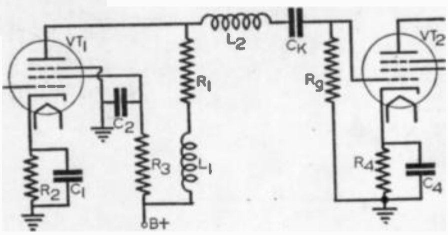


FIG. 11. Coils L_1 and L_2 here provide a combination of series and shunt compensation at high picture frequencies. Coupling condenser C_K is located on the grid side of L_2, for in this position the capacity between the outer plates of this condenser and the chassis serves to increase the value of the output shunt capacity.

should have about twice the capacity of C_i; if chassis and circuit conditions are such that more capacity is needed at C_o to give this relationship, C_K can be placed on the grid side of L so that its capacity to the chassis will in effect be across C_o. No additional capacity should be added to the circuit if the gain is to be maintained at its original level, for gain is dependent upon the combined capacities of C_i and C_o in a series compensating circuit like this.

Combined Shunt and Series Compensation. If a coil is placed in series with R_1 in Fig. *10*, the shunting effects of C_i can be minimized. The inductance of series compensating coil L can then be reduced, so that resonance occurs at a higher frequency. The circuit for this arrangement is shown in Fig. *11;* it gives flatter response and higher gain along with more uniform time delay. In this combined series and shunt compensating circuit, L_1 minimizes the effects of the combined input shunt capacities and L_2 minimizes the effects of the combined output shunt capacities.

Low-Frequency Amplification. It is because picture signals pass through an r-c coupled v.f. amplifier in their a.c. form that low-frequency transfer problems arise at each r-c coupling network.

In a typical r-c circuit like that shown in Fig. *8* or in Fig. *10*, the coupling condenser C_K is the chief cause of trouble. In the r-c audio amplifier circuit of a sound receiver it was sufficient to make the reactance of the coupling condenser negligible with respect to the grid-cathode resistance following the condenser, but in a television system the problem of low-frequency amplification is not so easily dismissed.

In discussing low-frequency amplification in a v.f. amplifier, we can concentrate upon the frequencies below the line frequency of 13,230 cycles. Proper transfer of these low frequencies from stage to stage in the v.f. amplifier insures correct contrast and correct background brilliancy in the reproduced image. Let us see why inability to transfer low frequencies properly has such a pronounced effect upon background brilliancy.

Square-Top Waves. Imagine a scene having the upper half white and the lower half black, as shown in Fig. *12A*. If synchronizing impulses are neglected, the wave form of the video signal at the t.c.r. tube should be as shown in Fig. *12B* in order to reproduce this scene. This *square-top wave* has a time duration equal to one vertical sweep of the scene (1/60 second) and hence the video signal for this scene has a fundamental frequency of 60 cycles. We can neglect synchronizing impulses in this discussion because they introduce frequency components higher than 13,230 cycles.

as shown in Fig. *12D*. Each change in the polarity of the charging voltage results in an initial maximum output voltage which gradually drops. This occurs twice each cycle. As a result, our signal voltage still has the same frequency at the output of this r-c coupling unit, but no longer has the square top.

Background Distortion. When the signal shown in Fig. *12D* is applied to the grid of a t.c.r. tube, the highest positive voltage will produce a pure white background, the zero voltage

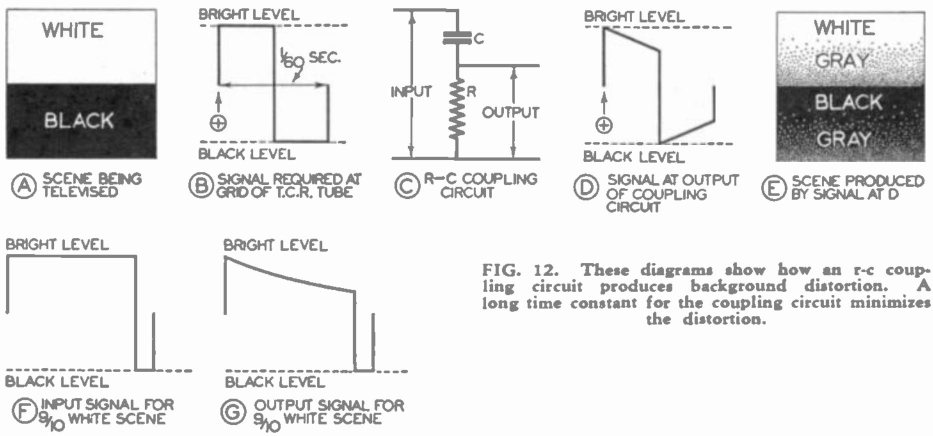


FIG. 12. These diagrams show how an r-c coupling circuit produces background distortion. A long time constant for the coupling circuit minimizes the distortion.

Let us see what effect the grid coupling elements shown in Fig. *12C* have upon this square-top signal. The instant the signal swings in a positive direction, charging current through the condenser reaches its maximum positive value, for at this time the condenser has no positive charge (no back e.m.f.). The voltage across *R* is therefore a maximum at this instant. As the condenser becomes charged, the charging current gradually reduces, and consequently the voltage across resistor *R* slowly decreases in a corresponding manner,

(corresponding to the maximum negative swing in the signal of Fig. *12B*) will give a pure black background, and intermediate voltages will give various shades of gray. As a result, this signal gives us a reproduced image which is white at the top but gradually turns gray as we approach the middle of the screen. There the picture suddenly turns black, corresponding to the change from white to black in the original scene, but changes from black to gray gradually as we move down to the bottom of the scene. Condenser *C* and resistor

R in Fig. *12C* together destroy the square top of the wave, thereby distorting our pure white and pure black backgrounds.

It is perfectly possible to have the upper nine-tenths of the scene white and the remaining one-tenth black, giving a video signal like that shown in Fig. *12F*. If this signal were passed through the r-c circuit shown in Fig. *12C*, the output signal would take the form shown in Fig. *12G*, and again we would have severe darkening of an area which should be white.

Remedies for Background Distortion. The solution to this difficulty involves the use of r-c circuits having a long time constant, so the condenser will discharge very slowly and lessen the amount of slope in the flat top of the wave; this time constant may be as long as .1 second. Of course, a d.c. amplifier would eliminate this difficulty entirely, but it has certain practical drawbacks which prevent its widespread use in v.f. amplifiers.

In addition to distorting the background, the r-c circuit in Fig. *12C* introduces a phase delay which serves to shift the background to an improper position. Some engineers consider this phase delay problem at low frequencies to be even more serious than improper background brightness.

The use of an r-c circuit with a long time constant will minimize background distortion; either *R* or *C* in Fig. *12C* can be made large, for it is the product of their values which determines the time constant. We have this additional requirement, that the capacity of *C* must be large in order to prevent serious phase delay. Making the capacity of condenser *C* as large as possible gives the required long time constant and at the same time keeps phase delay at a low value. In other words, making the reactance of *C* at low frequencies small with respect to the resistance of *R* will accomplish the desired results.

Frequency Response Requirements. Even though a coupling circuit passes pure sine wave signals down to 60 cycles per second without appreciable attenuation, we cannot assume that it will do the same for a 60-cycle square-top wave. Actually, a coupling circuit must have good frequency response down to at least 10 cycles in order for it to pass a 60-cycle square-top wave satisfactorily. Low-frequency compensation is essential in a v.f. amplifier stage in order to give this uniform response down to 10 cycles along with negligible phase delay. With proper circuit design and proper compensation, background distortion can be kept at a minimum.

Low-Frequency Compensation. From what has just been said, it would appear that the solution to the low-frequency problem in v.f. amplifiers involves making coupling capacity C_K (Fig. *10*) high in capacity, and making grid resistor R_g correspondingly high in ohmic value in order to secure a long time constant. There is, however, a practical limit to the amount which we can increase the capacity of C_K, for a condenser having a high capacity along with negligible leakage is quite bulky. (Leakage must be kept low in this condenser, for any leakage is bound to vary with voltage, thereby affecting the C bias on the following tube.) A bulky condenser cannot be used, for it will have appreciable capacity to the chassis, and the response at the high frequencies will suffer. Furthermore, we cannot make resistor R_g too large, for then it would no longer neutralize the effects of variations in the grid-cathode input resistance of the following tube.

We have the additional consideration that a long time constant for C_K and R_g would tend to maintain the grid of the following tube at a definite voltage, so that any feed-back voltages in this tube would have time to cause appreciable regeneration at low frequencies. This would be evident as intermittent blocking of the circuit (the identical phenomenon in sound receivers is known as motorboating). For these reasons, it is good design practice to employ an r-c circuit having a reasonably short time constant, about .01 second, and use a compensating circuit to offset the resulting poor response at low picture frequencies.

A widely used circuit for providing low-frequency compensation is shown in Fig. *13*. The insertion of R_F and C_F not only compensates for inadequate response at low frequencies, but also acts as a signal filter which prevents motorboating, and as a ripple filter which prevents power pack ripple voltages from entering the signal circuits.

The time constant of R_F and C_F is made at least as long as the time constant for C_K and R_g, and the value of R_F is so chosen that its resistance is greater than the reactance of C_F at the lowest frequencies to be passed. This makes R_F act to increase the plate load impedance at the very low frequencies, thereby boosting the gain of the stage. The addition of resistance to the plate load or to any other element in the circuit also serves to reduce the phase angle between the input and output voltages for the coupling network at low frequencies, thereby making time delay more uniform for all the lower frequencies. R_F would have to be infinitely large in order to give perfect compensation, but supply voltage limitations prevent any approach to this condition. Fortunately, such extreme compensation is not actually necessary.

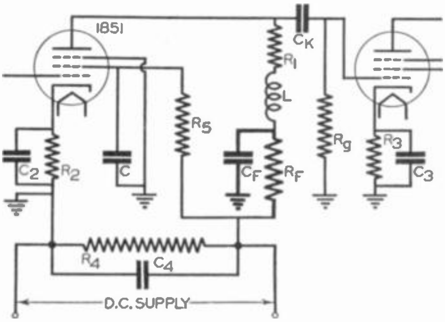


FIG. 13. Parts R_F and C_F in this v.f. amplifier circuit provide low-frequency compensation. Practical part values for an actual circuit are: R_1 = 2,000 ohms: R_F = 2,500 ohms; C_F = 1.5 mfd.; C_K = .25 mfd.; C_3 = 25 mfd.; R_3 = 150 ohms; L = about 100 microhenrys; R_g = .25 megohm.

Compensation by Degeneration. Referring to the cathode resistor and its by-pass condenser in Fig. *13*, we would normally expect that the reactance of C_2 would be low in comparison to the resistance of R_2. At very low frequencies, however, any practical value for condenser C_2 will have such a high reactance that its effect is negligible, and R_2 will act alone as the automatic C bias source. As a result, there will be out-of-phase voltages in the grid circuit, and these will cause degeneration.

In a video frequency amplifier

stage, degeneration of this nature lowers and at the same time flattens out the response curve at low frequencies, but this effect is by no means serious since any reduction in gain can easily be compensated for by increasing the value of compensating resistor R_F. On the other hand, a certain amount of degeneration is desirable at low frequencies, for it has the effect of increasing the a.c. plate resistance of the tube, and this in turn reduces the amount of phase delay.

By-pass and Filter Condensers. Condensers C, C_2, C_F, C_3 and C_4 in the v.f. amplifier stage of Fig. *13* all should have large capacities, and all except C_2 and C_3 must also have high voltage ratings. From the standpoint of economy, these condensers should all be of the dry electrolytic type. Electrolytic condensers, however, have an appreciable inductive reactance at high picture frequencies. This inductive reactance offsets the capacitive reactance, impairing the by-passing action and allowing high-frequency signals to flow into undesired paths. A practical solution involves shunting each electrolytic condenser with a low-capacity paper or mica condenser of the non-inductive type; the capacity of this shunt condenser will usually be about .05 mfd.

Instead of using a paper and an electrolytic condenser across R_2 in Fig. *13*, a single low-capacity paper condenser in series with a resistor can be used with equal effectiveness; this arrangement, shown in Fig. *14*, will still allow desirable degeneration to exist at low frequencies. Resistor R can be as much as 1,000 times greater in ohmic value than R_2. Condenser C_2 is charged by the voltage across R_2, and the voltage developed across C_2 acts on the control grid of the tube. Since C_2 and R together have a long time constant, the voltage across C_2 is relatively steady at the higher video frequencies, and there is no degenerative feedback. At low video frequencies, condenser C_2 charges and discharges in accordance with variations in the picture signal voltage developed across R_2 by plate current. The resulting signal voltage across C_2 acts upon the control grid; since this voltage is out of phase with

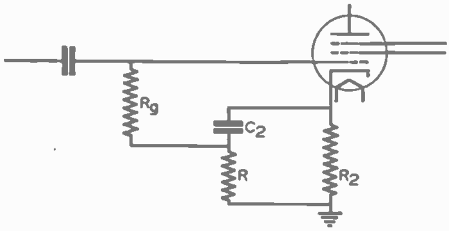


FIG. 14. Filter circuit sometimes used across the cathode resistor of a v.f. amplifier stage to provide a constant C bias voltage along with degeneration at low frequencies.

the incoming signal voltage, the desired degeneration is secured at low frequencies.

Number of V.F. Stages Required. As you already know, the grid of the t.c.r. tube must be fed with a video signal having a positive picture phase. The video detector can be arranged to provide a signal having either a positive or a negative picture phase. When the video detector provides a *positive* picture phase, *an even number of v.f. stages is required* (*either two or four*), for each stage reverses the phase of the signal 180°, changing it from negative to positive or vice versa. Two stages reverse the phase twice, restoring it to its original phase.

If the video detector provides a *negative* picture phase, *an odd number of v.f. stages must be used* (*either one, three or five*). When the a.g.c. section and the impulse separator section are to be connected to the video detector, the detector circuit must provide a signal having a negative picture phase; in this case the detector will be followed by one, three, or five v.f. amplifier stages. When phase-correcting stages are employed ahead of the a.g.c. section and ahead of the impulse separator, these sections may be connected to any point in the video detector or v.f. amplifier, and any type of video detector may be employed provided it is followed by the correct number of v.f. stages to give a positive picture phase at the t.c.r. tube.

Since the plate loads employed in v.f. amplifier stages have low ohmic values, the gain per stage is quite low. In order to secure maximum gain, tubes with high transconductance are required; the types 1851, 1852 and 1853 tubes used in the i.f. stages are also used for the v.f. stages, even though the variable mu features of these tubes are not needed.

D.C. Restoring Circuits

A.C. and D.C. Components. A v.f. amplifier employing r-c coupling between stages delivers a television signal in its a.c. form. For high image definition, it is considered a good practice to restore the d.c. component to this signal in a manner which will make the pedestals all line up again at a definite voltage level. Before considering the various methods employed for restoring the d.c. component, let us first review the differences which exist between the a.c. and d.c. forms of a television signal.

For simplicity, let us consider an imaginary scene which is divided horizontally into three different backgrounds, one white, one gray and one black. To reproduce each line in the white area, we will need a d.c. signal like that shown in Fig. *15A*; for a line in the gray area, the signal must be as shown in Fig. *15C*, and for a

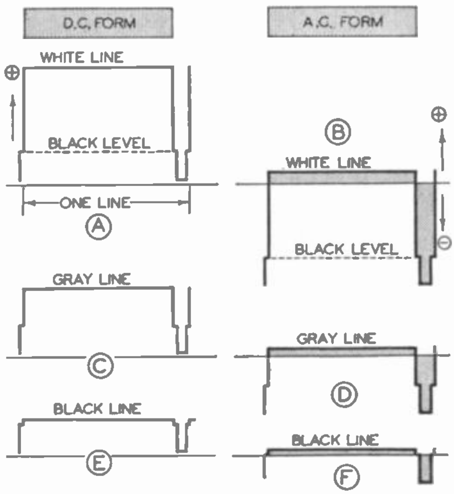


FIG. 15. Television signals in both their a.c. and d.c. forms for a white line, a gray line and a black line are shown here.

line in the black area, the signal must be as in Fig. *15E*. Notice that all three signals have a positive picture phase, just as is required at the input of the t.c.r. tube. Observe also that if these three signals (*A*, *C* and *E*) were placed side by side with their zero levels all on one line, the pedestals in all three signals will line up with each other. The television signals exist in this form at the output of any video detector which is connected to deliver a positive picture phase; these signals also exist at the output of a d.c. type of v.f. amplifier, and should exist at the grid of the t.c.r. tube if high image definition is to be secured.

Removing the D.C. Component. The use of capacity coupling between stages, such as the use of coupling condenser C_K in Fig. *13*, prevents transfer of a d.c. voltage from one stage to another, and consequently blocks out the d.c. component of each of these signals.

When the d.c. component is stripped from signal *A* in Fig. *15*, we have left only the a.c. component as shown at *B*. A fundamental characteristic of an a.c. signal is the fact that its average voltage over a period of time is zero. In other words, a d.c. voltmeter connected to the a.c. voltage source would read zero. This condition is present when the areas enclosed by the positive peaks are exactly equal to the areas enclosed by the negative peaks. Thus, the shaded area above the zero level in Fig. *15B* is equal to the shaded area below the zero level for each cycle.

Likewise, when the d.c. component is removed from the signal for one line of the gray background area in *C*, we get the a.c. signal at *D*. For the black background area we get the a.c. signal shown at *F*. Now imagine that these three a.c. signals (*B*, *D* and *F* in Fig. *15*) are alongside each other, with their zero lines all coinciding. We see that there is not much variation in the positive or upward swings of the signal, but that there is a great deal of variation in the negative swing. This variation throws the pedestals completely out of line with each other.

Why D.C. Restoration Is Needed. If the d.c. signals shown at *A*, *C* and *E* are applied to the grid of the t.c.r. tube in such a way that the pedestals line up with the cut-off bias for the tube (line up with point *a* on the E_g-B characteristic curve in Fig. *16*), impulses will always swing the spot into the blacker-than-black region, and picture signals will modulate the spot to the proper brilliancy.

On the other hand, if the a.c. signals shown at *B*, *D* and *F* in Fig. *15* are applied to a t.c.r. tube, with the zero-voltage level of the signal at cut-off, the impulses will swing the

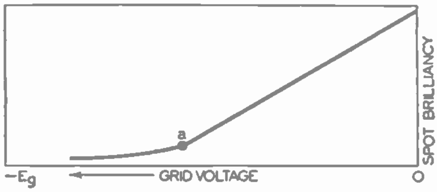


FIG. 16. Grid voltage-brilliancy characteristic curve for a t.c.r. tube. The grid voltage for brilliancy cut-off is at the sharpest bend in the curve (at *a*).

spot into the blacker-than-black region and the picture signals will drive the spot into the bright region. Now, however, there will be very little contrast between the picture signals for the black, gray and white areas. To be sure, there is some variation in the positive voltage for these different shades of lines, but this variation is quite small and is present in a dependable form only when there is very little variation in the shading along one line.

We therefore arrive at the conclusion that whenever the output of the v.f. amplifier is an a.c. signal, the d.c. component must be restored with pedestals lined up properly if high image definition is to be secured.

Why D.C. Restoration Is Possible. The fact that *the peak value of an* *impulse in an a.c. television signal is proportional to the brilliancy of the corresponding line* makes d.c. restoration possible. We will now consider typical d.c. retoring circuits which respond to these impulse peaks.

Simple D.C. Restoring Circuit. In studying signals *B*, *D* and *F* in Fig. *15*, we observed that the amplitude of the negative swing of the a.c. signal is proportional to line brilliancy; in other words, the greater the line brightness, the greater is the amplitude of the negative swing in the a.c. voltage. This characteristic of an a.c. television signal can be utilized to produce for the grid of the t.c.r. tube or for some other tube in the receiver a negative bias voltage which is proportional to line brightness. This bias voltage will automatically restore the d.c. component to the picture signal in the proper manner to line up the pedestals again.

A simple circuit which will accomplish this d.c. restoration is shown in Fig. *17*. The a.c. television signal voltage applied to points *a* and *b* acts through coupling condenser C_1 to develop across R_1 the desired a.c. signal voltage for application to the grid of the t.c.r. tube.

During the negative alternation of the a.c. picture signal (that which makes point *a* negative with respect to ground), the plate of diode *D* will be *positive* with respect to its cathode, and this tube will conduct current. Since the diode resistance when conductive is considerably lower than the ohmic value of R_1, we can consider the diode to be shorting out R_1 during the negative alternations. Current flowing through C_1 and the diode will charge C_1 to a voltage dependent upon the magnitude of the negative alternation, with polarity as indicated in Fig. *17*.

Observe that the positive terminal of C_1 is connected directly to the grid of the t.c.r. tube. Since R_1 is quite high in ohmic value, C_1 cannot discharge through it an appreciable amount during the positive alternation at *a*. The only other discharge path for C_1 is through *D*, but this is not conductive during a positive alternation. As a result, condenser

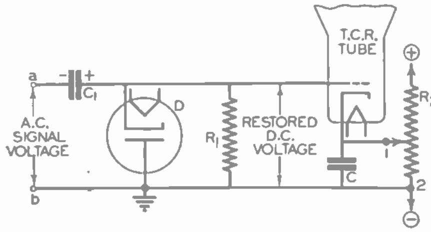


FIG. 17. Simple d.c. restoring circuit in which *D* is one half of a type 6H6 double-diode tube. In some television receivers a copper-oxide rectifier of small area may be used in place of a vacuum tube at *D*. Typical part values for this circuit are: C_1 = .03 mfd.; R_1 = 25,000 ohms.

C_1 supplies to the t.c.r. tube a positive bias which is proportional to line brilliancy. The brighter the line, the greater is the positive bias. This is exactly what we require, for the white-line a.c. signal at *B* in Fig. *15* requires a much higher positive d.c. bias for restoration to the d.c. signal at *A* than would be required to restore the black-line signal at *F* to that at *E*.

This bias voltage serves as the reference voltage for the a.c. signal. Positive alternations due to picture signals swing the t.c.r. tube grid in a positive direction from this bias, with the amount of swing at any instant being proportional to the brilliancy of the corresponding elemental area on the scene. Negative alternations due to impulses swing the grid in a negative direction from the bias value developed by this d.c. restoring circuit.

Each line of a picture produces a positive bias voltage which is proportional to its own line brilliancy. Since the d.c. component in the original television signal was also proportional to line brilliancy, this bias which we add to the picture signal restores the d.c. component in the correct manner to give alignment of pedestals.

The time constant selected for C_1-R_1 should be at least equal to the time duration of one line, but should not be greater than the time for one field. For normal scenes where line brilliancy varies from top to bottom of the scene, a time constant equal to the duration of from 10 to 20 lines is usually employed.

An adjustable negative bias for the t.c.r. tube is provided by potentiometer R_2 in Fig. *17*. The voltage between points *1* and *2* on this potentiometer is applied between the cathode of the t.c.r. tube and the chassis, and consequently it acts in series with the slowly varying positive restoring voltage developed across R_1. The potentiometer permits adjusting the bias in order to make the pedestals of the restored d.c. picture signal line up with the cut-off point on the E_g-B characteristic of the t.c.r. tube; since the most noticeable effect of this control is a change in background brilliancy, this control is known as the brilliancy control.

Use of Last V.F. Amplifier Stage as a D.C. Restorer. By using the circuit shown in Fig. *18*, it is possible to incorporate d.c. restoration in the last stage of v.f. amplification. This circuit also provides protection for the t.c.r. tube while the set warms up, for it applies a high negative bias to the grid of the t.c.r. tube during the interval when the filament of the tube in this last v.f. stage is heating up.

The video signal appearing across R_1 in its a.c. form is amplified in the usual manner by tube *VT*. The amplified a.c. signal voltage appears across plate load resistor R_2. Coils L_1 and L_2 provide shunt compensation which boosts the response at high

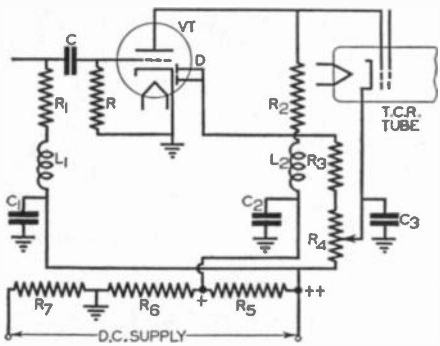


FIG. 18. V.F. amplifier output stage which also provides d.c. restoration and a high negative starting bias to protect the t.c.r. tube when the television receiver is first turned on.

picture frequencies. Since the signal across R_2 is applied directly to the grid of the t.c.r. tube, it must have a positive picture phase. The signal across R_1 must therefore have a negative picture phase as shown in Fig. *19*, since tube VT reverses the phase.

With a negative picture phase at the input of tube *VT* in Fig. *18*, the impulses will drive the control grid of this tube positive, causing electrons to flow through resistor *R* to ground. This electron flow makes the grid end of *R* negative with respect to ground, and consequently there is developed across *R* a d.c. voltage which is proportional to the amplitudes of the impulses and which is maintained very nearly at the peak value of the impulses because of the long time constant of C and R. The resistance of the R_1-L_1-R_5-R_6 path to ground is negligibly low with respect to the ohmic value of R from grid to ground, which is between .5 and 1 megohm. Since the negative bias developed in this manner is proportional to the amplitude of the positive or impulse peaks, it is proportional also to line brightness. This negative bias adds to the a.c. picture signal to give d.c. restoration with pedestals properly lined up.

Theoretically, the time constant for R-C should be equal to the time duration of one line. This time constant can, however, be made long enough to approximate and follow the average brightness for several lines. Doing this partially restores the low frequencies in the signal, thus providing additional low-frequency compensation.

Now let us see how this circuit provides starting protection for the t.c.r. tube. When the tube is warmed up (conducting) but no signal is entering the receiver, the grid of the t.c.r. tube is connected through R_2 (which has a low ohmic value) to a low-voltage positive terminal on the voltage divider, while the cathode of the t.c.r. tube is connected to either a higher or lower positive terminal than the grid, depending upon the position of the movable arm on brilliancy control potentiometer R_4. This potentiometer is a part of the voltage divider made up of R_4, R_3 and the combined diodes of tube VT. Since the cathode of tube VT is grounded, this voltage divider network is connected across R_5 and R_6 of the main power supply voltage divider.

When a signal voltage exists across R_2, its picture components drive the grid of the t.c.r. tube in a positive direction, providing the desired variations in spot brilliancy. This assumes, of course, that brilliancy control potentiometer R_4 has been adjusted to make the pedestals line up with the cut-off point on the E_g-B characteristic for the t.c.r. tube.

When a television receiver having the circuit of Fig. *18* is first turned on, the grid of the t.c.r. tube will be negative with respect to its cathode

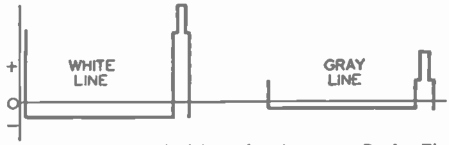


FIG. 19. The television signal across R_1 in Fig. *18* has the a.c. form shown here.

by a value equal to the voltage drop across R_5, regardless of the setting of R_4, for diodes D will not become conducting until the cathode of tube VT has warmed up. The power pack rectifier tube always heats up first under normal conditions. By the time the cathode of VT has heated up sufficiently to make diodes D conductive, the sweep circuit tubes will also be warmed up and the spot will be sweeping across the screen. An improper initial setting of R_4 thus cannot do any harm to the screen.

D.C. Amplification. Since the restored television signal is a d.c. signal, it is essential that there be a d.c. connection (no condensers in the path) from the d.c. restorer to the grid of the t.c.r. tube; this d.c. connection is present in both Fig. *17* and *18*. When d.c. amplification is used for the entire v.f. amplifier, this same d.c. path must exist from the video detector load to the grid of the t.c.r. tube.

A complete d.c. amplifier circuit is shown in Fig. *20*. The d.c. television signal developed across video detector load R_D-L_D is fed directly to the grid of *VT*, with resistor *R* furnishing the C bias for the tube. The grid of the t.c.r. tube is connected directly to the plate of *VT*, and the cathode of the t.c.r. tube is connected to point *2* on the plate load through

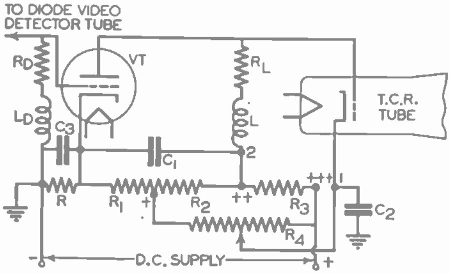


FIG. 20. D.C. amplifier stage directly connected to a t.c.r. tube.

potentiometer R_4, which serves as a brilliancy control. Potentiometer R_4 is connected to points on voltage divider R-R_1-R_2-R_3 which are respectively lower and higher in potential than point *2*, to permit either increasing or decreasing the normal negative bias developed by d.c. plate current flowing through R_L. Brilliancy control R_4 must be adjusted each time the contrast control setting is changed, in order to keep the pedestals lined up at the brilliancy cut-off point.

One drawback to the d.c. amplifier circuit shown in Fig. *20* is the fact that sometimes the receiver may be turned off with R_4 left in a position whereby the grid of the t.c.r. tube is driven positive with respect to its cathode when the set is next turned on, for the power pack may in some cases produce voltage across R_4 before tube *VT* warms up and produces a negative bias across R_L. If the sweep circuits are similarly slow in heating up, this positive bias may exist before the spot is swept across the screen, and burning of the screen will result.

A complete d.c. type of video amplifier circuit having provisions for preventing damage to the t.c.r. tube during the warming up period is shown in Fig. *21*. The grid of the t.c.r. tube is connected through R_4, L_3 and R_5 to a point on the voltage divider which is 296 volts positive with respect to ground. The cathode may be set to a value either higher or lower than 296 volts by adjusting brilliancy control potentiometer R_2, because R_2 is a part of an auxiliary voltage divider made up of diode D_2 and resistors R_1, R_2 and R_3. Diode D_2 heats up more slowly than the power pack rectifier tube when the receiver is turned on. The grid of the t.c.r. tube will then be connected to the +296 volt terminal, and the cathode will be connected through one side of R_2 and through R_3 to the +346 volt terminal (B++) on the power pack voltage divider, thereby making the grid 50 volts negative with respect to the cathode. By the time D_2 has warmed up, the sweep circuit tubes will also be warmed up and the spot will be in motion on the screen; under this condition an improper setting of R_2 can do no harm.

Slow-Heating Rectifier. A high-vacuum half-wave rectifier with a slow-heating filament has recently been developed for use in t.c.r. tube power packs. With quick-heating tubes in the sweep circuits, the sweep circuits will be in action before a spot appears on the screen, and there will be no danger of burning the fluorescent screen of the t.c.r. tube.

Contrast and Brilliancy Controls. Since the amplitude of the picture signal at the input of the t.c.r. tube may vary with the settings of the receiver controls, with the nature of the antenna installation and with the distance and power of the particular telecaster which is tuned in, it is essential that a television receiver be provided with a background brilliancy control and a contrast control so as to compensate for these changes in signal amplitude.

The operator who monitors the video portion of the television program at the studio of a television station must control the amplitude of the video component in such a way that the final picture at the receiver will represent true background conditions. This operator can compensate for scenes having insufficient or excessive general illumination. He does not usually attempt to compensate for the darkening of a scene which is intended to portray the approach of night, nor compensate for the passing of a cloud, for these changes are usually a desirable part of the scene being transmitted. Likewise, the turning off of a light in a "thriller" drama should not be compensated for by an increase in brilliancy, for this would spoil the desired effect.

Only desired changes in background brilliancy are transmitted by a television station. If the receiver is to reproduce these changes properly, the video frequency amplifier must have adequate low-frequency response.

A person viewing the image produced by a television receiver may desire to change the background brilliancy to suit his individual taste, even though this results in distortion. This is comparable to the situation where a person adjusts the tone control in a sound receiver to suit himself, even though the resulting program is distorted. Thus we have another reason for providing a background brilliancy control in a television receiver.

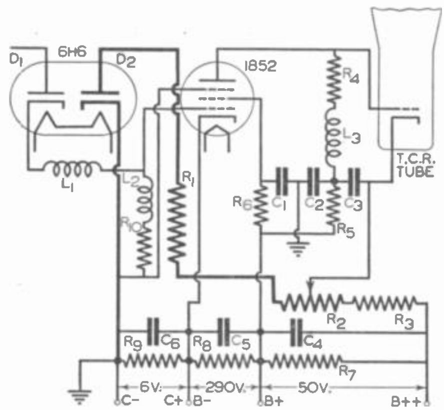


FIG. 21. Video detector circuit feeding into a v.f. amplifier stage which provides both d.c. amplification and starting protection for the t.c.r. tube. Typical part values for this circuit are: R_1 = 200,000 ohms; R_2 = 25,000 ohms; R_3 = 15,000 ohms. Potentiometer R_2 serves as the brilliancy control.

There is appreciable interlocking between the brilliancy and contrast controls, and consequently when one is adjusted, the other will usually require adjustment also in order to insure maximum contrast between elements along a line still keeping the pedestals lined up with the brilliancy cut-off point, so that the picture has maximum brilliancy and retraces do not show.

The video output circuits shown in Figs. *17* and *18* provide d.c. restoration and also add to the television signal a d.c. voltage which is due to the normal drop in the output plate load resistor. (The d.c. plate current for the output tube develops a negative bias across the plate load resistor, and the television signal causes the grid of the t.c.r. tube to swing in a positive direction from this bias value.)

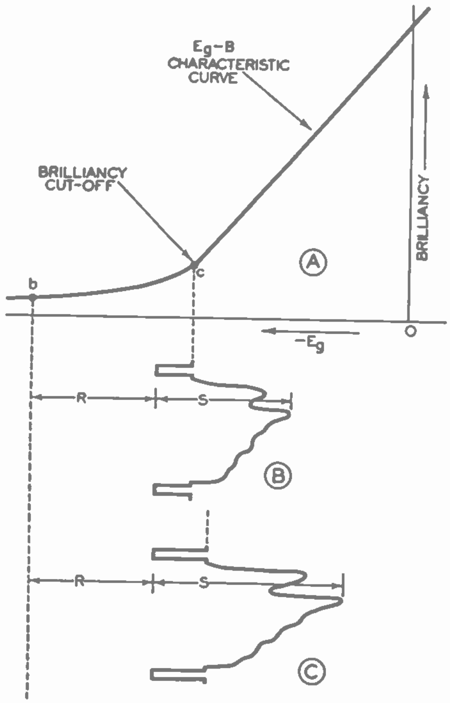


FIG. 22. The actions of the brilliancy and contrast controls in a television receiver are easily understood with the aid of this diagram.

The negative bias voltage developed across the plate load resistor of the video output tube will usually place the operating point of the t.c.r. tube beyond brilliancy cut-off, such as at point *b* in Fig. *22A*. In this case, therefore, the brilliancy control must add a positive voltage in order to make the pedestals line up at cut-off (at point *c*). The television signal under this condition will be as shown in Fig. *22B*, where the impulses swing the grid into the blacker-than-black region and video signals swing the grid into the gray and white regions.

If the television signal does not have sufficient swing or amplitude to give the desired contrast between elements, the gain of the video i.f. amplifier can be increased by changing the setting of the contrast control. This change in the contrast control setting will change the amplitude *S* without altering the value shown as *R* in Fig. *22B*. The result of increasing the gain or contrast is shown in Fig. *22C*; value *S* increases but value *R* remains the same. The pedestals no longer line up, so it is necessary to reduce the value of the positive voltage added by the brilliancy control in order to make them line up again. If this adjustment were not made, retraces at the end of each line would be partly visible, and the average brilliancy along a line would be higher than normal.

TEST QUESTIONS

Be sure to number your Answer Sheet with the *number* appearing on the front cover underneath the title of this text.

Place your Student Number on every Answer Sheet.

Send in your answers for this lesson immediately after you finish them. Doing this insures that the graded answers will reach you while the subject matter is still fresh in your mind, and you will get the greatest possible benefit from our speedy personal grading service. *Never hold up a set of lesson answers.*

1. Name three drawbacks to the use of d.c. amplifiers for video frequency amplification.
2. What effect do stray capacities and tube capacities have on the frequency response of an r-c coupled v.f. amplifier?
3. In what two units may angular movement of a vector be expressed?
4. If a 60-cycle signal and a 4-mc. signal both have the same phase delay angle, which will have the greater time delay?
5. Is constant time delay desirable in a v.f. amplifier?
6. At which frequencies (high or low) in the frequency range of an r-c coupled v.f. amplifier does the plate-to-grid coupling condenser affect phase delay and frequency response?
7. What effect does reduction in the ohmic value of the plate load resistor for a v.f. amplifier stage have upon gain and frequency response?
8. Why is a coil often introduced into the plate load of an r-c coupled v.f. amplifier stage?
9. If the video detector provides a signal having a negative picture phase, how many v.f. amplifier stages must be used ahead of the t.c.r. tube?
10. What characteristic of an a.c. television signal makes d.c. restoration possible?

Video Frequency Amplifiers and D. C. Restoring Circuits. No. 63 RH-1

1. A d.c. amplifier requires a costly heavy-duty power pack, is subject to low-frequency oscillation, and has excessively high heater-to-cathode voltages.

2. They limit the upper frequency range.

3. In degrees and in radians.

4. The 60-cycle signal.

5. Yes.

6. At low frequencies.

7. It lowers the gain and extends the upper frequency limit.

8. To give flatter frequency response and lessen the amount of phase delay.

9. An odd number; 1, 3 or 5 stages.

10. The fact that the peak value of an impulse in an a.c. television signal is proportional to the brilliancy of the corresponding line.

IMPULSE SEPARATORS, SWEEP CIRCUITS AND POWER SUPPLIES FOR TELEVISION RECEIVERS

64RH-2

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

LEARNING NEVER ENDS

"We cannot abandon our education at the school house door. We have to keep it up through life."

—CALVIN COOLIDGE.

NATIONAL RADIO INSTITUTE

WASHINGTON, D. C.

1942 Edition

A LESSON TEXT OF THE N. R. I. COURSE WHICH TRAINS YOU TO BECOME A

RADIOTRICIAN & TELETRICIAN

(REGISTERED U. S. PATENT OFFICE) (REGISTERED U. S. PATENT OFFICE)

NCP2M142

Printed in U. S. A.

Impulse Separators, Sweep Circuits and Power Supplies for Television Receivers

Introduction

THE circuits through which a television signal passes on its way from the receiving antenna through the preselector, the mixer-first detector, the video i.f. amplifier, the video detector, the v.f. amplifier and the d.c. restorer to the grid of the t.c.r. tube in a television receiver are fundamentally like those encountered in sound all-wave receivers. Of course, all these circuits in a television receiver are designed to have wide pass bands and to have acceptable phase delay, factors which are not so important in sound receivers.

Saw-Tooth Sweep Generators. The need for sweeping the electron beam in a t.c.r. tube both horizontally and vertically in synchronism with sweep circuits at the transmitter necessitates special television receiver circuits which are entirely absent in sound receivers. Thus, in a modern television receiver we must have additional local oscillators called *saw-tooth sweep generators*, which are designed to produce either a voltage or a current which varies uniformly from a maximum negative value to a maximum positive value with reference to ground, then rapidly returns from the high positive value to the high negative value.

With t.c.r. tubes employing electrostatic deflection of the electron beam, the sweep generators must provide large voltage variations. With t.c.r. tubes employing electromagnetic deflection, the sweep generators must provide large current variations. Simple saw-tooth sweep generator circuits are not capable of providing linear variations in voltage, and hence special circuits are required to correct the wave shape.

The saw-tooth voltage variations required in a sweep generator can be obtained by charging a condenser through a resistor, and discharging it through a vacuum tube or a gaseous type tube having a control grid. Under this condition, the tube can be made to act as an electronic switch which serves to start each charging and discharging action.

In some cases, a sweep generator circuit employing a condenser charged through a resistor will not oscillate by itself, making it necessary to provide impulses which will initiate the discharge at exactly the desired instant. Impulses suitable for this purpose are present right in the television signal; if sufficiently amplified before being applied to the grid of the sweep generator tube, these impulses can be made to control the sweep generator.

Why Self-Oscillating Circuits Are Desirable. One important reason for having a self-oscillating circuit ahead of the saw-tooth sweep generator in each sweep channel is *to help the receiver stay in synchronism with the transmitter during fading or atmospheric static.* A type of saw-tooth sweep generator which will oscillate by itself at approximately the correct rate can be used, or a separate oscillator stage known as a *blocking oscillator* can be placed ahead of an ordinary saw-tooth sweep generator (a charge-discharge circuit).

In either event, the synchronizing impulses are fed into the self-oscillating circuit to maintain the correct frequency under normal conditions. When synchronzing impulses disappear, the sweep circuits will lose their accuracy but will still keep the beam in motion, preventing damage to the fluorescent screen and preventing complete loss of the image. (The screen may be seriously burned if a bright spot is allowed to stay in one position for any length of time.) Furthermore, a self-excited oscillator is far less likely to be triggered off by static pulses, whereas a saw-tooth sweep generator which depends solely upon synchronizing impulses might be triggered off by a static pulse anywhere along a line.

Synchronizing impulses may vary greatly in intensity, depending upon the strength of the incoming television signal, causing a varying fly-back time if fed directly to the sweep generator. As you will later see, a blocking oscillator which is controlled by impulses *will always deliver constant-intensity pulses to the saw-tooth sweep generator, thereby insuring a constant fly-back time.*

Wave-Shape Correction. Practically all sweep generator circuits which depend upon the charging of a condenser through a resistor for the production of a saw-tooth wave form are essentially voltage-generating devices. These are therefore suitable for direct connection to the electrostatic deflecting plates of a t.c.r. tube provided the shape of the saw-tooth wave is corrected to give the desired linear sweep action. When electromagnetic deflection is employed, however, the sweep generator output voltage must be fed into a power stage which will change these voltage variations into current variations; again, a certain amount of wave shape correction is needed.

Sweep Channels. Since the beam in a t.c.r. tube must be simultaneously swept horizontally and vertically in order to reproduce the desired image, two separate sweep generator circuits are needed in a television receiver: 1. *A horizontal saw-tooth sweep generator;* 2. A vertical *saw-tooth sweep generator.* Each of these sweep generator circuits will contain a condenser charged through a resistor, along with a self-oscillating circuit which is either a part of or separate from the charge and discharge circuit. Furthermore, each of these self-oscillating circuits will be controlled by the synchronizing impulses associated with the television signal. A sweep generator with its associated circuits is called a *sweep channel;* we thus have a *horizontal sweep channel* and a *vertical sweep channel* in a television receiver.

Impulse Separation. As you know, the horizontal synchronizing impulses, the vertical synchronizing impulses and the video signals are all in the television signal which exists at the output of the video detector. Separation is therefore required before the synchronizing impulses can be fed into their respective channels. There are two essential steps in this separating process: 1. *The video signals must be clipped off (removed), leaving only the horizontal and vertical synchronizing impulses;* 2. *The horizontal synchronizing impulses must be separated from the vertical synchronizing impulses.*

Clipper. The circuit which *separates the video signal from the synchroniz-*

ing impulses is commonly referred to as the *clipper;* it is also called the *amplitude separator* or the *sync-video separator.* The process of clipping the video signals from the impulses is usually accomplished by sending the demodulated television signal (in its d.c. form, with pedestals lined up) through a diode, triode or pentode tube which is biased at a value which allows only the impulses to pass.

Frequency Separator. The circuit which separates the horizontal synchronizing impulses from the vertical synchronizing impulses is known as the *frequency separator* or *horizontal-vertical impulse separator.* Since the two types of impulses are considerably different in time duration, it is possible to separate them by employing suitable resistance - capacitance timing networks.

We will now consider in detail the various circuits employed in clippers, frequency separators, blocking oscillators, horizontal sweep generators, vertical sweep generators and wave shape correction circuits, along with connections between these various circuits and the television receiver.

Clipper Circuits

Clipper Requirements. The essential requirement for a television signal before it can be sent into the clipper (amplitude separator) for removal of the video signals is that *the pedestals must line up.* By considering typical television signals, we can readily see why this requirement is so important.

The television signal for successive lines which are respectively white, gray and black is shown in Fig. *1A* for the condition where the pedestals are all lined up at one level. The signal here has a negative picture phase, and is said to be in its d.c. form. This is the signal which is commonly fed into the clipper. (You will learn later that the input signal to the clipper could just as well have a positive picture phase provided the proper connections are made.)

When the d.c. form of television signal shown in Fig. *1A* is sent through a condenser, the d.c. component is removed; the result is the *a.c. form* shown in Fig. *1B.*

Diode, triode and pentode tubes all have an input voltage-output current characteristic similar to the *E-I* characteristic shown in Fig. *2.* This curve

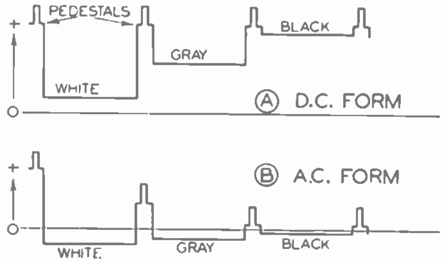


FIG. 1. Television signals in both their a.c. and d.c. forms for three successive lines which are white, gray and black respectively are shown here. Detail along each line is omitted for simplicity.

simply tells that the output or plate current will be essentially zero at a particular value of input voltage known as the cut-off voltage. Increasing the input voltage in a positive direction with respect to the cathode makes the output current *I* increase in a more or less uniform manner. In the case of a diode, cut-off occurs when the plate is slightly negative with respect to the cathode; as the plate voltage is increased in a positive direction (the plate is made positive), diode plate current increases linearly. In the case of a triode or pentode, current cut-off occurs at a definite negative value of grid voltage; increasing the grid voltage in a positive direction causes plate current to increase linearly.

If a diode, triode or pentode clipper tube is adjusted for current cut-off, the application of the d.c. television signal voltage in Fig. *1A* to the input of this tube would make the entire television signal appear in the output circuit. (The zero-voltage line in Fig. *1A* would in this case be at the cut-off voltage, and all parts of the television signal would swing the applied voltage more positive.) If, however, the tube bias was increased to a higher negative value *which made the pedestals in the d.c. signal all line up with cut-off*, as shown at *A* in Fig. *2*, only the impulses would produce output current, and the output signal in this case would be as shown at *B* in Fig. *2*. If this current is allowed to flow through a resistor, a corresponding impulse signal voltage will be developed across the resistor.

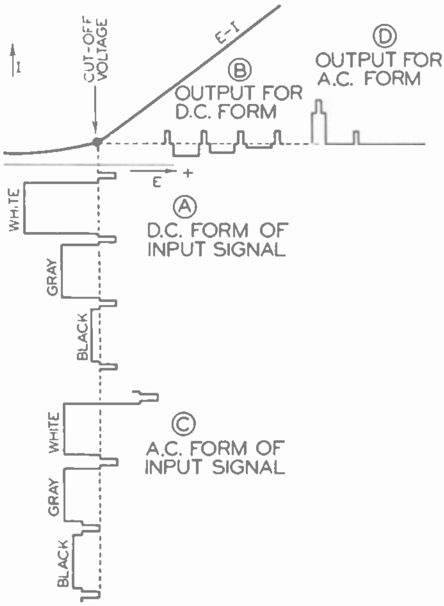


FIG. 2. These diagrams show that pedestals must be lined up in the television signal which is fed into the clipper tube, if proper separation of impulses from video signals is to be secured.

When the a.c. form of television signal shown in Fig. *1B* is applied to a clipper tube, however, it is no longer possible to adjust the negative bias to a point where all video signals will be rejected and all impulses will be passed. If, for example, we adjust the bias so that the pedestals for a gray line will line up with cut-off, as shown at *C* in Fig. *2*, the impulse for the gray line will be passed satisfactorily, but the black-line impulse will be rejected and a part of the video signal will pass along with the white-line impulse.

Reference to Fig. *3* will show that successful clipping action can be secured (impulses can be separated from video components) when the input signal to the clipper tube has either a positive or a negative picture phase. For simplicity, we will assume that both signals being considered are variations in positive potentials with respect to ground, as indicated at *A* and *C* in Fig. *3*.

Diode Clipper Circuit for Negative Picture Phase. If the signal in Fig. *3A*, having a negative picture phase, is applied to the diode clipper stage shown in Fig. *3B*, terminal *a* will always be positive with respect to terminal *g*. Under this condition, electrons will flow through the circuit in the indicated direction, developing across *R* a voltage having exactly the same wave shape as the input signal. Now suppose that we introduce at point *x* a d.c. voltage which makes point *g* negative with respect to ground. This voltage will cancel a part of the signal voltage. If the negative bias voltage which we insert has such a value that only the impulses will make the diode plate positive and cause current flow, we can secure the desired separation of impulses from video signals. Again it is obvious that pedestals must be lined up in the input signal if separation is to be completely effective.

Diode Clipper Circuit for Positive Picture Phase. Now consider the signal shown in Fig. *3C*, having a positive picture phase. When this is applied to terminals *a* and *g* in Fig. *3D*, point *a* will always be positive with respect to point *g*. This is the same as saying that point *g* will always be negative with respect to point *a*. Under this condition, the diode plate is negative with respect to the cathode, and no electrons flow. Impulses in the incoming signal will, however, make the plate *less negative* with respect to cathode than will any other part of the signal. If we introduce a d.c. voltage source at point *x* with its positive terminal connected to ground, we can adjust this bias voltage value until the impulses will actually drive the plate of the diode positive with respect to the cathode. Again we have the desired condition where only the impulses are effective in causing current flow and developing a voltage across *R*.

We thus arrive at the conclusion that the signal fed to the clipper stage may have either a negative or positive picture phase provided that the pedestals are lined up and the proper clipper circuit is used. When the signal is in its a.c. form, the pedestals must be lined up by using a d.c. restorer. You will learn later that clipping and d.c. restoration may take place simultaneously in a vacuum tube circuit.

As a general rule, *an a.c. signal having a negative picture phase is fed into the clipper*. The d.c. component is first restored, and the video signal is then clipped from the impulses. Sometimes an a.c. signal with a positive picture phase will be removed from the v.f. amplifier, but this will generally be reversed in phase by an r-c coupled amplifier stage prior to d.c. restoration and clipping.

Triode Clipper Circuit for Negative Picture Phase. A clipper circuit employing a biased triode tube to pass

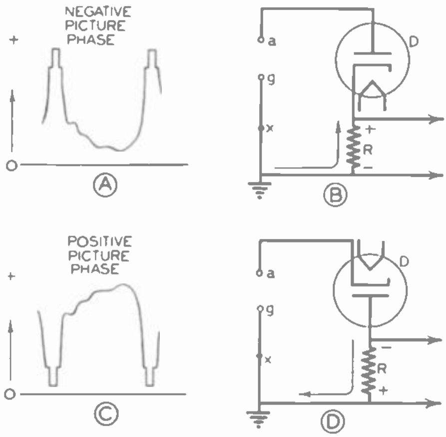


FIG. 3. Although a clipper stage can be designed to act on television signals with either a positive or negative picture phase, it is usually designed for a negative picture phase.

impulses while rejecting the video signal is shown in Fig. *4A*. along with the output circuit of a diode video detector.

First of all, observe that the video detector develops across load resistor R_D a d.c. picture signal having a *negative picture phase* (only positive swings of each i.f. cycle send current through the diode). This means that point *2* will always be positive with respect to point *1*. The grid of the clipper tube is connected directly to point *2*, while the cathode is connected through the moving arm of potentiometer R_3 to a point which is positive with respect to ground. This places an adjustable negative bias in series with the television signal voltage existing between points *1* and *2*, permitting adjustment of the circuit so only impulses will produce plate current flow through R_1 in the clipper stage.

Under these conditions, the grid of the clipper tube is always negative with respect to its cathode, and does not produce undesirable grid current

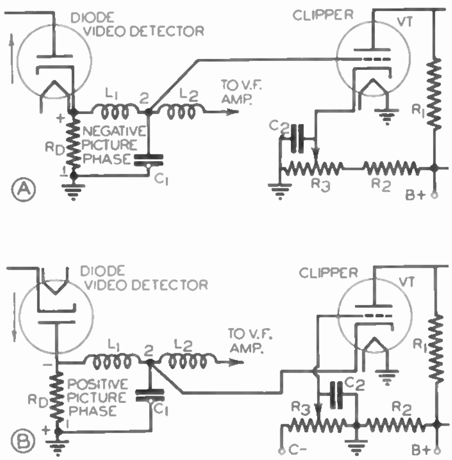


FIG. 4. Simple theoretical triode clipper circuits which are connected directly to the video detector.

flow through R_D. With the grid of clipper tube connected to point *2* rather than to the cathode of the video detector, the input capacity of clipper tube *VT* is in shunt with C_1, where additional capacity can be tolerated.

Triode Clipper Circuit for Positive Picture Phase. When the demodulated television signal at the output of the video detector has a *positive picture phase*, we can either use a d.c. amplifier stage to reverse this phase, then feed the signal into a triode clipper circuit like that shown in Fig. *4A*, or we can use the triode clipper connection shown in Fig. *4B*. In this latter circuit the signal voltage developed across R_D has a ***positive picture phase,*** making point *2* always ***negative*** with respect to point *1*. Under this condition, impulses will make point *2* more negative with respect to point *1* than will video signals. The cathode of the clipper tube is connected directly to point *2*, and the grid of this tube is connected to point *1* through potentiometer R_3, which provides an adjustable negative bias for the clipper tube. With no bias voltage, the grid of the clipper tube will be positive at all times, with impulses making the grid more positive than do video signals. The insertion of a negative bias voltage of the proper value permits lining up of the pedestals in the incoming signal with the plate current cut-off point, so that video signals will swing the grid more negative than cut-off and impulses will swing the grid more positive, allowing plate current to flow.

One drawback to the circuit in Fig. *4B* is that during impulses, the plate current of clipper tube *VT* will flow through R_D in a direction opposite to that taken by the diode plate current, thereby reducing the strength of impulses. The use of a clipper tube having a low plate current rating will minimize this undesirable effect.

Another drawback is that the grid-cathode and cathode-filament capacities of the clipper tube, shunted across C_1, may be excessively high and cause attenuation of high-frequency video signals.

Clipper Circuit Employing a Diode. Although the triode clipper circuits shown in Fig. *4* are theoretically correct, they are not satisfactory from a practical viewpoint for the simple reason that impulses are clipped while they are still at a low level. It is usually necessary to provide amplification ahead of the clipper stage.

A circuit in which the television signal for the biased diode clipper circuit is taken from the output of the first v.f. amplifier stage (a d.c. type amplifier stage) is shown in Fig. *5*. The video detector produces across R_L a signal voltage having a positive picture phase. This voltage acts on the grid of the first v.f. amplifier tube through a π-type low-pass filter made up of choke coil L and the tube interelectrode capacities. A signal voltage having a *negative picture phase* is developed across R and L_1, with point *1* always negative with respect to point *2*.

By inserting in the diode clipper circuit of Fig. *5* an adjustable d.c. voltage which makes point *2* positive with respect to the cathode of the diode end, we can secure a bias value which will allow only impulses to make the plate of D positive with respect to its cathode. Potentiometer R_2, connected into a voltage divider network between ground and B+, provides this adjustable positive voltage. The resulting electron flow through R_4 during impulses will develop across this resistor the desired impulse voltage, having the polarity indicated.

Coil L_1 in Fig. *5* compensates for the plate-cathode capacity of diode D and for other shunting capacities which might otherwise attenuate high-frequency components of video signals.

Typical Practical Clipper Circuits. Circuit connections for the clipper stage are greatly simplified if it is fed with the television signal *in its a.c. form, with a negative picture phase.* Under this condition, however, the additional function of *d.c. restoration* must be incorporated in the clipper.

Another requirement for successful clipping is that the amplitude of the impulses be sufficiently large to permit "clear-cut" clipping action. This means that if an a.c. television signal is removed at or near the video detector for clipping purposes, amplification as well as d.c. restoration must precede the clipper stage. In all cases, compensation should be provided somewhere in the v.f. amplifier for the input capacity of the clipper section.

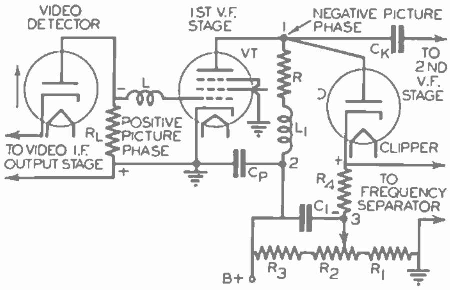


FIG. 5. Theoretical clipper circuit employing a diode vacuum tube as clipper and designed for use with a signal having a negative picture phase at the clipper input.

Practical Clipper Circuit Connecting to V.F. Output Stage. As you know, the plate of the v.f. amplifier tube preceding the v.f. output stage will always have a negative picture phase, as also will the grid of the v.f. output tube, for this output stage must provide a positive picture phase for the t.c.r. tube.

The practical clipper circuit shown in Fig. *6*, requiring a negative picture phase, may therefore be connected directly ahead of the v.f. output stage. Here the television signal is in its a.c. form, and hence the pedestals must be lined up by a *d.c. restorer* prior to clipping. Condenser C_1 blocks the d.c. plate supply voltage (or the d.c. grid bias voltage in the case of a grid connection).

A type 954 pentode tube is used in this circuit. The cathode is grounded, so that grid resistor R_g develops a negative bias voltage which is proportional to line brilliancy. C_1 together with R_g have a time constant equal to the duration of several lines, and hence this bias voltage changes in accordance with variations in the average brilliancy of several lines. This self-produced varying C bias makes the pedestals in the television signal

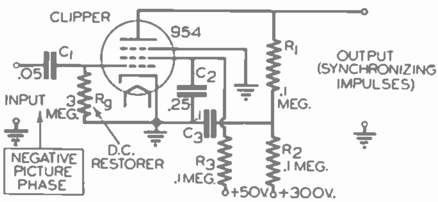


FIG. 6. Typical practical clipper circuit, designed to receive a high-level television signal in its a.c. form with a negative picture phase. This circuit is generally used when the clipper is connected just ahead of the v.f. output stage.

line up with the plate current cut-off point on the E_g-I_p characteristic curve of the tube at all times.* Under this condition only the synchronizing impulses can cause plate current to flow through R_1. These impulses develop across R_1 a voltage which counteracts the plate supply voltage and thus lowers the positive potential of the plate with respect to the chassis. This potential returns to normal at the end of each impulse.

Screen grid resistor R_3 is connected to a low-voltage supply terminal, in order to make the control grid of the tube draw current and develop a d.c. restoring voltage at reasonably low input signal levels.

Practical Clipper Circuit with One Stage of A.C. Amplification. When the television signal which is removed from the v.f. amplifier for clipping purposes has a positive picture phase, as would be the case for a connection to the plate circuit of the v.f. output stage, a clipper circuit like that shown in Fig. 7 is used.

The circuit employs a type 6F8G twin-triode tube, with section VT_1 serving as an a.c. amplifier and phase reverser, and section VT_2 providing the d.c. restoring and clipping actions. Condenser C_1 blocks the plate supply voltage of the output stage, so that only the a.c. components of the television signal produce a voltage across R_{g1}. Resistor R_1 prevents the clipper section from loading the plate circuit of the v.f. output stage. Cathode resistor R_C provides self-bias for the r-c coupled amplifier tube VT_1. No shunting capacity is required across this cathode resistor, since uniform response down to very low frequencies is not needed in a clipper section.

The television signal as developed across resistor R_2 is a pulsating d.c. voltage with a negative picture phase, but the pedestals are not lined up. Only the a.c. component of this signal is forwarded through C_2 to the grid and cathode of clipper tube VT_2. Observe that the cathode of VT_2 is

* Although this d.c. restoring action is similar to that used in the regular d.c. restorer for the video frequency amplifier, the d.c. restorer in the clipper circuit of Fig. 6 employs a much higher resistance so that the pedestals will line up with the plate current cut-off point. In the case of the conventional d.c. restorer used in the last v.f. amplifier stage or in the input circuit of the t.c.r. tube, the value of the grid resistor is much lower, somewhere between .5 and 1 megohm, so that impulse peaks line up at a level only slightly more negative than zero C bias.

grounded, and that grid resistor R_{g2} is quite high in ohmic value (3 megohms); this gives d.c. restoration and lines up the pedestals at the plate current cut-off point. Plate current thus flows through plate load resistor R_3 only during impulses. R_{g2} and C_2 together form a time delay circuit which

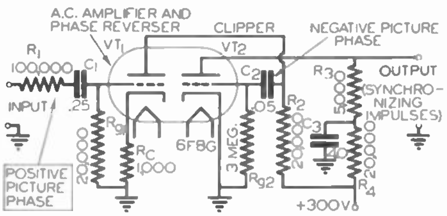


FIG. 7. Typical practical clipper circuit consisting of a combination a.c. amplifier, phase reverser, d.c. restorer and clipper. It is designed for use with a high-level a.c. signal having a positive picture phase, such as exists at the output of the last v.f. stage when normal d.c. restoration occurs directly ahead of the t.c.r. tube.

causes the d.c. bias on the clipper tube (the d.c. restoring voltage) to change gradually in accordance with variations in the average brilliancy for several lines.

Practical Clipper Circuit Which Connects to Video Detector. A clipper circuit designed for connection to amplification for impulses before they undergo d.c. restoration and clipping.

Section VT_1 and VT_2 of the twin-triode tube provide a.c. amplification, while triode VT_3 provides d.c. restoration and clipping. Grid resistor R_5 has the required ohmic value (about 3 megohms) to make the pedestal level of the restored signal line up at the cut-off point for this tube. This condition is obtained automatically because condenser C_3 and resistor R_5 act together as a time delay circuit which causes the d.c. bias to vary gradually in accordance with changes in average line brilliancy.

Coupling condenser C_1 strips off the d.c. component from the television signal at the output of the video detector, so that the grid of amplifier triode VT_1 gets an a.c. signal (with a negative picture phase). The signal across plate load resistor R_2 for this stage will therefore have a positive picture phase. Condenser C_2 transfers the signal to the grid of amplifier tube VT_2, which amplifies the signal and reverses its phase again, so that the signal developed across load resistor R_4 has a negative picture phase. This signal in

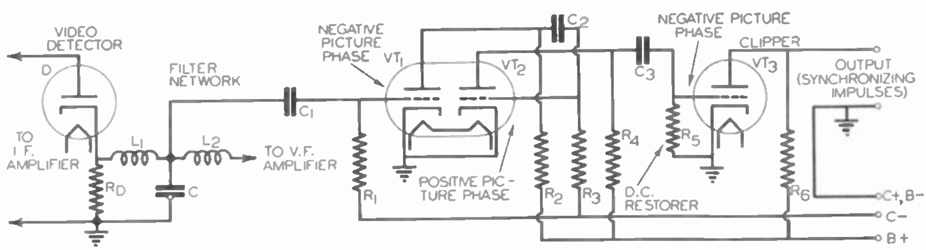


FIG. 8. Typical practical clipper circuit designed for connection to a video detector providing a negative picture phase. The television signal is amplified and reversed in phase twice by r-c coupled amplifier stages, then sent through a d.c. restorer circuit prior to clipping.

the filter network at the output of the video detector is shown in Fig. 8. Since the synchronizing impulses are relatively weak at this point, this circuit provides two stages of r-c coupled a.c. its a.c. form is fed through C_3 to the clipper tube, where the pedestals are restored in such a manner that only the impulses will develop an output voltage across R_6.

Important Characteristics of Clipper Output Impulses

After the clipper comes the *frequency separator section*, which serves to separate the horizontal and equalizing impulses from the vertical impulses. After separation, each group of impulses is sent into its own blocking oscillator, which in turn acts upon the corresponding sweep oscillator circuit. The principles of frequency separation can be better understood by first studying the characteristics of the impulse signals at the output of the clipper.

Wave Form of Clipper Plate Current. In all three of the typical practical clipper circuits just studied (Figs. *6*, *7* and *8*) the television signal has a negative picture phase at the input of the combination d.c. restorer and clipper tube. Furthermore, in each case, grid current flow through the grid resistor produces a negative C bias which lines up the pedestals of the picture signal and places them at the plate current cut-off bias value, as shown in Fig. *9A*. Since only the impulses will cause plate current flow through the clipper tube under these conditions, the *plate current* for the clipper tube will be as shown in Fig. *9B*.

Wave Form of Clipper Output Voltage. When the plate current of the clipper tube is zero, the plate-to-chassis voltage at this tube will be equal to the d.c. plate supply voltage (with no plate current flow, there is no voltage drop across the clipper plate load resistor). An impulse causes plate current flow through the clipper plate load resistor, producing across this resistor a voltage drop which lowers the plate-to-chassis voltage in the manner shown in Fig. *9C*. Observe that the phase of this signal voltage is the reverse of that for the signal shown in Fig. *9A*. This means that the impulse signals shown in Fig. *9C* correspond to a positive picture phase even though no picture signals are present.

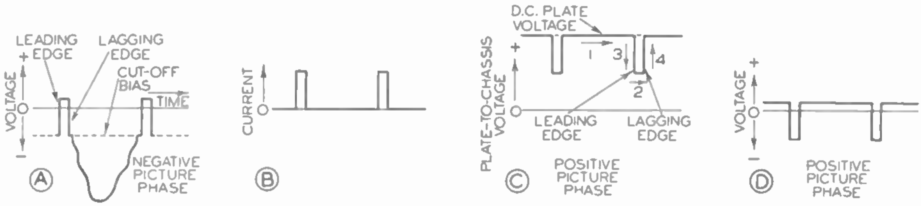


FIG. 9. Characteristics of signals before and after clipping. *A*—grid-cathode voltage for the clipper tube; *B*—plate current for the clipper tube; *C*—plate-to-chassis voltage for the clipper tube; *D*—same signal as at *C*, but with the d.c. component stripped off.

The passage of the impulse signal shown in Fig. *9C* through a condenser does not change its phase, but only serves to strip off the d.c. component. The impulse signal then assumes the a.c. form shown in Fig. *9D*.

Leading and Lagging Edges of Impulses. In dealing with impulses, that edge of an impulse which first arrives at a given point is called the *leading edge*. In diagrams, the left-hand edge of an impulse is always the leading edge, for it is common practice to plot time as increasing to the right. The other edge of an impulse is known as the *lagging edge* or *trailing edge*. The edges of the impulses have been identified in Figs. *9A* and *9C*.

Horizontal and Equalizing Impulse Acceptor Circuits

Let us assume that the impulse signal voltage shown in Fig. *9C* is present across plate load resistor R_L in Fig. *10A*, and is applied to the horizontal impulse acceptor circuit made up of condenser *C* in series with resistor *R*. In this circuit, the capacity of *C* is so small with relation to the ohmic value of *R* that the combination has a very short time constant, much shorter than the duration of an equalizing pulse. This means that condenser *C* charges and discharges rapidly, and no current flows when the voltage across R_L is constant. Referring to Fig. *9C*, the voltage is constant at the d.c. plate supply voltage level (*1*) and at the impulse peak level (*2*). Only at the leading edge (*3*) and the lagging edge (*4*) is the current changing and producing electron flow through circuit *R.-C.* in Fig. *10A*. The next question to consider is: In what direction will electron flow be through this circuit?

When the voltage across R_L and the voltage source in Fig. *10* (corresponding to the plate-to-chassis voltage of a clipper stage) is at a maximum voltage level *1* in Fig. *9C*, condenser *C* has a maximum charge. Since the upper terminal of R_L is always positive with respect to the chassis, plate *a* has a positive charge (a below-normal number of electrons), and plate *b* has a negative charge (an above-normal number of electrons). When a leading edge (*3*) arrives at R_L, the voltage drops; condenser *C* immediately gives up a part of its charge, so that plate *a* takes on electrons and plate *b* loses electrons.

Electron flow through the circuit for a leading edge is therefore in the direction shown in Fig. *10B*, producing across *R* a voltage drop having the indicated polarity. The amount of current flowing through this resistor depends essentially upon how fast the applied voltage is changing, and this is controlled by the slope of the edge of the impulse. (Although impulses are shown as being rectangular in the diagrams for simplicity, they actually do have a certain amount of slope. This slope is made the proper amount to give the desired current flow.)

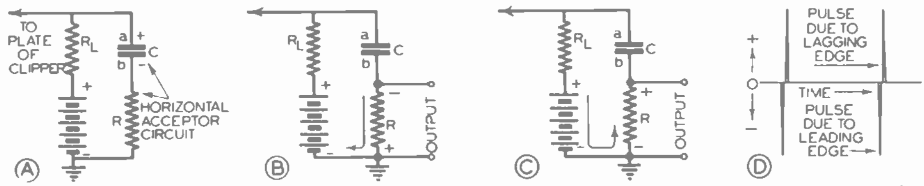


FIG. 10. Action of the impulse voltage in Fig. *9C* on a resistor-condenser circuit having a short time constant.

Current flow exists through *R* only for the extremely short interval during which the charge on condenser *C* is changing. After this interval, the charge on *C* remains constant for the duration of the impulse peak (*2*). The trailing edge of the impulse then becomes effective, making the plate-to-chassis voltage increase suddenly as shown in Fig. *9C*. If plate *a* is to become more positive to correspond to this condition, it must lose electrons, and these must flow to *b*. This electron flow from plate *a* through the circuit to plate *b* provides across resistor *R* a voltage drop having the polarity indicated in Fig. *10C*. The amount of electron flow depends essentially upon the slope of the trailing edge of the impulse.

If we were to plot the potential of point *b* with respect to ground for the duration of two horizontal lines, we would get a voltage wave like that shown in Fig. *10D*, in which the leading edge of each impulse produces a negative pulse and the lagging edge produces a positive pulse. We desire to have a positive pulse for each leading edge; we can reverse the phase of our signal to get this condition simply by sending the signal in Fig. *10D* of the clipper stages shown in Figs. *6*, *7* and *8*, we secure across the resistor in this horizontal impulse acceptor circuit a voltage consisting only of pulses *due to leading and lagging edges of impulses.* By sending these pulses through an r-c coupled amplifier stage, we can reverse their phase and secure the desired positive pulses for leading edges of synchronizing impulses.

Typical synchronizing impulses as fed to the clipper are shown in Fig. *11A*, and the pulses obtained after clipping, passage through a horizontal acceptor circuit, and phase reversal,

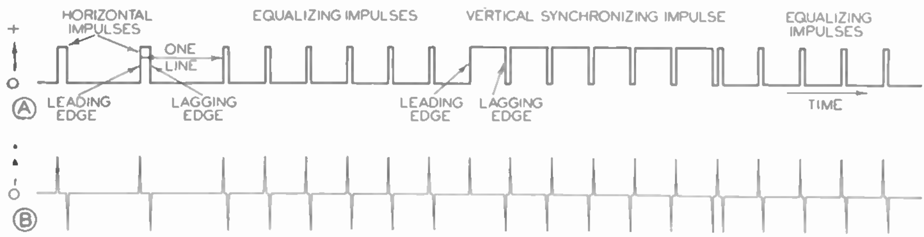


FIG. 11. The pulses at *B* are obtained when the horizontal, vertical, and equalizing impulses at *A* are sent through an *R-C* frequency separator circuit having a short time constant, then amplified by an r-c coupled stage.

through an r-c coupled a.c. amplifier stage.

We could just as well apply the synchronizing impulse signal in its a.c. form (Fig. *9D*) to the *R-C* circuit in Fig. *10A* (insertion of a high-capacity condenser anywhere in the circuit of Fig. *10A* will strip off the d.c. supply voltage from the signal in Fig. *9C*, giving the a.c. wave). The action of the *R-C* circuit with its short time constant remains the same, for it is the *change* in the voltage across the condenser which controls electron flow in the circuit.

We thus see that by connecting a horizontal impulse acceptor circuit (a resistor and condenser having a short time constant) to the output terminals are shown in Fig. *11B*. Note that pulses for controlling the horizontal sweep circuit exist even during the time of a vertical synchronizing impulse.

Vertical Acceptor Circuits and Integrating Circuits

We have just seen how the leading edges of impulses can be made to produce positive pulses which will control the horizontal sweep circuit. For the vertical sweep circuit, however, we require a circuit which will ignore the line and equalizing impulses as well as the vertical serrations, but will respond to the long vertical impulses. Here, also, a simple r-c impulse acceptor circuit will suffice, provided *the circuit has a long time constant and the output pulses are removed from the condenser* (instead of from the resistor).

The output circuit for the clipper stages in Figs. *6, 7* and *8* has been redrawn in a simplified manner in Fig. *12A;* here R_L represents the plate load resistor and the plate supply filter resistor together, and E represents the d.c. plate supply voltage. R and C in this circuit constitute the *vertical acceptor circuit.*

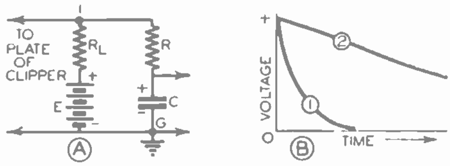


FIG. 12. In this acceptor circuit, *R* and *C* have a long time constant and hence have integrating properties. This circuit delivers only pulses at the vertical or field frequency.

Video signals exist for more than 80% of the time in a television signal. Since the clipper tube draws current only on impulses, there will be no plate current to produce a voltage drop across R_L *during video signals,* and condenser C will be charged to the full d.c. voltage value of E.

During impulses, plate current flows through the clipper tube and through R_L, producing across R_L a voltage drop which opposes the supply voltage E and thereby lowers the d.c. voltage applied to R and C in series. Under this condition, condenser C begins to discharge through R and R_L. Since the ohmic value of R is very much larger than that of R_L, we can neglect R_L. If the time constant of R and C together were short, the condenser would lose its voltage quite rapidly, as shown by curve *1* in Fig. *12B*. Actually, however, this *R-C* circuit has a long time constant, and condenser C changes in potential slowly, as indicated by curve *2* in Fig. *12B*. Let us see how this use of a long time constant permits the production of vertical pulses.

Figure *13A* shows the nature of the signal voltage existing between points *1* and *G* in Fig. *12A;* video signals are entirely absent, since they have been removed by the clipper. Impulses swing the voltage in a negative direction (corresponding to a positive picture phase). Each leading edge of an impulse thus tends to lower the voltage across C, as indicated in Fig. *13B*. During the time corresponding to the leading edge of each equalizing impulse, the voltage across C begins dropping, as indicated in Fig. *13B*, but returns to its maximum value again after the equalizing impulse simply because the voltage did not remain at the lower value long enough for the *R-C* circuit to discharge completely.

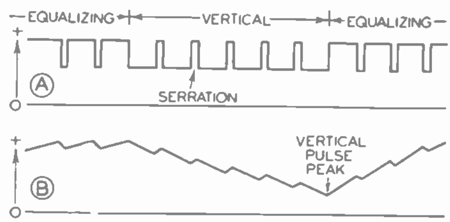


FIG. 13. The action of clipped synchronizing impulses upon an *R-C* circuit having a long time constant is shown here. Equalizing impulses and serrations are integrated (smoothed out), so that the vertical impulses determine the fundamental frequency of the output signal.

During passage of a serrated vertical impulse, however, the voltage acting on C is maintained at the lower level for a relatively long time, equal to three times the time of one line. Condenser C thus has a much longer time in which to discharge. At each serration in the vertical impulse the supply voltage returns to normal for a short instant and tends to recharge the condenser. The amount of charging which occurs is negligibly small, however, because the time duration of a serration is so short. As a result, condenser C discharges gradually during the entire period of a vertical impulse, as shown in Fig. *13B*.

At the end of the vertical impulse, condenser C has attained its minimum charge. During the equalizing impulses which follow, the voltage applied to the condenser is a maximum value practically all of the time, and the condenser almost completely recovers its full charge by the time the last equalizing impulse has passed.

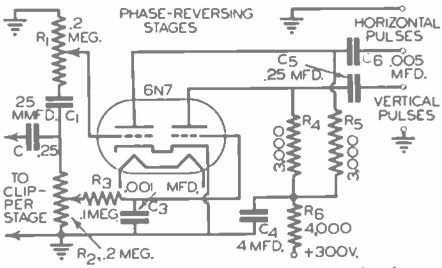


FIG. 14. Typical frequency separator circuit employing a twin triode for amplifying and reversing the phases of the separated pulses.

Although the vertical signal pulse shown in Fig. *13B* is positive at all times, the vertical pulse peak actually corresponds to a voltage swing in a negative direction. If a large-capacity condenser were placed between R_L and R in Fig. *12A* in order to block out the d.c. component, the voltage across C would be negative part of the time, with the peak most negative. In order to convert the negatively-swinging vertical pulse shown in Fig. *13B* into the positively-swinging pulse needed for the vertical sweep generator circuit, this signal must be passed through an r-c coupled amplifier stage.

Remember that in the r-c type of horizontal impulse acceptor circuit the output pulses are removed from the resistor and the circuit has a short time constant; in the r-c type of vertical impulse acceptor circuit, the distinguishing features are a *long time constant and removal of output pulses from the condenser.*

Typical Frequency Separator Circuits

Arrangement Using Two Acceptor Circuits. The typical frequency separator circuit shown in Fig. *14* is essentially a combination of two R-C acceptor circuits, one having a short time constant so it will accept horizontal impulses, and the other having a long time constant so it will accept only vertical impulses.

The output signal of the clipper stage is applied to potentiometer R_2 through d.c. blocking condenser C, with the result that the impulse signal voltage across R_2 has the a.c. form shown in Fig. *9D*. This voltage acts upon horizontal acceptor circuit R_1-C_1, producing voltage pulses across R_1 only for the leading and lagging edges of impulses.* These pulses swing in a negative direction for leading edges of impulses, and hence must be reversed in phase.

A part of the pulse voltage across R_1 is fed into the left-hand triode of the type 6N7 twin-triode tube in order to secure phase reversal. As a result, leading edges of impulses produce the

* The time constant of R_1-C_1 is about 10 micro-seconds, which is far shorter than the duration of a complete horizontal impulse. The ohmic value of R_2 must be added to that of R_1 when computing the time constant, for the discharge current of C_1 flows through R_1 and R_2 in series.

desired positive voltage pulses across plate load resistor R_5. This voltage across R_5 is fed to the horizontal blocking oscillator circuit through condenser C_6, which has a small capacity and hence blocks out anything lower than the line frequency of 13,230 cycles.

A part of the impulse signal voltage developed across potentiometer R_2 is forwarded to circuit R_3-C_3, which has a long time constant (about 300 micro-seconds; that portion of R_2 between the moving arm and ground must be added to R_3 when computing this time constant). Since the time of one complete vertical impulse is about 230 micro-seconds, C_3 has ample time to discharge during each vertical impulse. The voltage pulse across C_3 therefore corresponds essentially to the vertical synchronizing impulses. Leading and lagging edges of horizontal as well as equalizing impulses have very little effect upon the voltage across C_3, as was indicated in Fig. *13B*.

The vertical pulse voltage developed across C_3 is impressed on the grid-cathode of the right-hand section of the 6N7 tube. The resulting plate current flow develops across plate load resistor R_4, the required positive pulse. This output voltage is applied to the vertical blocking oscillator circuit through condenser C_5, which has a high capacity and hence passes the desired low frequency.

The intensity of the horizontal or line pulses in the output of this frequency separator stage is controlled by R_1, while the intensity of the field or vertical pulses is controlled by R_2.

Combination Clipper and Frequency Separator Circuit. A simple two-tube circuit arrangement which provides both clipping and frequency separation is shown in Fig. *15*. When this arrangement is connected to a video detector which provides a positive picture phase, it will deliver the required positive horizontal and vertical pulses without the use of phase-reversing amplifiers.

The first v.f. amplifier stage is of the d.c. type, employing a type 1851 pentode tube connected directly to the output of the video detector. If the detector produces a signal having a positive picture phase, the signal across

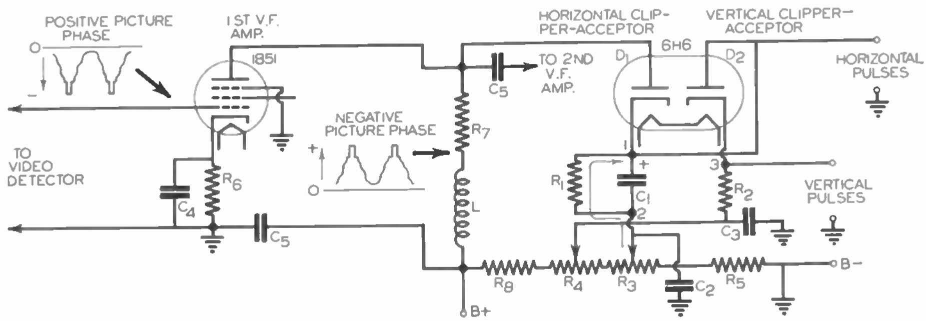


FIG. 15. Simple combination clipper and frequency separator arrangement employing only a single 6H6 tube, and fed by a pentode d.c. amplifier which serves as the first v.f. stage. It delivers a d.c. signal with a negative picture phase, eliminating the need for a separate d.c. restorer for the clipper. The values of R_1 and C_1 are somewhat critical, and are best determined by experiment. Values which have proved satisfactory in one case are .0015 mfd. for C_1 and 15,000 ohms for R_1.

plate load R_7-L of this pentode tube will have a negative picture phase, and will be in its d.c. form with pedestals lined up. This means that impulses will swing the plate of the pentode more positive with respect to the chassis.

The television signal voltage developed across pentode plate load R_7-L is applied to diode section D_1 of the type 6H6 tube through R_1-C_1 and through voltage divider network R_8-R_4-R_3. Potentiometer R_3 is adjusted so that the cathode and plate of D_1 will be at the same potential whenever pedestals are coming through. Under this condition, impulses will make the plate of D_1 positive with respect to the cathode, and the resulting electron flow through R_1 will make point *1* positive with respect to point *2* for the duration of each impulse. This means that the net voltage between point *1* and the chassis will increase (become more positive) for the leading edge of each horizontal and equalizing impulse, exactly as is required for the horizontal blocking oscillator.

Now let us see how we secure vertical pulses. Observe that the plate of diode D_2 in Fig. *15* is connected to point *1*, while the cathode is connected through diode load resistor R_2 to potentiometer R_4 in the voltage divider. This means that the voltage acting upon diode D_2 is the difference between the voltage developed across R_1 by impulses and the bias voltage existing between the moving arms of potentiometers R_3 and R_4. Potentiometer R_4 can be adjusted so that the plate of D_2 will be slightly negative with respect to its cathode for the peaks of all horizontal and equalizing impulses existing across R_1; this condition is possible because R_1 and C_1 together have a time constant somewhat longer than the duration of an impulse.

A serrated vertical impulse lasts long enough for the voltage across R_1-C_1 to build up, and hence this voltage exceeds considerably the maximum value which can be developed by a horizontal impulse. A vertical impulse therefore makes the plate of D_2 positive, and the resulting electron flow through R_2 develops across this resistor the desired positive vertical pulse.

The simple combination clipper and frequency separator circuit just described is used primarily in small and inexpensive television receivers. Its performance is by no means perfect, and the adjustments of R_3 and R_4 are somewhat critical, but these drawbacks are in some cases offset by its lower cost.

Blocking Oscillators

Typical Blocking Oscillator Circuit. The advantages of having a blocking oscillator (self-excited oscillator) just ahead of each saw-tooth sweep generator circuit were discussed earlier in this lesson. Briefly, these advantages were: 1. *To help the receiver stay in synchronism with the transmitter during fading or atmospheric static conditions;* 2. *To maintain a constant pulse intensity, thus insuring a constant fly-back time.*

A widely used blocking oscillator or pulse generator circuit is shown in Fig. *16A*. Transformer T is so connected that any disturbance or change in the plate circuit serves to induce in the grid circuit a voltage which swings the grid of the tube *positive*. This positive feed-back voltage causes plate current to increase, producing more feed-back voltage, with the process building up almost instantly. The positive swings in grid voltage make the grid draw current; as a result, electrons flow downward through R_1 and R_2 to ground and develop across these resistors a voltage which charges condenser C_1 and makes the grid negative with respect to cathode. Plate current immediately drops to zero, after which condenser C_1 discharges through R_1 and R_2 (R_4 is so low in ohmic value that its effect upon the rate of discharge is negligible). This duces periodically between grid and chassis a voltage having the wave form shown by the solid-line curve in Fig. *16B*, with the grid having the indicated polarity with respect to the chassis. Naturally, the time between pulses is longer than the time constant value, for condenser C_1 must discharge to considerably beyond 63 per cent before feed-back starts again.

Feed-back occurs when the voltage between grid and ground approaches zero, as at point *O*. If a synchronizing pulse arrives at the input of this blocking oscillator a short time ahead

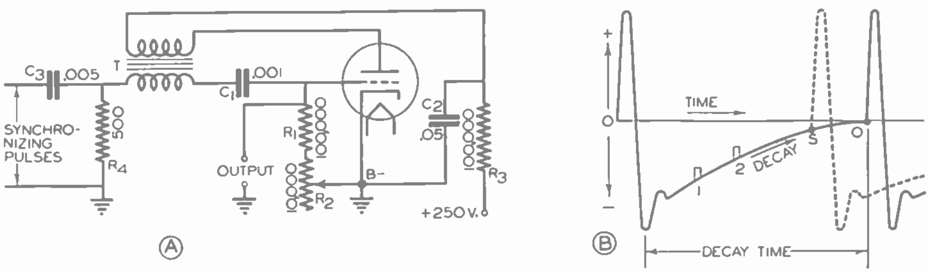


FIG. 16. Blocking oscillator designed to produce positive pulses at approximately the line frequency of 13,230 cycles *(A)*, and type of output voltage wave produced by this circuit *(B)*. This same circuit will produce pulses at approximately the field frequency of 60 cycles if C_3 is omitted, R_1 is changed to 200,000 ohms, R_2 is changed to 50,000 ohms, and C_1 is changed to .25 mfd. In the circuit shown here, C_3 and R_4 serve to reject low frequencies while allowing line frequencies to pass. In the low-frequency version of this circuit, an extra by-pass condenser ahead of the blocking oscillator shunts high frequencies to ground. The blocking oscillator circuits thus assist in the process of frequency separation.

discharge occurs slowly, with its exact rate depending upon the time constant of the circuit which includes *C*, R_1 and R_2.

No feed-back occurs during discharge since there is no plate current. After C_1 has almost completely discharged, feed-back starts again. Instantly the grid is driven positive, then negative again by grid current. The time constant of C_1 and $R_1 + R_2$ (about .0001 second) controls the frequency. R_2 is a 10,000-ohm rheostat which provides the essential vernier adjustment of circuit frequency.

The circuit in Fig. *16A* thus pro- of point *O*, such as at point *S*, this impulse will initiate feed-back and thus control the frequency of pulse generation by this circuit. Low-intensity static pulses such as are shown at points *1* and *2* in Fig. *16B* will not initiate feed-back.

The decay time (Fig. *16B*) for the r-c circuit of a blocking oscillator should be *longer* than the time between synchronizing pulses. If the decay time is only slightly longer, a low-amplitude pulse will be sufficient to give adequate control. If the decay time is made considerably longer than the time between synchronizing pulses, the pulses must be more intense; under this condition it will be more difficult for static pulses to take over control. On the other hand, if the decay time is less than the time between synchronizing pulses, the circuit will automatically initiate feed-back, and synchronizing pulses will have no control. This means that the decay time must be longer than 1/13,230 second for horizontal blocking oscillators, and longer than 1/60 second for vertical blocking oscillators.

The decay time during which condenser C_1 in Fig. *16A* discharges can be varied by adjusting the value of R_2. In actual practice, this rheostat is adjusted until the blocking oscillator "holds on to" synchronizing pulses; for this reason, engineers often call R_2 the *hold control.*

Sweep Generator Principles

Force Required on Beam. In order to sweep the electron beam horizontally in the proper manner in a t.c.r. tube, a force having the saw-tooth characteristic shown in Fig. *17* must act upon the beam, and this force must be repeated 13,230 times each second. A similar force, repeated 60 times each second, is required for vertical deflection of the beam.

Voltage Required. In electrostatic deflection systems, the deflecting voltage is developed across a resistor (the extremely high resistance existing between two deflecting plates), and consequently the applied voltage, the voltage existing between the deflecting plates, and the force on the beam will all have exactly the same wave shape.

Current Required. With electromagnetic deflection, the force acting upon the electron beam is directly proportional to coil current. This means that the coil current must have a saw-tooth characteristic. When a saw-tooth voltage like that shown in Fig. *17* is applied to a deflecting coil, however, the current flowing through the coil will not have this wave shape. The reason for this takes us back to the fundamentals of electricity and radio.

If a voltage of constant value is applied to a coil having zero resistance, the current through the coil will increase gradually and continually to an infinitely great value. The electrical inertia of the coil prevents this current from rising to infinity immediately after the circuit is closed. The rate of increase of current is dependent upon the value of the applied voltage and upon the inductance of the coil; a high voltage gives a faster increase in current than does a low voltage.

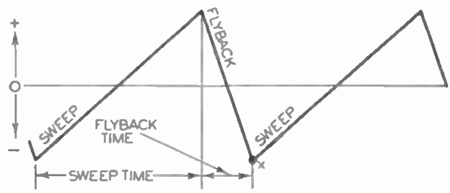


FIG. 17. The force acting on the electron beam in a t.c.r. tube must have this saw-tooth wave shape. In the case of electrostatic deflection, the deflecting plate voltage must have this same wave shape. In the case of electro-magnetic deflection, the deflecting coil current must have this wave shape.

If the applied voltage is suddenly reversed in polarity, the current will decrease gradually at the same rate at which it increased; if the voltage is increased in magnitude simultaneously with polarity reversal, the current will decrease at a faster rate than it increased. Thus, the polarity of the voltage which is applied to the coil determines whether the change will be an increase or a decrease.

Figure *18* illustrates the above facts. If a voltage having the wave form at *B* is applied to a coil having zero resistance, the current through the coil will have the wave form shown at *A*.

Any practical deflecting coil will have a certain amount of resistance, however, and the power amplifier tube which serves as the voltage source for the coil will have a plate resistance which must also be considered. The voltage required to send a saw-tooth current through the combined resistance of the coil and the power tube will have a saw-tooth shape. This means that the voltage required to send a saw-tooth current through a combination of a coil and resistance will be the sum of two voltage waves, one having the shape shown at *A* in Fig. *18* and the other having the wave form shown at *B* in Fig. *18*. The voltage required will therefore have the wave form shown at *C* in Fig. *18*.

We thus arrive at the conclusion that for electrostatic deflection the saw-tooth sweep generator must produce a voltage having the saw-tooth wave form shown in Fig. *17*, while for electromagnetic deflection the sweep generator must produce a voltage having the wave form shown in Fig. *18C*.

Basic Sweep Generator Circuit. Saw-tooth sweep voltages at either the horizontal or the vertical sweep frequency can be obtained by charging a condenser through a resistor. After each charging period, the condenser must be discharged; the frequency at which the condenser is discharged determines the frequency of the signal.

Either a gaseous or vacuum triode tube may be used for discharging the condenser in a basic one-tube saw-tooth sweep generator circuit. The *gaseous tube will discharge the condenser automatically* without external excitation by a signal, whereas the vacuum tube requires a "trigger" voltage or pulse to initiate the discharge. Both gaseous and vacuum tube circuits require an input signal which will control the exact rate of the discharge. In a television receiver, the positive pulses produced by the frequency separator or the positive pulses produced by the pulse-controlled blocking oscillator will determine the rate of discharge.

A simple saw-tooth sweep generator circuit which can be used with either a vacuum or gaseous tube is shown in Fig. *19*. Let us assume first that tube *VT* is a vacuum tube of the triode type, with R_1 omitted for the time being. If the grid of the tube is biased highly negative with respect to its cathode at the start of a cycle, no plate current will flow. Assume that condenser *C* is originally discharged at this instant; it will therefore be charged by the B+ voltage source through resistor *R*. The curve in Fig. *20* shows the manner in which voltage

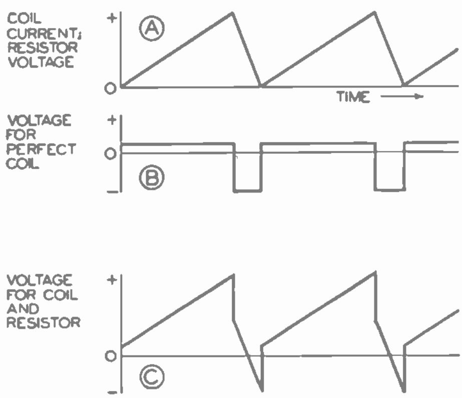


FIG. 18. The voltage required to send a saw-tooth current wave through a practical deflecting coil is shown here at *C*. In a practical circuit, an adjustable value of direct current would be sent through the deflecting coil along with the saw-tooth current at *A*, in order to center the reproduced image on the screen.

e_C across C will increase with time during this charging process. Voltage e_C will reach a value equal to .63 times the supply voltage E_B in the time constant period for this *R-C* circuit.

Notice that the initial rise in condenser voltage in Fig. *20* is rather linear, becoming less linear as time increases. If tube *VT* is of the vacuum

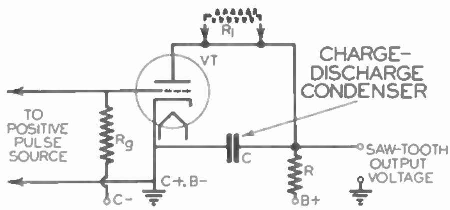


FIG. 19. Fundamental saw-tooth sweep generator circuit. Alternate charging and discharging of condenser *C* produces an output voltage with a saw-tooth wave form.

type, this charging action will go on indefinitely, with the condenser voltage approaching closer and closer to the supply voltage E_B but never quite reaching it.

If a positive pulse is injected into the grid-cathode circuit of the tube during this charging action, and this pulse has sufficient magnitude to swing the grid more positive than plate current cut-off, the plate-cathode path through the tube will become conductive, and condenser *C* will discharge through this path. The greater the magnitude of the positive pulse, the lower will be the ohmic value of the plate-cathode path, and the faster will be the discharge. When the positive pulse is removed, tube *VT* again becomes non-conductive, and condenser *C* starts charging again. Under these conditions the voltage across *C* is a pulsating d.c. voltage having the wave form shown in Fig. *21*. Observe that it never reaches the plate supply voltage and never drops to zero.

Neither the charge nor the discharge portions of the wave in Fig. *21* are linear. The discharge portion is of little importance, however, since we merely require a return to the minimum value *in a definite period of time* (the spot on the screen is darkened during this return period). The charge portion *must be linear*, however. In the case of the horizontal saw-tooth sweep generator, this is essential for proper placing of elements along a line; in the case of a vertical saw-tooth sweep generator, linearity is essential in order to give a linear vertical sweep with the horizontal lines equally spaced.

One way to insure linear charging of condenser *C* in the saw-tooth sweep generator circuit of Fig. *19* is to use an *R-C* network having a short time constant. This reduces the output voltage, however, making it necessary to employ a high-voltage charging source in order to secure the required magnitude of sweep voltage.

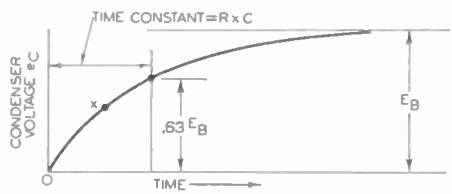


FIG. 20. Manner in which the voltage e_C across a condenser increases with time as the condenser is charged through a resistor by a fixed d.c. voltage source E_B.

In the circuit of Fig. *19*, the *R-C* network must have a time constant longer than the time for one saw-tooth cycle. Furthermore, the frequency of the saw-tooth output voltage must be controlled by the positive pulses fed into this circuit. The discharge time is governed by the plate resistance of the tube, and this in turn is governed by the amplitude and duration of the incoming pulses. It is, therefore, highly important *that all positive pulses fed into the saw-tooth sweep generator have the same amplitude and duration.*

Gaseous Saw-Tooth Sweep Generator Circuit. If a gaseous tube such as a type 884 or type 885 is used for *VT* in Fig. *19,* condenser *C* will discharge periodically even when no positive pulses are fed into the circuit. For a given negative C bias on a gaseous triode, a definite plate voltage is required to produce conduction. The higher the C bias, the greater must this plate-cathode voltage be. If the supply voltage is higher than this plate "ignition" voltage, condenser *C* will eventually charge up to a voltage sufficient to cause ignition. The gas in the tube then ionizes, and we have both electron flow and ion flow through the tube. Under this condition, the tube is essentially a short circuit; at least, its resistance is negligibly small in comparison to the ohmic value of *R*, and the charge on condenser *C* will flow out almost instantly.

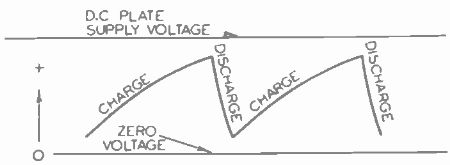


FIG. 21. Saw-tooth wave form of the output voltage delivered by the charge-discharge sweep generator circuit shown in Fig. *19*.

Since we want condenser *C* to take a definite period of time for its discharge, resistor R_1 is inserted in the plate lead of the tube in the manner indicated in Fig. *19*. The value of this resistor is adjusted to give the desired discharge rate. R_1 serves another useful purpose, in that it limits tube current to a safe value. Without this resistor, the full voltage across the condenser would be applied to the triode, and the cathode of the tube might be ruined by excessive ion bombardment.

With a gaseous triode in the circuit of Fig. *19* and with *R* and *C* adjusted to give charge and discharge at a frequency lower than that desired for the sweep generator, a positive impulse at the grid input will lower the plate voltage required for ignition. This circuit can therefore be arranged so that a positive pulse will initiate the discharge and thus control the frequency of the circuit.

Except for the self-oscillating characteristic, the action of a gaseous triode circuit is the same as that of a vacuum tube circuit. Linearity of charge is obtained by proper adjustment of the values of *C*, *R* and the B+ supply voltage. If adequate linearity cannot be obtained with a normal supply voltage value, the wave shape-correcting coil can be introduced in series with charging resistor *R* in Fig. *19*. With proper design, this coil can be made to retard the flow of charging current in the region around point *x* on the curve of Fig. *20*, thereby making the charging current flow more or less uniformly into the condenser and giving an essentially linear increase in the condenser voltage.

Another method for insuring linear charging of condenser *C* involves inserting a diode tube in series with the B+ supply lead. This tube maintains the supply current at an essentially constant value, thereby insuring a linear increase in the condenser voltage.

Sweep Generator For Electromagnetic Deflection. The circuit shown in Fig. *19* is suitable for generating a saw-tooth sweep voltage for an electrostatic deflecting system, but for electromagnetic deflection a charge-discharge circuit like that shown in Fig. *22* is required. This circuit will produce an output voltage having a wave form similar to that shown in Fig. *18C*; when this voltage is fed to a power output tube having a coil (a t.c.r. tube deflecting coil) as plate load, the desired saw-tooth current wave will be obtained.

Section VT_1 of the twin-triode 6N7 vacuum tube in Fig. *22* acts as the blocking oscillator, while section VT_2

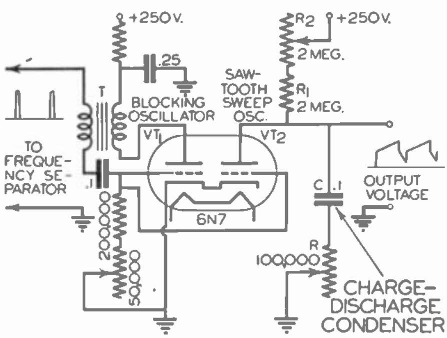


FIG. 22. Combination blocking oscillator and saw-tooth sweep generator circuit which delivers a special form of saw-tooth output voltage suitable for electromagnetic deflection. Circuit constants given here are for the 60-cycle output required by the vertical deflecting coil. Variable resistor *R* is called the *vertical peaking control*.

acts as the saw-tooth sweep generator. The grid of VT_2 is directly connected to the grid of VT_1; the saw-tooth sweep generator tube thus gets its negative bias along with the positive pulses. The chief difference between this circuit and that shown in Fig. *19* lies in the insertion of adjustable resistance R in series with C, so that the output voltage is the sum of the instantaneous voltages across R and C.

Let us begin our analysis of the circuit in Fig. *22* at that instant when plate current through VT_2 is zero. The plate supply voltage begins charging condenser C through resistors R_2, R_1 and R. The voltage across the condenser increases in the manner indicated by the curve in Fig. *20*, but the voltage across resistor R is initially a maximum and decays to zero.

The reason for this is simply that at the beginning of the charging period, the condenser has no back e.m.f. (no charge) to limit current flow, and maximum current flows through the circuit for an instant, developing a maximum voltage across the resistor. As the condenser acquires a charge or back e.m.f., less and less current flows, and consequently the voltage across R drops. The result is that the combined output voltage across C and R rises suddenly to a value determined by the d.c. supply voltage and the combined resistance of R, R_1 and R_2, after which the output voltage increases linearly in the desired manner.

When a positive synchronizing pulse is fed into blocking oscillator tube VT_1 by the frequency separator, the blocking oscillator immediately applies its positive pulse to the grid of VT_2, lowering the plate resistance of this tube. Condenser C immediately begins to discharge. The reversal in the direction of electron flow through R makes the output voltage drop instantly to a lower value; condenser C then discharges at the desired rate. When the positive pulse is removed, condenser C begins charging again, with the initial rush of current through R causing the voltage to rise suddenly again to the value at the start of the new cycle. The entire cycle then repeats itself.

Since R_1 and R_2 together have a very much higher ohmic value than R, the charging rate during charge is determined essentially by the values of R_1 and R_2. The value of R is critical, however, for it determines the magnitudes of the vertical portions of the output voltage wave show in Fig. *22*. In this circuit, as in the circuit of Fig. *19,* the plate resistance of the saw-tooth sweep generator tube controls the discharge rate.

The circuit shown in Fig. *22* is designed to produce 60-cycle sweep voltages, for application to a power output tube which will convert these voltage changes into corresponding current changes. With resistor R omitted, however, this circuit will be satisfactory for electrostatic deflection.

Multi-Vibrator Sweep Circuits

A combination blocking oscillator and saw-tooth sweep generator circuit which is widely used in television receivers is shown in Fig. *23*. This arrangement is essentially a relaxation oscillator of the multi-vibrator type, so designed that its frequency of oscillation can be controlled by pulses.

R_2 in Fig. *23* is the input resistor and R_3 the output resistor of triode vacuum tube VT_1, while R_3 is the input resistor and R_1 is the output resistor of triode vacuum tube VT_2. The plate of VT_2 is connected to the grid of VT_1 through R_4 and C_1 in series. Condenser C_1 blocks the d.c. plate supply of VT_2, preventing it from acting on the grid of VT_1. R_4 prevents R_1 (which has a low ohmic value) from shorting R_2 (which has a high ohmic value). Resister R has a much higher ohmic value than R_1 combined with the plate resistance of VT_2. The circuit is so arranged that a rise in the plate current through VT_2 causes the voltage at point *2* to swing in a *positive* direction with respect to ground, thus reinforcing the rise in plate current. With these facts in mind, let us now consider how the circuit works.

A positive increase in the potential of point *2* and the grid of VT_2 makes this tube send a higher plate current through R_1 (C_3 is a high-capacity by-pass condenser which permits application of the voltage across R_3 to the grid and cathode of VT_2). This makes the plate end of R_1 more negative than before with respect to the other

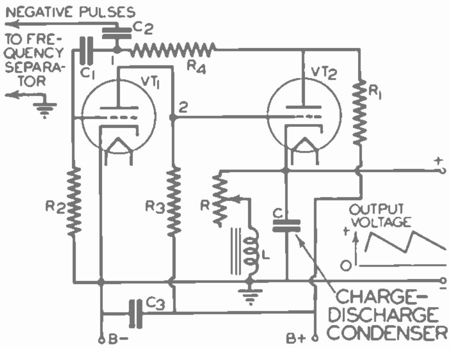


FIG. 23. Fundamental multi-vibrator circuit, which acts both as a blocking oscillator and as a saw-tooth sweep generator.

terminal of R_1. The voltage across R_1 is applied to R_2 through resistor R_4 and condensers C_1 and C_3, thereby driving the grid of VT_1 *negative* with respect to ground. Plate current through VT_1 drops, lowering the voltage drop across plate load R_3 and making point *2 more positive* than before with respect to ground. This in turn drives the grid of VT_2 more positive than before with respect to its cathode. This process repeats itself up to the limits of the circuit, with plate current of VT_2 increasing and plate current of VT_1 decreasing.

Since R has a much higher resistance than either R_1 or the plate-cathode resistance of VT_2, most of the d.c. supply voltage is dropped across R, and only a small amount exists between the plate and cathode of VT_2 or across R_1. Plate current through VT_2 finally increases to the point where the voltage drop which it produces across R is so great that there is insufficient plate voltage across the tube itself; VT_2 then stops conducting. At this instant, condenser C is charged to the full voltage existing across R (the resistance of L is so low that it may be neglected). There is now no voltage drop across R_1 to act upon grid resistor R_2, so the grid of VT_1 swings in a positive direction and makes plate current through R_3 *increase;* this makes the potential of point *2* swing in a *negative direction*, placing a negative bias on VT_2.

As soon as VT_2 stops conducting, condenser C begins discharging through R, and the voltage across the condenser begins dropping (decaying) at a rate which depends upon the time constant of C and R. While this occurs, the plate-cathode voltage of VT_2 is increasing. After a definite period of discharge, this plate-cathode voltage will be high enough so that the tube will begin conducting again despite the negative bias which is now on the grid of VT_2. Feed-back again occurs, followed by blocking and continued repetition of the entire cycle of events.

The building up of plate current and the charging of condenser C occurs rapidly, while the discharge of condenser C through R takes place slowly. The charging time is controlled essentially by the ohmic values of R_1, R_2 and R_3. The discharging time is controlled by the values of R and C. Coil L is introduced into this circuit in order to make the discharge linear. The output voltage will have the saw-tooth form shown at the right in Fig. *23* and also in Fig. *24A*.

A positive pulse appearing across R_3 will tend to cause plate current to flow through VT_2 even with a reduced plate-cathode voltage. This positive pulse can therefore initiate feed-back and charging of condenser C. If pulses are fed into the circuit regularly, they will take over control of the output frequency.

In order to produce a positive pulse at R_3, a negative pulse should exist across R_2. The decay time for condenser C must be longer than the interval between pulses in order for the pulses to take over control. For this reason, R is made adjustable and is known as the "hold" control.

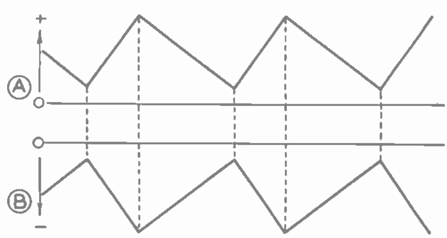


FIG. 24. Output voltage of the multi-vibrator circuit shown in Fig. *23* before *(A)* and after *(B)* passage through a phase-reversing amplifier stage.

If the frequency separator produces negative pulses, its output may be connected to point *1* in the circuit of Fig. *23*. If the frequency separator produces positive pulses, its output should be connected at point *2*.

The phase of the saw-tooth sweep voltage produced by this multi-vibrator circuit is incorrect for the deflecting plates. For this reason, the output signal must be sent through a phase-reversing amplifier. This will deliver the signal shown in Fig. *24B*, which has the wave shape and phase required by the t.c.r. tube. (If the image is to be viewed in a mirror supported at a 45-degree angle above the t.c.r. tube screen, the only circuit change needed is reversal of the vertical sweep channel output leads, assuming that balanced deflection is employed.)

Typical Deflection Circuits

Having covered the fundamental actions of amplitude separators, frequency separators and saw-tooth sweep generator circuits, let us now consider how the saw-tooth output signals of sweep circuits can be made to deflect the electron beams in t.c.r. tubes. We will study several typical complete circuits for entire deflection systems of television receivers, so that any special features not yet considered can be called to your attention.

Scanning System for Balanced Electrostatic Deflection. The circuit for a complete scanning system extending from the output of the clipper stage to the deflection plates of the t.c.r. tube is shown in Fig. *25*, along with the t.c.r. tube power pack circuit and the video amplifier output connections to the t.c.r. tube.

At input terminals *a* and *b* of this scanning system, both horizontal and vertical synchronizing impulses are present, these having been separated from the video signals by the previous clipper stage. The impulses at these terminals correspond to a *positive picture phase*, which means that impulses will swing the potential of point *a* in a negative direction with respect to point *b* and ground. The .25 mfd. condenser in the lead going from terminal *a* blocks the d.c. component of the synchronizing impulses, and hence the impulses are a.c. in form as they enter the resistance-capacitance network which serves as the frequency separator.

After separation, the horizontal pulses are fed into the horizontal scanning channel made up of tubes *1*, *2*, *3*, *4* and *5* and the horizontal deflecting plates of the t.c.r. tube. Vertical pulses pass through the vertical scanning channel made up of tubes *6*, *7*, *8*, *9* and *10* and the vertical deflecting plates. Potentiometer R_1 controls the amplitude of the horizontal pulses fed into the horizontal scanning channel, while potentiometer R_2 provides

Courtesy DuMont Labs., Inc.

Production line scene in a television cathode ray tube factory. As the last step in the pumping operation which removes all air from a t.c.r. tube, the metal elements inside the tube are heated to incandescence by placing around the neck of the tube two coils (connected in series) which carry high-frequency current. This drives gases out of the metal electrodes and supports, lengthening the useful life of the tube. The large metal cylinder above the tube is lowered during the actual process to protect the operator from flying glass in case the tube shatters due to defects in the glass. The inside of this cylinder is lined with heating elements, which serve to heat the glass envelope and drive gases from it during the evacuating process. The tube shown here employs electrostatic deflecting plates.

the same amplitude control for the vertical scanning channel.

Tube *1* amplifies the horizontal synchronizing pulses and at the same time reverses their phase, so that it delivers signals corresponding to a negative picture phase. Tube *6* provides amplification and phase reversal in this same manner for the vertical pulses. Each tube has its own plate load resistors and decoupling condensers.

R_3 is the final load resistor for tube *1;* the pulse voltage across this resistor is a.c. in form, with each horizontal pulse making the potential of the ungrounded end of R_3 swing *in a positive direction* with respect to ground.

Tube *2* serves as the horizontal blocking oscillator, and employs transformer T_1 for feed-back purposes. C_1 and R_5 determine the time constant and hence the natural frequency of the blocking oscillator circuit, with R_5 serving as the horizontal hold control. The actual frequency, however, is controlled by the horizontal synchronizing pulses.

The positive pulses produced by the horizontal blocking oscillator are fed from the grid of tube *2* through a 5,000-ohm resistor shunted by a .0008-mfd. condenser to the grid of horizontal saw-tooth sweep generator tube *3*. The resistor-condenser combination prevents pulses from swinging the grid of tube *3* excessively positive, and at the same time reduces the amplitudes of the pulses by applying a self-generated negative C bias to them. The horizontal saw-tooth sweep generator thus receives constant-amplitude pulses which swing its grid in a positive direction with respect to ground. C_3 is the charge-discharge condenser in this circuit.

Tube *7* serves as the vertical blocking oscillator, with transformer T_2 providing feed-back. The natural oscillating frequency is governed by C_2 and vertical hold control R_6, and the final frequency is controlled by the vertical synchronizing pulses.

Tube *8* serves as the vertical sweep generator tube, with condenser C_4 being charged and discharged to produce the saw-tooth sweep voltage. A direct connection between the grids of tubes *7* and *8* serves to feed into tube *8* the positive pulses required to initiate each discharge.

Returning to the horizontal sweep channel, observe that the d.c. supply voltage which charges condenser C_3 in the saw-tooth sweep generator circuit is applied through resistor R_7 and potentiometer R_8. Adjusting R_8 varies the amplitude of the saw-tooth sweep voltage, thereby controlling the amount of horizontal sweep and the width of the picture. Potentiometer R_{10} is a similar control for the vertical saw-tooth sweep voltage. Since both R_8 and R_{10} control the size of the final picture and the aspect ratio of the picture, these potentiometers are called the *size controls*.

The saw-tooth output voltage of the horizontal sweep generator circuit is fed into a push-pull output stage consisting of tubes *4* and *5* arranged in a phase inverter system. Tube *4* is fed directly by the sweep generator, with the input saw-tooth voltage being developed across R_{11}. The output voltage, 180° out of phase with the input, is developed across R_{12}. R_{13} and R_{14} constitute a voltage divider connected in shunt with plate load R_{12} of tube *4*, with R_{13} having the smaller ohmic value. The relatively small saw-tooth voltage developed across R_{13} is fed to the grid of tube *5*, resulting in an amplified saw-tooth voltage across plate load R_{15} for this tube. In this way we secure the phase inversion necessary for push-pull action. The output voltages are developed across R_{12} and R_{15}, with point *c* at a negative potential

nected to horizontal deflection plates H_1 and H_2 through d.c. blocking condensers, and consequently a saw-tooth voltage in its a.c. form is fed to these deflection plates. In the same manner, output terminals *e* and *f* of the ver-

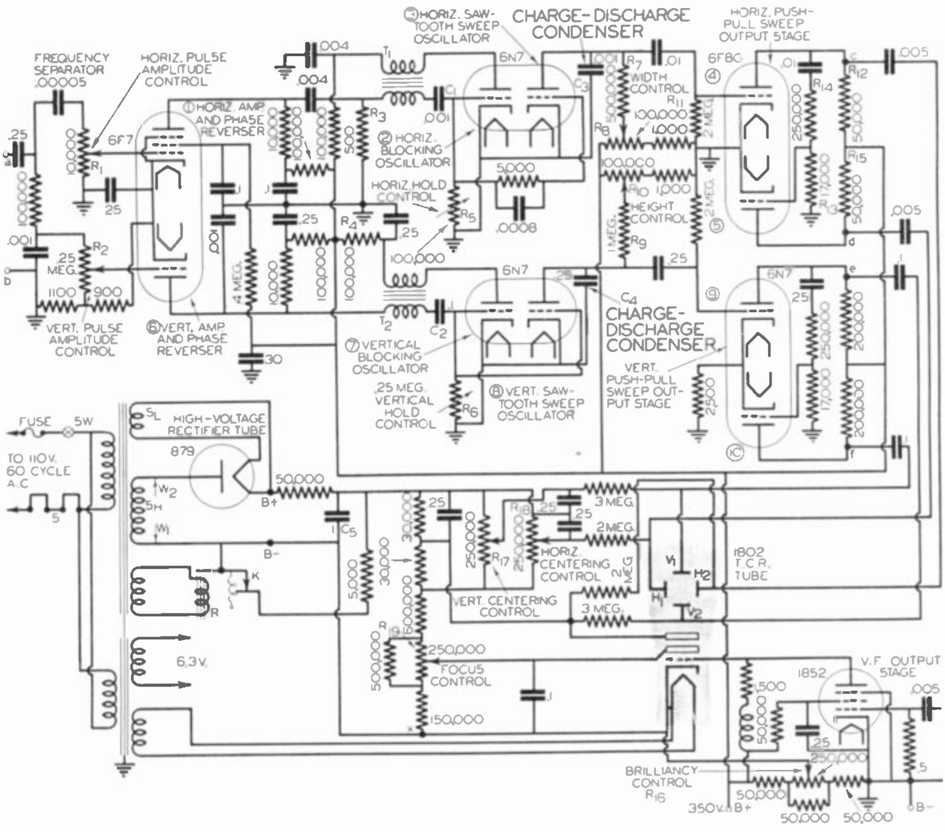


FIG. 25. Circuit diagram of a complete scanning system developed by Sherman of RCA for use with a 5-inch diameter t.c.r. tube. (The circuit has been modified and simplified slightly for instructional purposes.)

whenever point *d* is positive, and vice versa.

A similar phase inverter circuit is used for the output stage of the vertical sweep channel, with tubes *9* and *10* developing their output voltages between terminals *e* and *f*.

Output terminals *c* and *d* of the horizontal sweep channel are con-

tical sweep channel are connected to vertical deflection plates V_1 and V_2 through condensers.

Observe that output terminals *c*, *d*, *e* and *f* trace eventually to the low-voltage terminal of the t.c.r. tube power pack. This means that practically the entire second anode voltage of the t.c.r. tube is applied to the condenser in each deflecting plate lead. (The left-hand terminals of the condensers trace through the sweep channel output load resistors to a +350-volt point in the v.f. output stage and then to point x on the power pack voltage divider, while the right-hand terminals of the condensers trace through the spot-centering networks containing controls R_{17} and R_{18} to the cathode of the high-voltage rectifier tube, which in this particular circuit is at a potential of +2000 volts with respect to ground.) This means that the working voltage rating of each of these condensers must be 2000 volts or higher.

An independent power pack is used for the t.c.r. tube, in accordance with common practice. The power pack and all t.c.r. tube connections to it are either covered or well insulated to minimize danger of shock. A cover must be removed in order to make any repairs, adjustments or replacements in the power pack, and this act automatically opens interlock switches S, interrupting the primary circuit of the power transformer and de-energizing relay R, so that contacts K close. This places a 5000-ohm resistor across high-voltage filter condenser C_5, discharging it quickly. If this condenser were not discharged, it would hold its charge for a long period of time, and could deliver a serious shock to a person touching the condenser terminal or some wire connected to this terminal.

The cathode of the type 879 rectifier tube is the high-voltage or B+ terminal of the t.c.r. tube power pack, and the inside end of the high-voltage secondary winding on the power transformer is the B— or low-voltage terminal. Instead of being grounded, this B— terminal connects to the moving arm of brilliancy control potentiometer R_{16} in the voltage divider for the main receiver power pack. Thus, B— for the t.c.r. tube power pack will be somewhere around 200 volts positive with respect to ground, depending upon the setting of the brilliancy control.

Controls R_{17} and R_{18} can be adjusted to insert either a positive or negative d.c. bias voltage in a deflection circuit in order to center the image properly on the screen. Potentiometer R_{19} provides a control over the focus of the spot on the screen by varying the voltage applied to the first anode.

The only controls in this circuit which are mounted on the front panel of the receiver are brilliancy control R_{16} and focus control R_{19}; all of the other controls are somewhere in the back of the chassis, since they need be adjusted by a Teletrician only when the receiver is installed or is being serviced.

Scanning System for Unbalanced Electrostatic Deflection. A complete scanning system employing gaseous triode tubes for generation of a saw-tooth sweep voltage is shown in Fig. *26*. This circuit is designed for 3-inch and 5-inch diameter t.c.r. tubes, and uses an unbalanced arrangement for feeding the sweep voltages to the electrostatic deflecting plates.

Horizontal and vertical synchronizing impulses with a positive picture phase are fed to terminals a and b, and hence impulses swing point a in a negative direction with respect to point b and ground. Horizontal impulses are separated from vertical impulses by the input resistance-capacitance network. Horizontal pulses are then fed into amplifying and phase-reversing tube *1*, with potentiometer R_1 serving as the amplitude control for horizontal pulses. Vertical pulses are fed into phase-reversing and amplifying tube *4*, with R_2 serving as the amplitude control in this case.

in this manner is self-oscillating.

Gaseous triode tube *5* serves as the vertical saw-tooth generator, and is fed with positively-swinging pulses by tube *4*. Each gaseous triode is negatively biased by a cathode-to-chassis resistor; since current is drawn through the cathode resistors only

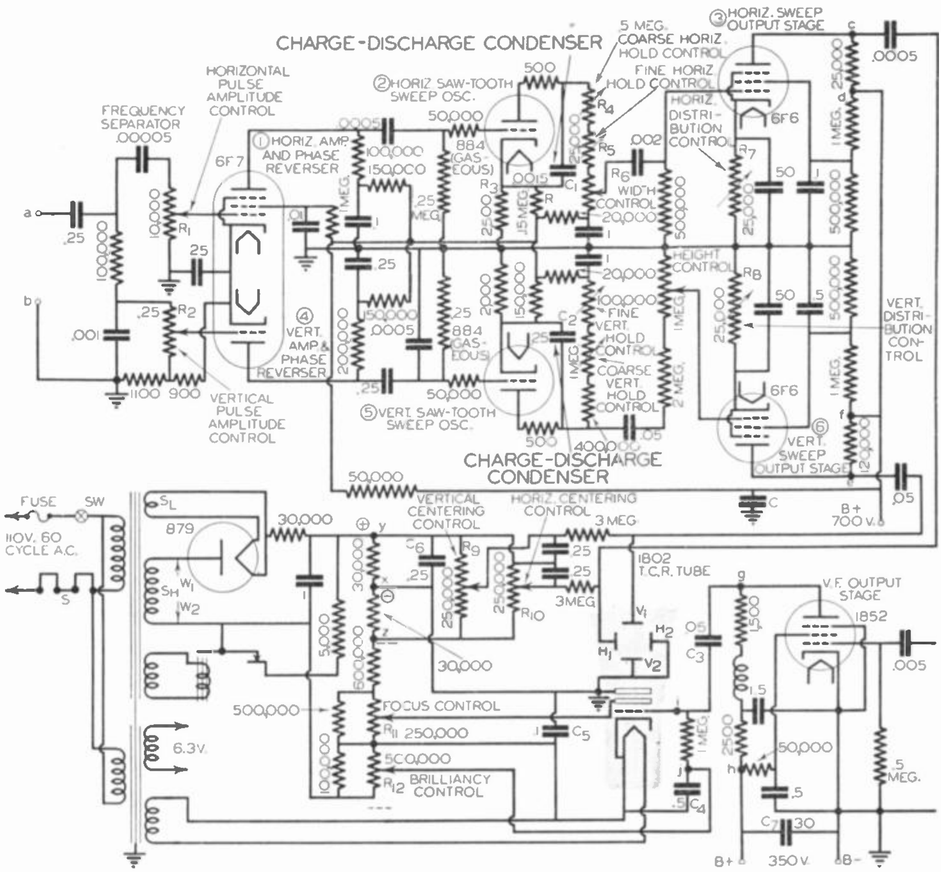


FIG. 26. Scanning system employing gas triodes as self-excited saw-tooth sweep generators.

Tube *2* is a gaseous triode serving as the horizontal sweep generator, and is fed with horizontal synchronizing pulses which make its grid swing in a positive direction with respect to the cathode. No blocking oscillator tube is used, for a gaseous triode connected

when the tubes are ignited, bleeder resistors are required to draw current through the cathode resistors at other times. Thus, resistor R in the voltage supply network connects to the cathode end of R_3. The additional C bias developed across R_3 due to plate current flow when the tube is ignited helps to extinguish the tube. Condensers C_1 and C_2 are respectively the horizontal and vertical charge-discharge condensers.

In the horizontal sweep channel, charging current for condenser C_1 passes through R_6, R_5 and R_4, and hence these resistors together with C_1 control the natural frequency of oscillation of the circuit (a 1 mfd. condenser between the lower end of R_6 and ground prevents other supply lead resistors from affecting the time constant of this circuit). R_4 and R_5 are the hold controls, with R_4 serving for coarse adjustments and R_5 for the fine or vernier adjustments. R_6 is the size control, determining the width of the image on the screen. A somewhat similar system is used in the vertical sweep channel for insuring that vertical synchronizing impulses will control the vertical sweep generator tube and for providing picture-height adjustments.

Pentode tube *3* serves as the output stage for the horizontal sweep channel, and develops its output signal between terminals *c* and *d*. In addition to amplifying and properly phasing the sweep output voltage for application to the t.c.r. tube, this stage also corrects the wave form.

You will recall that the charging curve for a condenser bends downward as time increases, as shown in Fig. *20*, and that the E_g-I_p characteristic of a vacuum tube has an upward bend near the plate current cutoff point. By adjusting the operating C bias on the sweep output amplifier stage *so that the upward bend in the grid voltage-plate current characteristic of the sweep output amplifier tube compensates for the downward bend in the condenser charging curve,* it is possible to correct the linearity of the saw-tooth sweep voltage.

Variable resistor R_7 controls the operating point on the E_g-I_p characteristic of tube *3;* since it has the effect of distributing the elements of the image uniformly along a line, it is called the *horizontal distribution control* or *horizontal astigmatic control.*

A similar distribution control, R_8, is used in the output stage for the vertical channel (in the cathode lead of tube *6*). This channel produces between terminals *e* and *f* a properly phased saw-tooth voltage at the vertical sweep frequency of 60 cycles.

Note that terminals *d* and *f* are both grounded through filter condenser *C* in the low-voltage power pack. This condenser has a high capacity, and hence acts as a short to ground for saw-tooth voltages at both the horizontal and vertical sweep frequencies. Output terminal *c* is connected to horizontal deflecting plate H_1 through a .0005-mfd. d.c. blocking condenser, while output terminal *e* is connected to vertical deflecting plate V_1 through a .05-mfd. d.c. blocking condenser. Deflecting plates V_2 and H_2 of the t.c.r. tube are both grounded directly, and hence the chassis completes the circuit between a pair of deflecting plates and the output terminals of the corresponding sweep channel. In this circuit, the blocking condensers need only withstand the 700-volt output voltage of the main power pack in the receiver.

Observe that point *x* on the voltage divider of the high-voltage power pack is grounded, along with the second anode and deflecting plates H_2

and V_2. This makes point *y* positive with respect to ground, and point *z* negative with respect to ground. The horizontal and vertical centering controls, R_9 and R_{10}, are connected between points *y* and *z*, and hence can apply either a positive or negative voltage in series with the a.c. sweep voltage in order to center the picture on the screen.

Potentiometer R_{11} in the voltage divider serves as the focus control, for its moving arm connects to the first anode. Potentiometer R_{12} serves as the brilliancy control, for it varies the fixed C bias on the control grid of the t.c.r. tube.

The v.f. output voltage appears between points *g* and *h*, with point *h* grounded through 30-mfd. condenser C_7. The cathode of the t.c.r. tube is grounded through .1-mfd. condenser C_5; both these condensers have negligible reactance to v.f. signals, hence we can consider that point *h* is directly connected to the cathode of the t.c.r. tube insofar as v.f. signals are concerned. Output terminal *g* connects to the grid of the t.c.r. tube through condenser C_3. This condenser must be able to withstand the maximum output voltage of the t.c.r. tube power pack plus the B+ voltage applied to the output tube of the v.f. amplifier. If C_3 were shorted, the full voltage of the t.c.r. tube power pack would be applied to the type 1852 v.f. output tube and to other tubes in the receiver, causing serious damage.

The presence of condenser C_3 means that the video signal is in its a.c. form when applied to the t.c.r. tube. Actually, there is no d.c. restoration in this circuit. If d.c. restoration is desired, a special d.c. restorer stage can be connected between points *i* and *j* for this purpose. D.C. restoration is not considered essential by some television engineers in receivers employing small-diameter t.c.r. tubes such as the 5-inch type 1802 tube used in this circuit.

Complete Multi-Vibrator Scanning System. A scanning system employing a multi-vibrator and designed for balanced electrostatic deflection is shown in Fig. *27*. Horizontal and vertical synchronizing impulses with a negative picture phase are developed at terminals *a* and *b* by the clipper stage, with impulses making point *a* swing in a positive direction with respect to point *b*.

The horizontal and vertical impulses are separated from each other by the input resistance-capacitance network. Horizontal pulses go to tube *1* and vertical pulses to tube *5*, both of which provide amplification and phase reversal. The amplified horizontal pulses swing point *c* in a negative direction with respect to point *d* and ground.

Tubes *2* and *3* together form a multi-vibrator type horizontal sweep generator, with C_1-L_1-R_3 making up the charge-discharge circuit. Since pulses swing the grid of tube *2* in a negative direction, and since tube *2* reverses the phase, pulses will swing the grid of tube *3* in a positive direction, thereby initiating the charging of condenser C_1.

Coil L_1 serves to correct the wave form of the saw-tooth output voltage. For the horizontal sweep channel its value should be about 100 henrys, but this value is not critical. Variable resistor R_3 serves as the horizontal hold control.

Tubes *6* and *7* constitute the vertical multi-vibrator type saw-tooth sweep generator, with C_2-L_2-R_4 making up the charge-discharge circuit. The action of this circuit is essentially the same as that of its corresponding circuit in the horizontal channel, but the values of the parts are somewhat different. L_2 in this case, for example, is about 2000 henrys.

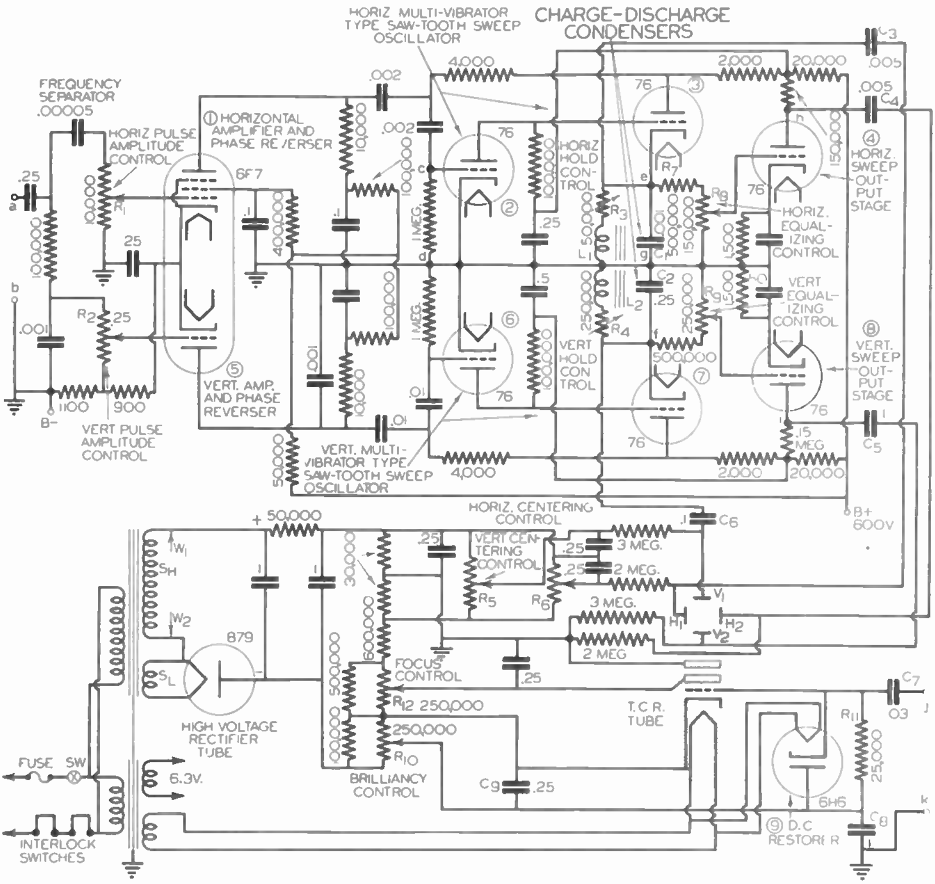


FIG. 27. Scanning system employing multi-vibrators as self-excited saw-tooth sweep generators, and providing a push-pull output for balanced electrostatic deflection.

Note that both the horizontal and vertical deflecting plates of the t.c.r. tube are of the balanced feed type, with R_5 and R_6 serving as the beam-centering controls. These centering controls apply to the deflecting plates through high-value resistors a low d.c. voltage which can be either positive or negative with respect to ground according to the requirements of the image.

A somewhat unique scheme is used to secure push-pull output voltages. The horizontal saw-tooth sweep voltage developed between points *e* and *g* by the horizontal multi-vibrator is applied to voltage divider R_7-R_8. A part of the voltage across equalizing control potentiometer R_8 is applied to the grid of tube *4*, a low-gain d.c. amplifier stage. When an impulse makes point *e* swing in a positive direction with respect to ground, the grid of tube *4* will likewise swing positive and the plate of tube *4* (point *h*) will be driven in a negative direction with respect to the chassis. The output voltage is adjusted by means of R_8 so the voltage swing in a negative direction at point *h* with respect to ground is equal to the voltage swing in a positive direction at point *e*. In the same manner, points *f* and *i* serve as the balanced output terminals for the vertical sweep channel.

Blocking condensers C_3 and C_4 are inserted in the horizontal sweep feed leads to permit only a.c. saw-tooth voltages to act upon the horizontal deflecting plates and to prevent grounding of points *e* and *h*. Blocking condensers C_5 and C_6 serve the same purpose in connection with the vertical sweep channel. Since the deflecting plates are very nearly at ground potential, these blocking condensers need only withstand the d.c. supply voltage to tubes *4* and *8* (600 volts in this case). The circuits are designed to give the correct picture size, as no size control is provided. Potentiometers R_8 and R_9 may, however, be used to a limited extent for adjusting the size of the image on the screen.

The power pack has the usual safety interlock switches. The second anode of the t.c.r. tube is grounded in this circuit, and consequently the cathode of the t.c.r. tube is at a high negative potential. A still higher negative potential which can be varied by means of potentiometer R_{10} is applied to the grid of the t.c.r. tube through resistor R_{11}, thus providing for a brilliancy control. Potentiometer R_{12} in the power pack voltage divider is connected to the first anode, and serves as the focus control.

The v.f. input to the t.c.r. tube is through terminals *j* and *k*, with *j* being connected to the plate of the last v.f. amplifier tube and *k* being a chassis connection. Condenser C_8 permits application of this v.f. input signal to resistor R_{11} without grounding R_{11} (the lower end of this resistor is at a high negative potential, as has already been pointed out). Condenser C_8 must be able to withstand the full voltage developed by the t.c.r. tube power pack. Condenser C_7 serves to separate the t.c.r. tube power pack from the v.f. amplifier power pack, and consequently this condenser must be able to withstand the sum of the voltages developed by these power packs.

Diode tube *9* serves to restore the d.c. component to the television signal after it has passed through C_7 and C_8 in an a.c. form. R_{11} acts with C_7 to provide time delay for the d.c. restorer circuit. By connecting the d.c. restorer directly to the grid and cathode of the t.c.r. tube (through C_9) in this manner, d.c. restoration can be made independent of power pack separation problems.

Complete Scanning System for Electromagnetic Deflection. When a t.c.r. tube designed for electromagnetic deflection is employed in a television receiver, the scanning system shown in Fig. *28* can be used. The first stages of this system are essentially the same as those shown in Fig. *25*, and hence need not be discussed in detail. Tube *1* serves to amplify and reverse the phase of the horizontal synchronizing pulses delivered to it by the frequency separator network, while tube *6* serves the same function in the vertical sweep channel. Tube *2* is the blocking oscillator for the horizontal channel, while tube *7* is the vertical blocking oscillator.

In the vertical sweep channel, non-linear charging of condenser C_1, and hence is known as the *vertical distribution control.*

The output of tube *9* is fed to vertical deflection coil V_L through step-down transformer T_1, which is of the auto transformer type, in order to provide a proper match between the deflection coil and the plate resistance of output tube *9*. Observe that the

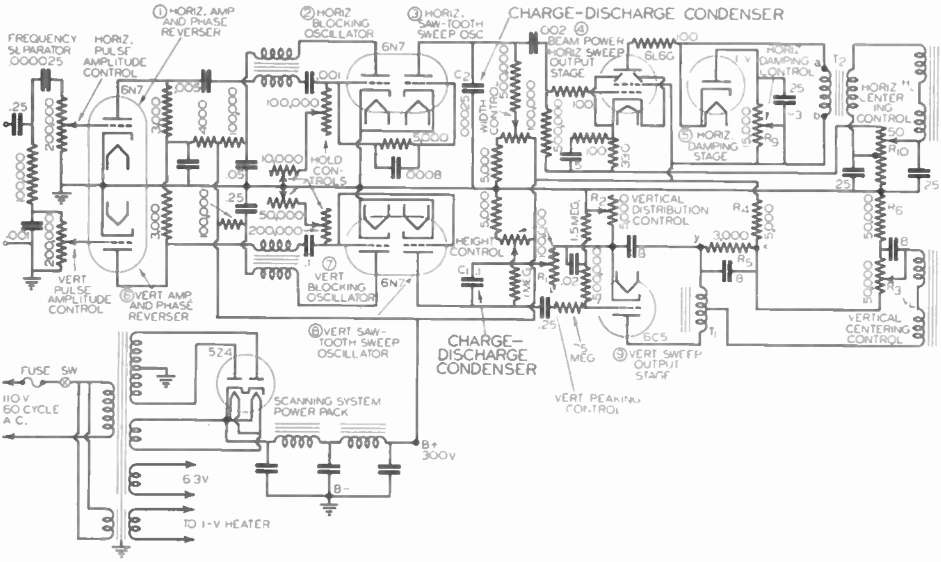


FIG. 28. Typical scanning system for electromagnetic deflection. Matching transformer T_2 and horizontal deflecting coil H_L must be able to pass all frequencies up to about 130,000 cycles to avoid distortion of the saw-tooth sweep voltage. The filament-chassis and cathode-chassis capacities of damping tube *5* will attenuate high-frequency components in the saw-tooth sweep voltage, destroying the linearity of the sweep, but this effect can be minimized by using a special filament transformer having a low primary-to-secondary capacity to serve only the type 1-V tube.

vacuum triode *8* serves as the saw-tooth sweep generator, with C_1 being charged and discharged through *peaking control* R_1 to produce the combined saw-tooth voltage shown in Fig. *18C*. This voltage across C_1 and R_1 is applied to the grid and cathode of vertical sweep output tube *9*. Cathode resistor R_2 for this tube is variable; it is adjusted to correct for d.c. plate current of the output tube flows through T_1, R_5 and R_4 to $B+$. The saw-tooth a.c. output voltage developed across the upper part of T_1 is applied to the vertical deflecting coil V_L through one section of potentiometer R_3 and through R_5, and consequently the d.c. voltage drops across these two resistors act in series with the a.c. television signal. R_3 can be adjusted so its voltage drop is either larger or smaller than the drop across R_5, thereby providing a means for centering the beam vertically on the screen.

In the horizontal sweep channel, condenser C_2 in the output circuit of tube *3* is charged and discharged to give the desired saw-tooth voltage. A horizontal deflecting coil having many turns (high inductance) would have a tremendous reactance at the line frequency, necessitating a high-voltage signal source. To eliminate this need, the horizontal deflecting coil is made with considerably less turns than the vertical deflecting coil, and a type 6L6G beam power amplifier tube (*4*) is used in the horizontal sweep output stage to provide the required higher current.

Because of the small number of turns used for H_L, its reactance is extremely low even at the line frequency of 13,230 cycles. Matching transformer T_2 steps up the impedance of H_L in order to bring it closer to the extremely high plate resistance value of the power tube (*4*), but even with this step-up, the load placed on the power tube is still essentially resistive. Since a saw-tooth voltage applied to a resistance will give a saw-tooth current through that resistance, there is no need for a peaking control in the horizontal sweep channel. We can feed an ordinary saw-tooth wave to the horizontal deflecting coil and secure satisfactory results.

An automatic damping circuit is desirable in the horizontal sweep channel of a television receiver employing electromagnetic deflection, in order *to suppress oscillations which would otherwise occur each time the saw-tooth sweep oscillator stops discharging its condenser.** Tube *5* in series with resistor R_9 forms the automatic damping circuit in Fig. *28*.

During the sweep (charge) portion of the saw-tooth voltage cycle, plate current through tube *4* is increasing, and the resulting electron flow through the primary of T_2 makes point *a* negative with respect to point *b*. Under this condition, the plate of tube *5* is positive with respect to its cathode; this tube is now conductive, placing resistor R_9 in series with the plate-cathode resistance of tube *5* across the primary of T_2. This extra resistance serves to damp the oscillations.

Plate current for tube *4* passes through a 330-ohm cathode resistor and through horizontal beam-centering control R_{10} to the chassis. By placing the movable arm of potentiometer R_{10} at one side or the other of its tap, a fixed bias voltage of the desired polarity can be inserted in the circuit. R_{10} serves as the horizontal beam-centering control.

With electromagnetic deflection, a separate power pack is invariably used for the scanning system. Under this condition, there are no direct connections between the final v.f. output stage, the high-voltage power supply and the two sweep channels.

---

* Any inductance has inertia and tends to maintain its magnetic energy. Thus, when the current is dropping along the fly-back line in Fig. *17*, and is suddenly changed in direction at point *x*, the current tends to fly beyond point *x*, or overshoot. The primary winding of T_2 in Fig. *28* (with terminals *a* and *b*) will have a certain amount of leakage inductance and distributed capacity which together form a resonant circuit. This resonant circuit will go into oscillation at the beginning of each new line (at point *x* in Fig. *17*) unless the condition is suppressed in some way; oscillation of this type would tend to distort the left side of the image.

Power Pack Problems

Scanning System Power Pack. A single power pack can be used to supply d.c. power for both the scanning system and the signal circuits of a television receiver. When voltages greater than 400 volts are needed for the scanning unit, however, it is wiser to use a separate power pack for the scanning unit.

High-Voltage Power Pack for T.C.R. Tube. From the standpoint of economy, an independent power pack should always be used for the t.c.r. tube. The generation of the high d.c. voltage required by a large t.c.r. tube introduces transformer construction problems which were relatively unimportant in sound receivers.

In the circuit of Fig. *25*, lead W_1 of high-voltage secondary winding S_H on the power transformer is at a potential of about 200 volts with respect to ground, depending upon the particular setting of R_{16}. This lead goes to the inside turns of S_H, so only a moderate amount of insulation will be needed between S_H and the iron core of the transformer.

Lead W_2 is alternately highly positive and highly negative with respect to lead W_1 and ground. If filament winding S_L for the high-voltage rectifier tube is wound over S_H, as is usual practice, a voltage equal to twice the peak value developed by S_H will exist between S_L and W_2. The insulation between S_H and S_L must therefore be adequate to withstand this voltage.

If S_L is wound near the core of the power transformer, it will always be at a high positive potential with respect to ground, and only half as much insulation will be required for this winding. In this case, however, it may be advisable to use a separate filament transformer for S_L, with adequate insulation in it to withstand the full power pack output voltage.

In the t.c.r. tube power pack circuit shown in Fig. *26*, the positive output terminal of the power pack (point y) is very nearly at ground potential. If rectifier tube filament winding S_L is wound directly over the core, normal insulation between it and the core will be sufficient. Lead W_1 will be alternately at essentially ground potential and at a high negative potential with respect to ground, and lead W_2 will always be at a high negative potential. This means that S_H must be adequately insulated from the core. If S_L were wound over the high-voltage secondary winding, double insulation would be required between S_L and S_H.

It is preferable to use the t.c.r. tube power pack connection shown in Fig. *27*. Lead W_1 on the high-voltage secondary winding is nearly at ground potential. If W_1 goes to the inside turns of S_H, only normal core insulation is required. W_2 would then come from the outside turns of S_H. Since S_L is directly connected to S_H, little insulation is required between S_L and S_H. Grounding of the positive terminal of the t.c.r. tube power pack in this way simplifies transformer design problems.

TEST QUESTIONS

Be sure to number your Answer Sheet with the *number* appearing on the front cover underneath the title of this text.

Place your Student Number on every Answer Sheet.

Send in your answers for this lesson immediately after you finish them. Doing this insures that the graded answers will reach you while the subject matter is still fresh in your mind, and you will get the greatest possible benefit from our speedy personal grading service. *Never hold up a set of lesson answers.*

1. What is the function of the clipper stage in a television receiver?
2. What is the essential requirement for a television signal before it can be fed to the clipper?
3. What section follows the clipper in a television receiver?
4. Which parts of the synchronizing impulses produce sharp pulses in the horizontal impulse acceptor circuit?
5. Name the two distinguishing features of the r-c type of vertical impulse acceptor circuit.
6. State briefly the two important reasons for having a blocking oscillator ahead of each saw-tooth sweep generator in a television receiver.
7. Should the decay time for the r-c circuit of the blocking oscillator be longer or shorter than the time between the synchronizing impulses which control that oscillator?
8. In the basic one-tube saw-tooth sweep generator circuit, which type of triode tube (vacuum or gaseous) will discharge the condenser automatically without external excitation?
9. Explain why it is possible to correct the linearity of the saw-tooth sweep voltage by adjusting the C bias on the sweep output amplifier stage.
10. Why is an automatic damping circuit desirable in the horizontal sweep channel of a television receiver employing electromagnetic deflection?

1. It separates the video signal from the synchronizing impulses.

2. The pedestals must line up.

3. The frequency separator.

4. The leading and lagging edges of the synchronizing impulses.

5. A long time constant, and removal of output pulses from the condenser.

6. 1. To help maintain synchronism with the transmitter during fading and static conditions; 2. To maintain a constant pulse intensity, insuring a constant fly-back time.

7. Longer.

8. A gaseous triode.

9. The C bias is adjusted so that the upward bend in the grid voltage-plate current characteristic of the amplifier tube compensates for the downward bend in the condenser charging curve.

10. To suppress oscillations which would otherwise occur each time the saw-tooth sweep oscillator stops discharging its condenser.

SERVICING OF TELEVISION RECEIVERS

65RH-3

THIS IS THE LAST LESSON OF YOUR COURSE

When you have completed this lesson, you should start on your final examination. Or, as a suggestion, this is a splendid point to make a thorough review, in order to get a high Grade on your Final Examination.

J. A. Dowie
Chief Instructor

TB2-2-142

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

COMMENCEMENT—AND YOUR FUTURE

This is the last regular lesson in the National Radio Institute Course. With it, you have received a thorough basic training in Radio, Electronics and Television. But more than this, you have learned to think for yourself; you have acquired the ability to locate and use printed information which has been prepared by others; you have learned to answer questions precisely, briefly and clearly—you have learned to do exactly the type of work which leaders of men must do to gain their successes.

With all these added qualifications, new developments in your chosen field should be no obstacle; you are equipped to keep in step with future developments.

It has been a real thrill for me to watch your progress through this Course, to see you "tackle and hurdle" even the "toughest" lessons in the Course. My admiration—my heartiest congratulations—my wishes for happiness and speedy success go to *you*—a man *who will not quit* when new problems arise!

J. E. SMITH.

NATIONAL RADIO INSTITUTE

WASHINGTON, D. C.

1942 Edition

A LESSON TEXT OF THE N. R. I. COURSE
WHICH TRAINS YOU TO BECOME A
RADIOTRICIAN & TELETRICIAN
(REGISTERED U. S. PATENT OFFICE) (REGISTERED U. S. PATENT OFFICE)

NCP15C542 Printed in U. S. A.

Servicing of Television Receivers

Acquiring a Safe Television Servicing Technique

THERE is no place for guess-and-try procedures in television receiver servicing. With anywhere from twelve to thirty tubes, two or even three complete power packs, and at least twice as many parts as in an ordinary sound receiver, a television receiver requires intelligent, carefully planned servicing techniques. Mere "fumbling about" is not only a useless waste of time, but may also upset receiver adjustments which are very difficult to correct.

High-Voltage Precautions. The high voltages required in a television receiver can be very dangerous, and must be treated with proper respect at all times. Receivers are provided with safety interlock switches which open automatically whenever the cover of a high-voltage section is removed, or even when the back of the receiver cabinet is removed. This precaution serves to protect both the user and the Teletrician from dangerous high-voltage terminals which would otherwise be exposed. The television servicing techniques presented in this lesson will generally work *without the presence of dangerously high voltages.*

Never attempt to close an interlock switch after removing the cover, for this will remove the protection afforded you by these switches. Always be sure that the television receiver on which you are working is completely grounded. This affords you protection in case of a breakdown between the primary and secondary windings of the high-voltage power transformer.

In those rare cases where it is absolutely necessary to work on the high-voltage power pack or make voltage measurements with power on, keep one hand in your pocket whenever the other is in the vicinity of a high-voltage lead or terminal. Furthermore, be absolutely certain that no part of your body is touching a grounded object while you are working on the chassis with one hand. If the floor of your shop is of concrete or any material which is conductive when wet, use a rubber mat on the floor, or place a platform of two-inch thick planks in front of your bench, supporting them on lengths of 2" x 2" wood. Do not use nails to assemble the platform. Furthermore, keep your workbench clean, with all equipment on it arranged in an orderly manner. These precautions will prevent a dangerously high current from flowing through your entire body in the event of accidental contact with a high-voltage terminal.

How To Handle T.C.R. Tubes. Always wear sturdy leather gloves and shatter-proof goggles when handling the larger sizes of television cathode ray tubes. These tubes are evacuated to a very high degree of vacuum during manufacture, hence normal atmospheric pressure may place tons of pressure upon the glass. A collapse of a 12-inch tube (an implosion) can be as serious as an explosion.

The large end of a t.c.r. tube, and particularly the rounded edges of the screen, must not be struck, scratched or subjected to more than moderate pressure at any time. Never place the tube on a metal surface or rest it on a table in such a way that this rounded edge might become scratched. T.C.R. tubes should never be subjected to sudden changes in temperature.

Some t.c.r. tubes are equipped with protective lids and shields. Do not at any time remove the close-fitting cone-shaped section of the protective shield, for this is designed to be installed with the tube in the receiver cabinet. Do not open the shipping carton, install, remove or handle the t.c.r. tube in any manner unless you are wearing shatter-proof goggles and heavy gloves. Warn other people to stay away from you unless they are similarly equipped. While handling a t.c.r. tube, keep it well away from your body.

The protective carton lid and the shipping carton of a t.c.r. tube should be preserved, particularly the lid, and this should be placed upon the shield whenever the tube is removed from the receiver. Discarded t.c.r. tubes *should be removed from your shop as soon as possible*, for these tubes still are a potential danger even though they are no longer useful. *Never attempt to destroy a tube yourself;* return it to your nearest t.c.r. tube distributor.

High-Voltage Filter Condenser Precautions. Always remember that the high-voltage filter condensers can store a dangerous quantity of electricity. Some receivers have automatic condenser-shorting switches which operate whenever the cover of the power pack is removed, and serve to discharge the condensers. When these switches are not present, always discharge the high-voltage condensers with a high-voltage insulated cable having a high-voltage probe at each end. Connect one end of this lead to ground first, then touch the other end to each terminal of each high-voltage condenser, holding the lead on each terminal for about five seconds. (It is a good idea to do this as an added precaution even if the receiver has an automatic condenser-shorting switch.) It is good practice to use only one hand for this, keeping the other in your pocket.

General Servicing Procedures

The procedures for locating defects in television receivers are fundamentally the same as are employed for servicing sound receivers. In both cases we have two distinct types of complaints to consider: 1. *A dead receiver;* 2. *An improperly operating receiver.* A television receiver has a *sound section* and a *sight section*, hence we must consider both conditions in each section.*

Sound Channel. The servicing of the sound channel of a television receiver need not be considered in this lesson, since the procedures involved are the same as for regular sound receivers.

In the servicing of television receivers, effect-to-cause reasoning is your most powerful tool. This applies both to the sound and sight channels, and is a fortunate condition in that it permits locating the defect without risking contact with high voltages. Learn to interpret the "story" which appears on the t.c.r. tube screen or comes from the loudspeaker, and your television servicing work will be greatly simplified.

Picture Channel. When the sight channel of a television receiver is dead (no images are produced on its screen), your problem will naturally be the locating of the defective tube, section, part or lead. This should be done in a logical manner, with elimination of surface defects coming first. Chassis tests are made with extreme care in a television receiver, and only after the high-voltage power pack has been disconnected.

When a television receiver fails to produce a satisfactory image, the na-

* According to RMA standards, a television receiver is *"a receiver having complete channels for the television picture and its associated sound."* A picture receiver is *"a receiver for pictures only, with no facilities for receiving the associated sound."* A picture receiver with sound converter is *"the same as a picture receiver, with the addition of an incomplete sound channel, requiring the use of a suitable auxiliary sound receiver."*

ture of the defect in the image will very often indicate the fault and its probable location. First of all, however, readjust all receiver controls carefully to make sure the trouble is due to an internal defect rather than to misadjustment of the controls.

Servicing Technique for Dead Television Receivers

The remainder of this text is to be devoted to the sight channels of television receivers, so let us assume that a dead television receiver is one in which no picture appears on the t.c.r. tube screen. There may, however, be a line, dot or other pattern on the screen.

Line or Spot on Screen. When the sound portion of a telecast is heard but only a vertical line is seen on the screen, you can assume that there is a defect in *the horizontal sweep channel or in its connection* to the horizontal deflecting plates of the t.c.r. tube. Although extremely rare, a stationary spot on the screen could exist, and could be due to defects in both the vertical and horizontal sweep channels; most likely, however, would be a single defect in the common power supply to these two sweep channels. Whenever you see only a single spot on the screen, always adjust the brilliancy control *immediately* to dim or extinguish the spot and prevent further damage to the fluorescent screen.

Gassy T.C.R. Tube. A blue glow in the neck of the t.c.r. tube, surrounding the elements of the electron gun, is an indication that this tube is gassy and should be replaced. A blue glow in the funnel of the tube is normal, however. Before inserting a new tube, be sure to check the filter condensers and the filter choke coil or filter resistor in the t.c.r. tube power pack for normal continuity and normal resistance, as a defect in one of these parts may have been the cause of the t.c.r. tube failure. (Excessive filter condenser leakage is indicated if the condenser feels hot immediately after the set has been turned off and the condenser terminals shorted.)

Stationary Raster on Screen. If the entire screen is illuminated by a pattern of horizontal lines (known as a raster) when the brilliancy control is at its normal position, you can determine which section the defect is in simply by adjusting the receiver controls. Advance the brilliancy control until you can see the vertical retrace lines extending diagonally across the screen. If these retraces and the horizontal lines do not wander in a vertical direction when the receiver is tuned to a television station or to a picture signal generator, you can assume immediately that the synchronizing impulses are controlling the vertical blocking oscillator; the defect will very likely be in the video frequency amplifier, somewhere between the t.c.r. tube and the point at which a connection to the clipper stage is made. You can verify this conclusion by adjusting the vertical hold control (a semi-adjustable control which determines the natural frequency of the blocking oscillator); if the lines begin wandering when you change the setting of the control, your conclusion is correct.

Moving Raster on Screen. If the horizontal lines observed on the screen wander continually right from the start and cannot be stopped by adjusting the hold control, the trouble is very likely ahead of the point to which the clipper stage is connected. If the sound portion of the television program is heard, however, you know that the preselector and mixer-first detector are all right, and can concentrate your attention upon the stages following the mixer-first detector. If no sound is heard, then the trouble will probably be in the mixer-first detector, the local oscillator, the preselector or the antenna system.

No Raster on Screen. If there is no pattern whatsoever on the screen even when the brilliancy control is advanced, first try adjusting the centering controls. Some one may have thrown these so far out of adjustment that the picture is entirely off the screen. Absence of any image whatsoever may also be due to too negative a bias on the grid of the t.c.r. tube or to failure of the high-voltage power supply for the t.c.r. tube. If effect-to-cause reasoning indicates that the trouble is in the t.c.r. tube power supply, check this as your next step.

Checking the T.C.R. Tube Power Supply. Static tests with an ohmmeter come first. Pull the receiver plug out of the wall outlet, remove the back of the receiver, remove the metal housing of the t.c.r. tube power pack, then ground each high-voltage filter condenser terminal in turn with the special high-voltage shorting cable. Allow ample time for each filter condenser to discharge completely.

Refer to the schematic circuit diagram and to the pictorial wiring diagram of the television receiver to determine tube socket terminals between which you can check for continuity and for correct resistance with your ohmmeter. If ohmmeter tests above the chassis do not reveal the defect, then remove the entire t.c.r. tube power pack chassis for more complete tests. Remember the general rule that continuity should exist between any high-voltage terminal in the t.c.r. tube circuit and the cathode of the high-voltage rectifier tube.

When a t.c.r. tube power pack defect is causing a dead receiver, an ohmmeter check will generally be sufficient to locate the defect. Only in rare cases will it be necessary to measure power pack voltages in the case of a dead receiver (voltage measurements are more necessary in improperly operating receivers).

For absolute safety, high-voltage insulating gloves such as are worn by power company linesmen should be used while checking the power pack chassis when power is on. Gloves of this type do not remain in good condition indefinitely; they should be replaced periodically. The multimeter should be properly adapted for high-voltage use as described later in this lesson, or a special high-tension voltmeter should be used. Be sure the chassis is securely grounded even when it is removed from the cabinet. If you don't use gloves, keep one hand in your pocket and keep all parts of your body away from grounded objects. Whenever high voltages are present, these precautions should be observed even when you are measuring low voltages in the t.c.r. tube circuit or its power pack, for you may accidentally come in contact with a dangerously high voltage.

Checking Signal and Scanning Circuits. If analysis or tests indicate that the high-voltage power pack and the t.c.r. tube connections to it are all in good condition, the next step is a check of signal circuits or scanning circuits, depending upon the symptoms observed. The usual preliminary circuit disturbance test or stage-by-stage elimination test may be performed once the proper precautions have been taken to disconnect the high-voltage power pack. Turn the receiver off, wait a few minutes for the filter condensers to discharge through load resistors (or discharge each condenser yourself with an insulated cable), then either unsolder the leads to the primary of the high-voltage power transformer or remove the fuse in the transformer primary lead. Do not depend upon the safety interlock switches to keep the power pack disconnected, for you might accidentally bump against one and thus close its contacts.

Circuit Disturbance Test. To make a circuit disturbance test in a dead television receiver after the t.c.r. tube power pack is disconnected, you can use an ordinary cathode ray oscilloscope or an audio amplifier with loudspeaker as an output indicator. In either case, the output indicator is connected to the plate and chassis terminals of the final v.f. amplifier tube. In the case of a c.r.o., adjust its controls until the horizontal sweep is operating and is producing a horizontal line on the screen. Now turn on the television receiver.

If you are dealing with a completely dead television receiver, only a horizontal line will appear on the c.r.o. screen. When any stage is electrically disturbed, the surge will be relayed to the end of the system, where it will produce an erratic vertical displacement on the c.r.o. screen (a click in the case of a loudspeaker) if all stages between the source of the disturbance and the c.r.o. are in working order. Since single-ended metal tubes are widely used in television receivers, the disturbance test will generally be done by pulling out and reinserting each tube in turn. Always wear gloves when pulling tubes, for metal tubes can become quite hot during normal operation.

Starting at the v.f. output stage, work toward the antenna input terminals, introducing a disturbance in each stage in turn along the line by pulling and reinserting tubes. Having located the defective stage (the first one which will not pass the disturbance), test the tube in this stage, then remove the chassis and test parts and connections in this stage in the usual manner with a multimeter. If no indication is secured for the v.f. output stage, check the power pack.

Checking Sweep Circuits With a C.R.O. If your initial analysis indicates a defect in one of the sweep channels, connect a c.r.o. to the output of the suspected channel. If the blocking oscillator and the following stages are working, you should get a saw-tooth voltage wave on the c.r.o. screen when you synchronize the c.r.o. horizontal sweep circuit with the sweep channel output frequency. Failure to get this saw-tooth sweep voltage indicates a failure or defect either in the charge-discharge circuit, the blocking oscillator circuit, or in the power supply connection for that channel. If neither channel gives the correct output voltage, look for a defective connection or part in the common power supply for both channels.

Dynamic Stage-By-Stage Defect-Isolation Test. The defective stage in a television receiver can just as well be located by employing a dynamic isolation test in which the c.r.o. is advanced stage by stage from the output of the video detector to the output of the last v.f. amplifier stage while a signal generator is connected to the video detector input. The signal generator is then advanced stage by stage from the video detector input toward the antenna while the c.r.o. is connected across the video detector output. An ordinary all-wave signal generator can be used, provided it can produce a fundamental or harmonic frequency equal to a video r.f. carrier value, and can be modulated with an audio tone.

Improperly Operating Receivers

When an image of some sort appears on the screen of a television receiver, but is streaked with queer patterns, lacks definition, moves around, lacks contrast, has improper background brilliancy, has double images or has some other defect which makes viewing unsatisfactory, the television receiver is operating improperly. A few minutes spent upon effect-to-cause reasoning in a case like this really pays, so do not be too anxious to look into the chassis. Here are some reasons why you should think before you act.

Check All Receiver Controls. First of all, make certain that the observed image defect is not due to misadjustment of the receiver controls by the owner. Tune in the best possible image with the front-panel controls, then check the semi-adjustable controls at the back of the receiver. A television receiver can operate improperly even when no circuit defect exists, if these controls are not adjusted properly.

Inability of the synchronizing impulses in the transmitted signal to hold the image steady may be due to improper setting of the hold controls. These controls may have been originally set too close to the limit of their adjustment range. Improper picture size, improper centering of the image, and non-linear distribution either horizontally or vertically are all difficulties which can generally be corrected by resetting the semi-adjustable controls.

Is Better Performance Possible? The limitations of the television receiver on which you are working should be given full consideration, for the customer may be expecting far more in the way of performance than the receiver is capable of giving. A study of the circuit diagram and a knowledge of the capabilities of the television receiver in question will tell you when it is useless to attempt an improvement in performance.

Is Trouble Outside of the Receiver? Streaks in the image, snow-storm spots scattered over it, or queer patterns superimposed upon the desired image may be due to outside interference or to a reduction in antenna pick-up due to a change in the antenna system. For example, if the original antenna gave just enough pick-up for a satisfactory signal, any deterioration of the antenna system may lower the signal-to-noise ratio enough to make picture reception unsatisfactory. Ghosts and blurred images may be due to an improper antenna installation or to some change made in the vicinity of the antenna after its initial installation.

Using Effect-to Cause Reasoning. Having made certain that the observed type of improper operation is due to a circuit defect, effect to-cause reasoning can be put to good use. For example, black or white horizontal bands in the image, either fixed or moving up or down on the screen, may be due to power line a.c. in the signal circuits. Distorted images may be due to power line a.c. in the scanning system; if the edges of the image are wavy when the size of the image is reduced, you have verification of this trouble.

Lack of high definition in the image may be due to excessive shifting of the local oscillator frequency, so that the video i.f. side frequencies corresponding to the higher video frequencies do not get through the video i.f. channel. Improper background brilliancy may also be due to oscillator frequency shift.

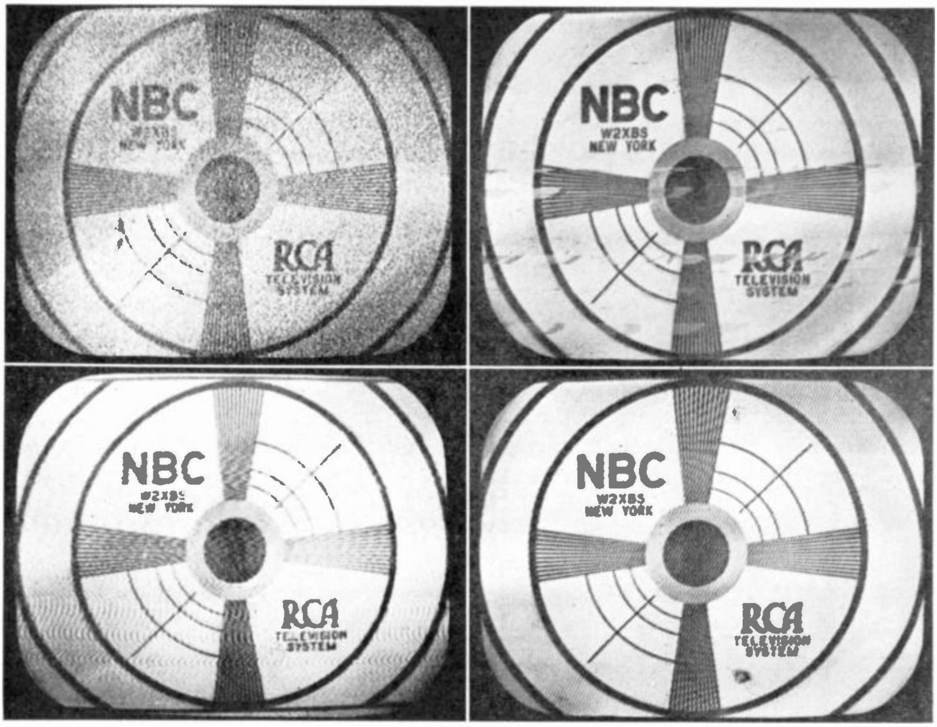
A poor connection anywhere in the receiver may cause snow storms on the image, or on-and-off flashing of the image. If hiss is heard in the sound channel at the same time, this trouble may be due to interference originating outside of the receiver (shorting the antenna and ground terminals together should eliminate the interference pattern in this case). Interference observed in both the sound and sight channels may originate in sections ahead of the mixer-first detector, since these are common to both channels.

Lack of adequate hold (a moving image) accompanied by fading of the image may be due to a defect in the automatic gain control system, especially if the output volume of the sound channel remains constant during fading of the picture.

Servicing techniques for the various conditions under which improper operation may occur will now be considered separately.

Outside Interference

When the complaint is noise interference which is causing snow storms or streaks in the picture, the remedy



Courtesy RCA Mfg. Co., Inc.

Effects of interference upon a typical test pattern as reproduced on a television receiver screen. The pattern is that used by NBC television station W2XBS in New York City.

Upper left: Effect of too weak a signal upon the test pattern. Under this condition, receiver sensitivity is a maximum, and tube hiss gives the effect of a snowstorm on the screen. External noise interference may also appear on the screen when the signal is too weak. The remedy involves improving the pick-up of the antenna system.

Upper right: Auto ignition interference is being picked up by the receiving antenna or transmission line, causing speckles, streaks, white or black spots and momentary loss of synchronization. Move the antenna farther away from the street.

Lower left: Interference produced by diathermy equipment in a hospital or doctor's office. In some cases, the interference pattern may drift up and down on the screen. Increasing the efficiency of the antenna system may help; otherwise, locate the offending machine and cooperate with the owner in reducing the amount of interference which is radiated.

Lower right: Beat frequency interference, due to a heterodyne beat between the picture carrier and a harmonic of some local sound or picture transmitter.

Mastery of the theory and operating principles of television receivers, coupled with actual experience with these receivers, will enable you to apply effect-to-cause reasoning successfully to the servicing of improperly operating television receivers. Servicing techniques for the various conditions under which improper op-

is essentially a matter of moving the antenna to a location which is less susceptible to the noise signals. Tune the receiver to a telecaster, and try various antenna locations while watching the image, until an antenna position is found which gives a satisfactory signal-to-noise ratio. When ghost images, blurring or phase interference effects are due to reception of reflected signals along with the direct signal, the same procedure is used.

If automobile ignition interference is a source of trouble, the antenna should be moved away from the road or street. If a diathermy machine is causing trouble, it should be located. A directional receiving antenna which is oriented to give maximum rejection of signals from this machine can then be installed. When external noise interference cannot be eliminated by shifting or adjusting the antenna, the interference source must be traced and the trouble eliminated at the source by installing suitable filter condensers, chokes and shielding screens.

Phase interference will not be directly visible on the screen. It can be suspected, however, whenever pick-up is inadequate in a location where a better signal-to-noise ratio can be expected and the antenna system has already been checked for continuity and leakage. The remedy involves changing the antenna position, changing the length of the transmission line, or changing the line terminations, as the case may be.

When erratic splotches are seen on the screen, indicating a loose connection, prove to yourself where they originate by grounding both antenna terminals. Of course, no image will be seen under this condition, but if the splotches are still present when the brilliancy control is advanced, you know that the trouble is in the receiver rather than in the antenna.

Educating the Customer

Manufacturers of television receivers have used every possible means to make the tuning of their sets as simple as possible. In most cases the actual tuning in of a station is accomplished instantly either by pressing a button or by turning a selector switch. In some sets, a fine tuning control is provided, giving vernier tuning as a supplement to instantaneous tuning. In any event, one tuning control takes care of both the sight and sound portions of the television program.

Oscillator frequency drift will affect the sound portion of a television program far more than it will the sight portion. If the sound becomes distorted in a receiver employing pre-set tuning controls, the local oscillator control may require resetting.

With receivers having manual tuning, it is essential that the customer tune for the clearest and loudest sound output, as this automatically tunes in the picture portion of the program. Failure to get high-definition pictures when this is done may indicate either improper oscillator adjustment or a very large error in the alignment of either the sound or video i.f. channel. This alignment can be checked with an ordinary all-wave signal generator.

The focus, contrast and brightness controls will generally give the customer far more trouble than will the tuning controls. Adjusting the focus control for the sharpest possible image (maximum detail) is usually quite simple, and generally is satisfactory. Of course, adjusting for normal line width would be better; this can be done even when no station is on the air, merely by advancing the brilliancy control and adjusting until the lines are as wide as possible without blending together; in other words, each line must be distinctly visible.

Be sure to explain to the customer the interaction between the contrast and brilliancy controls. Point out that the contrast control should be adjusted until elemental details in the image are clear. The brightness control should then be adjusted until the background has the correct brightness. Tell the customer that these adjustments should be repeated once.

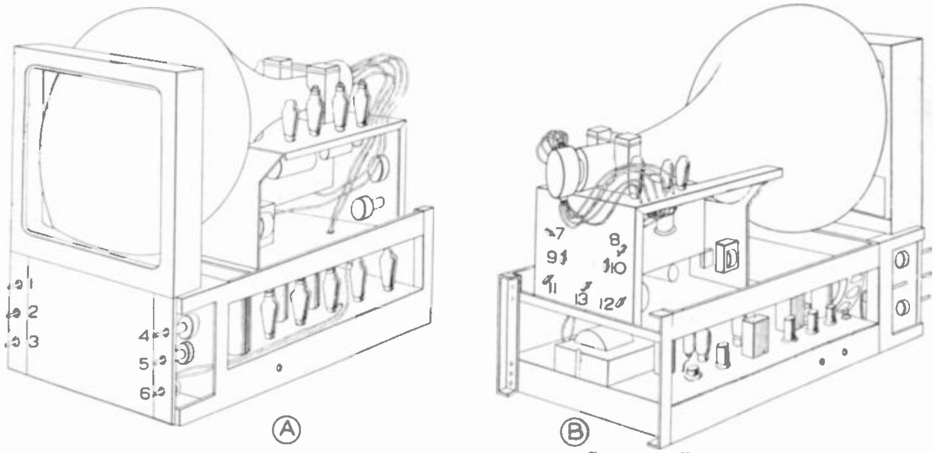
Pre-set Adjustments

The front panel controls for a typical television receiver are shown in Fig. *1A*, and the pre-set controls for this same receiver are shown in Fig. *1B*. The pre-set controls are of the knob type in this case, but you will also encounter screw-driver type controls. Both types may either be grouped together at the back of the chassis or scattered on the chassis to simplify wiring. It is generally necessary to refer to the chassis layout diagram of a television receiver to determine the location and purpose of each pre-set control.

Centering and Size Controls. Two important pairs of pre-set controls are the *picture-centering controls* and the *size controls*. The vertical centering control moves the entire picture vertically up or down, while the horizontal centering control moves the entire picture horizontally to the left or right as required. The size controls change the *width* and *height* of the picture on the screen.

Preliminary adjustment of the centering and size controls can be made even when no station is tuned in. First of all, turn the receiver on. As soon as the tubes warm up, the blocking oscillators will sweep the beam horizontally and vertically. Advance the brightness control until the horizontal lines are visible. The sweeps will now be "free-running" at the natural frequencies of the horizontal and vertical blocking oscillators. Adjust the height and width controls until all four edges of the pattern can be seen on the screen, adjust the centering controls until this pattern is exactly in the center of the screen, then readjust the size controls until the pattern fills the entire mask on the screen. The amplitudes of the saw-tooth sweep voltages will change when synchronizing impulses are present, so make a final check of these controls while a station is tuned in, in order to make the image exactly fit the mask on the screen.

Hold Controls. The next pre-set controls to adjust are the horizontal and vertical hold controls, associated with the horizontal and vertical saw-tooth sweep oscillators respectively. Tune in a television station. If one is not on the air, you can use an ultra-high frequency signal generator which



Courtesy Allen B. DuMont Labs., Inc.

FIG. 1. Front and rear views of DuMont type 180 superheterodyne television receiver, employing 22 tubes including the 14-inch diameter t.c.r. tube. The six front-panel tuning controls shown in view *A* are: *1*—Contrast and ON-OFF; *2*—Station Selector; *3*—Fine Tuning; *4*—Brightness; *5*—Focus; *6*—Volume. The seven pre-set controls shown on the rear panel in view *B* are: *7*—Vertical Hold; *8*—Horizontal Hold; *9*—Vertical Centering; *10*—Horizontal Centering; *11*—Height; *12*—Width; *13*—Linearity Control (also called astigmatic or distribution control).

is modulated by picture and synchronizing impulses, feeding its output into the antenna and ground terminals of your receiver. Adjust the brightness and contrast controls on the front panel until some modulation of the beam (a pattern) is observed. If the picture is now moving up or down on the screen, adjust the vertical hold control carefully until the picture is stationary. If the horizontal control is originally out of adjustment, part or all of the picture will be jumbled; adjust this control until the jumbling disappears and the desired stationary picture is evident. If coarse and fine hold controls are provided, set the *fine* control in its mid-position, adjust the *coarse* control, then make final adjustments with the *fine* control. Finally, readjust the contrast and brilliancy controls until the picture is clear and bright.

Odd Effects. In adjusting the hold controls, several odd effects may be observed. You will recall that the natural time for each cycle is longer than 1/60th second for the vertical blocking oscillator and longer than 1/13,230 second for the horizontal blocking oscillator. (If these times were shorter, synchronizing impulses could not take over normal control under any condition.)

Two Pictures Side by Side. It is perfectly possible to have the horizontal hold control so adjusted that the horizontal blocking oscillator is free-running at one-half the correct frequency (a time of about 1/6,615 second per cycle). The synchronizing pulses will be present at the beginning and middle of each blocking oscillator cycle, but will not be strong enough at the middle of the cycle to cause discharge and give the correct horizontal sweep frequency. As a result, the *output frequency* of the saw-tooth sweep generator is half the correct value, and the amplitude of the output voltage is a little higher than normal. This means that two complete horizontal lines will affect the electron beam during each horizontal sweep, and we will see two essentially identical images side by side on the screen, separated by a vertical black line approximately in the center of the screen. To correct this condition, simply adjust the horizontal hold control to *decrease* the amount of resistance it places in the horizontal blocking oscillator circuit.

Sometimes there will be a control which varies the amplitude of the synchronizing pulse which is fed into the blocking oscillator; increasing the pulse amplitude by means of this control will make control of the blocking oscillator by the synchronizing impulses more dependable.

Two Pictures, One Above the Other. A similar analysis will show that two essentially identical images, one above the other on the screen, separated by a horizontal black line approximately in the center of the screen, occur when the vertical blocking oscillator is allowed to run freely at about 30 cycles. Reducing the resistance which the vertical hold control inserts in the circuit will bring the natural frequency up to the correct value of almost 60 cycles. If a control for varying the amplitude of the pulse fed into the vertical blocking oscillator is present, it can be adjusted to improve the dependability of operation.

Left Half of Picture Superimposed on Right Half. If the horizontal blocking oscillator is allowed to run freely at one-half the correct time (twice the correct frequency), we will see an image with the right-hand half superimposed on the left-hand half. This occurs because the beam is swept horizontally back and forth twice for each line of the picture, with the horizontal blocking oscillator being controlled only by every other horizontal synchronizing pulse. The remedy is to increase the resistance of the horizontal hold control.

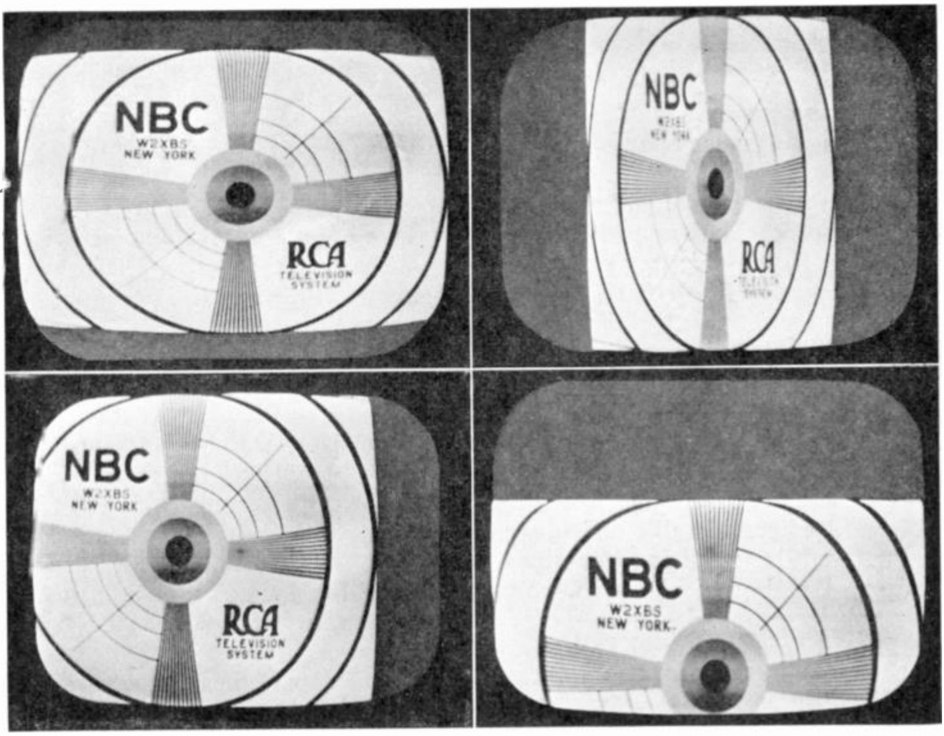
Top Half of Picture Superimposed on Bottom Half. If the vertical blocking oscillator is allowed to run freely at half the correct time (twice the correct frequency), we will see the lower half of the image superimposed on the upper half. Increasing the resistance of the vertical hold control will remedy the situation.

Ordinarily it is not sufficient to adjust the hold controls for a stationary image. Because interference is invariably present, the hold controls must be advanced so as to give a longer free running period in each case than might ordinarily seem necessary. This insures the synchronizing pulses will be essentially the only controls on the sweep rates. The hold controls should not be advanced too far, however, for then double images will occur, and weak synchronizing impulses will lose their hold on the image too easily.

Vertical Pulse Amplitude Control. Although interlacing of lines is more or less automatic, improper discharging of the condenser in the vertical sweep circuit may give improper centering between lines. This can be due to building up of the vertical pulse in the frequency separator either too early or too late for proper initiation of discharge. This condition can be corrected by adjusting the amplitude of the pulse fed into the vertical blocking oscillator. In some cases a biasing control on the amplifier stage ahead of the vertical blocking oscillator will be provided for this purpose; look for it.

Linearity Controls. Some television receivers will have one or more *linearity controls,* also known as distribution or astigmatic controls. These controls serve to make their respective sweep voltages linear. When these controls are present, adjust them until the proportions of objects at all parts of the picture seem normal. Better yet, focus the beam sharply, then adjust the *vertical* (*top* and *bottom*) *linearity* controls until the lines on the screen are the same distance apart at all points, and adjust the *horizontal* (*right* and *left*) *linearity* controls until the proportions of all objects in the picture are normal (none is unusually wide or narrow).

Peaking Control. In television re-



Courtesy RCA Mfg. Co., Inc.

These photographs of an actual test pattern reproduced on the screen of a television receiver show the effects of improper settings of the semi-adjustable centering and size controls at the back of the receiver chassis.

Upper left: Picture on screen is too short, due to improper setting of the height control.

Upper right: Picture is too narrow, due to improper setting of the width control.

Lower left: Picture is too far to left on screen, due to improper setting of horizontal centering control.

Lower right: Picture is too far down on screen, due to improper setting of the vertical centering control.

ceivers employing electromagnetic deflection, you will often encounter two other pre-set controls. One is the *peaking control* associated with the charge-discharge condenser in the vertical scanning channel. This controls the amplitude of the square-wave pulse on which the saw-tooth signal "rides." It affects the linear displacement of the lines at different parts of the screen, and hence must be set to give uniformly spaced lines all over the screen.

Damping Control. In the horizontal sweep channel you may find a *damping control*, associated with the damping stage. If this control is not properly set, oscillations will occur at the start of each charging cycle, and will tend to blur the left side of the picture and make this side excessively bright. This damping control should therefore be adjusted for maximum clearness at the left side of the screen.

Final On-the-Air Test. With all pre-set controls adjusted, a final test with a telecaster tuned in is ordinarily sufficient. If considerable difficulty is encountered in adjusting for linear horizontal and vertical sweep, however, it is sometimes desirable to check the linearity of sweep more accurately with the aid of a signal generator.

Linearity Adjustments With an Audio Signal Generator. An ordinary audio signal generator is connected to the grid and cathode terminals of the t.c.r. tube, and is set at some multiple of 60 cycles (1,920 cycles, the 32nd multiple, is a good value). With the set turned on but no station tuned in, the sweep circuits will run free at their natural frequencies. Under this condition, positive alternations of the signal generator output voltage will swing the t.c.r. tube grid positive and allow horizontal scanning lines to show; negative alternations will blank out the horizontal lines, giving a black horizontal bar across the entire screen for the duration of each negative alternation. The effect will be alternate black and white horizontal bars across the screen. An image like this, appearing when no television station is tuned in, is called a *test raster.*

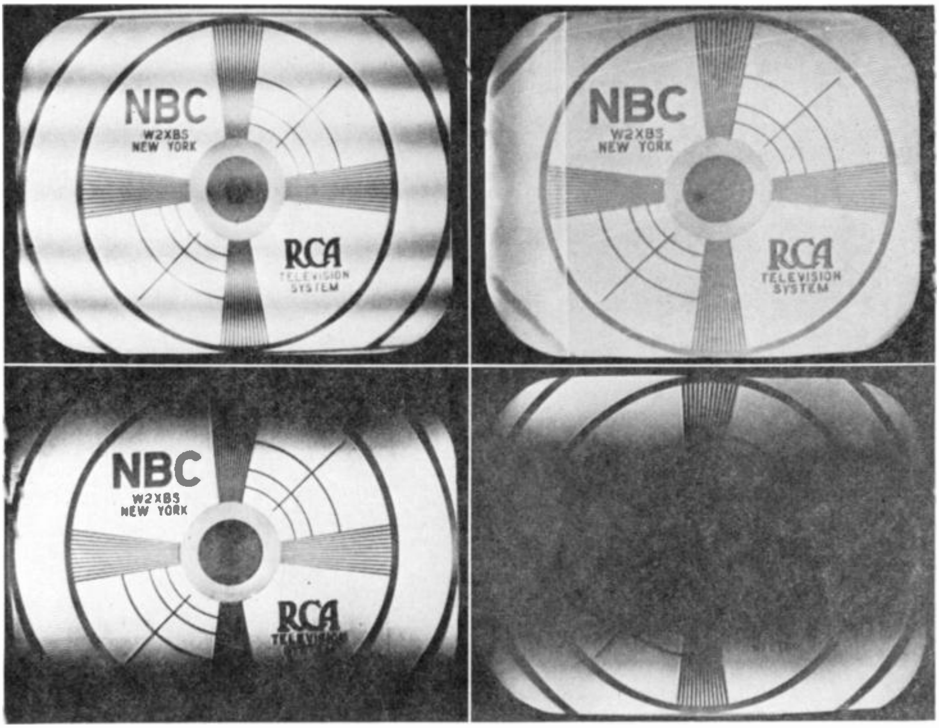
To stop vertical movement of the raster, connect the signal generator output terminals also to the input of the vertical sweep channel. Adjust the amplitude control at the input of this channel (at the output of the frequency separator) until the pattern of black bars becomes stationary and does not flicker. The number of black bars will be equal to the multiple; thus, the 32nd multiple of 60 cycles (1,920 cycles) will give 32 black horizontal bars on the screen. The vertical peaking control and the top and bottom linearity controls should now be adjusted so that all bars *are uniform in width and are uniformly spaced apart.*

If the d.c. restorer is disconnected or made ineffective, the audio signal generator may be connected to the input of the v.f. amplifier instead of to the t.c.r. tube. In this case, the audio signal will be fed automatically to the vertical sweep channel for synchronizing purposes.

The linearity of the horizontal sweep channel can be checked by feeding into the grid and cathode of the t.c.r. tube a signal which is some multiple of 13,230 cycles. If a signal having 40 times this frequency is used, 40 vertical lines or bars will be observed on the screen. The signal generator in this case should be connected to the input of the horizontal sweep channel, to synchronize the horizontal sweep with the signal generator output and give a stationary pattern. If the horizontal sweep is linear, these vertical bars will be equal in width and will be equally spaced apart; if not, the left and right linearity controls should be adjusted.

Television Trouble-Shooting Chart

An improperly-operating television receiver is literally a sign-post pointing out probable locations of the trouble. Special test patterns which are transmitted by television stations from time to time, particularly at the beginning of a telecast, assist the Teletrician in diagnosing the nature of the defect. A number of photographs of the NBC test pattern, as seen on a television receiver under different receiving conditions and with different receiver faults, are included in this book; a careful study of these photos and of the following television trouble-shooting chart will assist you in developing the ability to reason from observed effects to their logical causes.



Courtesy RCA Mfg. Co., Inc.

Upper left: Moving horizontal black and white bars like this indicate that sound signals (simple tones) are affecting the video channel. Adjustment of the fine tuning control may clear up the trouble; if not, check the sound i.f. rejector circuits in the video i.f. channel.

Upper right: Effect of damping tube failure in a receiver employing electromagnetic deflection. In general, damping circuit defects cause blurring or improper brightness at the left side of the picture, due to transient oscillations which occur when the horizontal charge-discharge condenser begins d arging again at the start of a new horizontal sweep.

Lower left and lower right: Excessive 60-cycle ripple in the video amplifier. Either one or two horizontal black bars occur, depending upon the phase.

The nature of the observed effect on the television screen is described in the left-hand column of the chart, while the probable causes for this effect are listed in the middle column, and remedies are given in the right-hand column. Unless otherwise indicated, assume that the sound section of the television receiver is performing satisfactorily and that all picture characteristics except those mentioned in the left-hand column are essentially normal.

It would clearly be impossible to give directions for finding and correcting all of the possible troubles which could occur in the various models of television receivers. Most of the common troubles and their remedies are

TELEVISION TROUBLE-SHOOTING GUIDE

(Sound channel is operating normally unless otherwise specified)

OBSERVED EFFECT	PROBABLE CAUSES	REMEDIES
1. No image, pattern or spot on t.c.r. tube even when brilliancy control is fully advanced.	1. Failure of high-voltage power pack. Excessively high negative bias on t.c.r. tube grid. Image or pattern is entirely off the screen. Defective t.c.r. tube.	1. Check high-voltage power pack. Check t.c.r. tube bias. Check settings of beam-centering controls. Try another t.c.r. tube.
2. No image. Raster is present. Back traces are visible when brilliancy control is advanced, and are stationary.	2. Defect in video amplifier or its power supply connections. (Stationary raster indicates synchronizing impulses are controlling sweep circuits.)	2. Check tubes, parts and leads in the v.f. amplifier between the clipper connection and the t.c.r. tube
3. No image. Raster is present. Back traces are visible when brilliancy control is advanced, but are moving.	3. Defect in video i.f. amplifier, video detector, video amplifier stages ahead of clipper input connection.	3. Check tubes, parts and leads in signal and supply circuits of suspected stages. (Moving raster indicates synchronizing impulses are not controlling vertical blocking oscillator.)
4. No image. *No sound.* Raster is present. Back traces are visible when brilliancy control is advanced, but are moving. Telecaster is known to be on air.	4. Defect in receiving antenna, preselector, oscillator or mixer-first detector. (Moving raster and absence of sound indicates that no signals are getting through the mixer-first detector output circuit.)	4. Check tubes, parts and leads in signal and supply circuits in and ahead of mixer-first detector. Check the low-voltage power supply serving these stages. Check the antenna system.
5. Only a spot on t.c.r. tube screen. (No saw-tooth voltage on horizontal and vertical deflecting plates.)	5. Failure of power pack which serves sweep system. Defect in any voltage supply lead or part which is common to both horizontal and vertical sweep channels.	5. Check power pack serving sweep system, particularly the rectifier tube and filter condensers. Check common voltage supply connections to both sweep channels.
6. Horizontal line only. (No saw-tooth voltage on vertical deflecting plates.)	6. Failure of the vertical sweep channel, due to a defect in the vertical blocking oscillator stage or between this stage and the vertical deflecting plates.	6. Check tubes, parts, leads and supply voltages, working from vertical blocking oscillator to vertical deflecting plates.
7. Vertical line only. (No saw-tooth voltage on horizontal deflecting plates.)	7. Failure of horizontal sweep channel, due to a defect in the horizontal blocking oscillator stage or somewhere between this stage and the horizontal deflecting plates.	7. Check tubes, parts, leads and supply voltages, working from vertical blocking oscillator to horizontal deflecting plates.
8. Insufficient picture width. (Horizontal sweep voltage too low.)	8. Improper setting of horizontal size control. Defective tube, defective part or improper supply voltages in horizontal saw-tooth sweep oscillator stage or horizontal sweep output stage.	8. Adjust horizontal size control. If picture is still too narrow, check tubes, parts and supply voltages in horizontal output stages.
9. Insufficient picture height. (Vertical sweep voltage too low.	9. Improper setting of vertical size control. Defective tube, defective part or improper supply voltages in vertical saw-tooth sweep oscillator stage or in vertical sweep output stage.	9. Adjust vertical size control. If picture is still too short, check tubes, parts and supply voltages in vertical saw-tooth sweep oscillator stage and vertical output stage.
10. Picture not centered with respect to mask. (Shifted to one side, to top or to bottom.)	10. Improper setting of vertical or horizontal beam centering control, giving improper bias on deflecting plates. Electromagnetic deflecting coils improperly positioned.	10. Adjust beam-centering controls. Adjust positions of electromagnetic deflecting coils; always turn off power when working on deflecting coils.
11. Picture is tilted with respect to mask.	11. Magnetic deflecting coils are not properly oriented. Electrostatic deflection type t.c.r. tube is not properly oriented.	11. Rotate electromagnetic deflecting yoke or entire t.c.r. tube until the tilt is eliminated. Turn off power when making adjustments.
12. Two narrow, full-height pictures side by side, separated by a black vertical bar.	12. Horizontal sweep circuit is operating at one-half normal frequency due to improper setting of horizontal hold control.	12. Increase frequency of horizontal tal blocking oscillator by adjusting horizontal hold control.
13. Two short, full-width pictures one above the other, separated by a black horizontal bar.	13. Vertical sweep circuit is operating at one-half normal frequency due to improper setting of vertical hold control.	13. Increase frequency of vertical blocking oscillator by adjusting vertical hold control.
14. Right-hand half of picture superimposed on left-hand half.	14. Horizontal sweep circuit is operating at twice normal frequency due to improper setting of horizontal hold control.	14. Decrease frequency of horizontal blocking oscillator by adjusting horizontal hold control.
15. Bottom half of picture superimposed on top half.	15. Vertical sweep circuit is operating at twice normal frequency due to improper setting of vertical hold control.	15. Decrease frequency of vertical blocking oscillator by adjusting vertical hold control.

OBSERVED EFFECT	PROBABLE CAUSES	REMEDIES
16. Entire picture slips or moves up or down. Picture is clear, with normal contrast and no abnormal interference patterns.	16. Vertical sweep channel is not "holding on to" vertical synchronizing impulses. Pulses at the input of the saw-tooth sweep generator may be too weak.	16. Check for defective parts or tubes in the vertical sweep channel, the frequency separator, the clipper and any synchronizing impulse amplifier stages if adjustment of the vertical hold control does not clear up the trouble.
16A. Same as above but with interference patterns.	16A. Excessively strong static or man-made interference pulses may be taking over control of the vertical sweep channel, or video signals may be getting through the clipper and affecting the vertical sweep generator.	16A. Listen to the vertical sweep output with headphones (high voltage off); video signals in this sweep channel may give a raspy tone instead of the usual steady tone (some sweep generator circuits will not pass video signals, so this test is not conclusive.) Adjust the hold controls.
17. Entire picture slips or moves up or down. Picture is dim, with poor contrast and interference patterns.	17. The v.f. signal at the input to the clipper is too weak, indicating trouble somewhere ahead of the clipper, a poor antenna system, or too low signal strength at the receiver location.	17. Check all tubes and parts for defects which could cause low gain in stages between the clipper input and the antenna. Check the antenna system for signal pickup and interference pickup. Readjust vertical hold control.
18. Part of the picture (usually at the top) is highly distorted and shifted in a horizontal direction. Rest of picture is clear, with normal contrast and no abnormal interference patterns. No vertical movement.	18. Horizontal sweep channel is not "holding on to" horizontal synchronizing impulses, with result that picture "tears." Pulses may be too weak at the input of the saw-tooth generator. Video signals may be getting through the clipper and affecting the horizontal sweep generator.	18. Check for defective parts or tubes in the horizontal sweep channel, the frequency separator, the clipper and any synchronizing impulse amplifier stages if adjustment of the horizontal hold control does not clear up the trouble.
19. Part of the picture is highly distorted and shifted in a horizontal direction. Picture is dim, with poor contrast and interference patterns.	19. The v.f. signal at the input to the clipper is too weak, indicating trouble somewhere ahead of the clipper, a poor antenna system, or too low signal strength at the receiver location.	19. Check all tubes and parts for defects which could cause low gain in stages between the clipper input and the antenna. Check the antenna system for signal pickup. Readjust horizontal hold control.
20. All parts of picture are fuzzy—not clearly defined — and fine details are blurred.	20. Electron beam may not be properly focused on t.c.r. tube screen, due to improper focusing electrode (first anode) voltage.	20. Adjust focus control for maximum clearness of sharply defined lines in picture. If this does not help, check the focus control and associated parts in the voltage divider of the t.c.r. tube power pack.
21. Only the fine details in the picture are blurred or absent. Particularly noticeable on distant scenes or long studio shots.	21. Loss of higher video frequency components, due to attenuation of these components somewhere in the receiver. Consider whether it is due to original limitations in receiver performance.	21. Check alignment of video i.f. coupling units. Look for defects in the coils, condensers, resistors, and leads of coupling and equalizing circuits in the video i.f. amplifier, video detector and v.f. amplifier.
22. Picture is smeared, with white or black shadows at the right of each object.	22. Loss of lower video frequency components, accompanied by excessive phase shift at low frequencies.	22. Look for a shorted low-frequency compensating resistor in a v.f. amplifier load circuit, or an open plate or screen grid by-pass condenser in the v.f. amplifier. Look for defect in the coils, condensers, resistors and leads of video i.f. and v.f. coupling units and in low-frequency compensating circuits.
23. Vertical retraces are visible in picture.	23. Brightness and contrast controls are not properly set, or signal intensity at t.c.r. tube input is inadequate.	23. Lower the setting of the brightness control and advance the contrast (gain) control. If normal brilliancy cannot be secured without having retraces visible, check all video signal circuits for a defective part. Check antenna pickup and television signal strength at antenna location.
24. Insufficient contrast between light and dark portions of the picture.	24. Inadequate signal strength at input of t.c.r. tube. Sound i.f. carrier may be beating with video i.f. carrier in video dectector to give a strong 4.5 mc. signal which brightens entire picture. Defective t.c.r. tube or d.c. restorer.	24. Advance the contrast (gain) control and readjust the brightness control. Check sound i.f. rejector circuit in video channel. Look for defect in d.c. restorer circuit. Try a new t.c.r. tube.

OBSERVED EFFECT	PROBABLE CAUSES	REMEDIES
25. Excessive contrast between light and dark portions of the picture.	25. Excessive signal strength at input of t.c.r. tube, due to contrast (gain) control being advanced too far. excessive signal input to receiver.	25. Lower the contrast control setting. Lower any sensitivity controls which are present in receiver.
26. Objects at left and right sides of image or at center appear wider or narrower than normal.	26. Non-linear horizontal sweep.	26. Adjust bias on horizontal sweep output tube until trouble is eliminated. Check horizontal saw-tooth sweep generator and horizontal linearity control circuit.
27. Bright vertical band along left side of picture.	27. Horizontal flyback time is too long. Picture signal is modulating electron beam as it approaches the left side of the picture during a slow horizontal retrace.	27. Look for a defective part in the horizontal saw-tooth sweep generator, particularly the parts which govern fly-back time. Check for excessive capacity between horizontal deflecting plate leads and chassis. In a gaseous triode sweep generator, the current-limiting resistor may be too large.
28. One or two wide dark horizontal bands on picture. If receiver and telecaster are on different power line systems, these bars may move slowly up or down.	28. Excessive power line a.c. hum or ripple in video amplifier.	28. Check filter condensers in video and t.c.r. tube power packs for opens and loss of capacity. Check plate and screen-grid by-pass condensers in v.f. amplifier. Check v.f. tubes for cathode to heater shorts.
29. Many irregularly-positioned horizontal black and white bars or geometric patterns on picture.	29. Sound signals are getting into the video channel and causing "cross talk."	29. Readjust the vernier tuning control. Check the sound i.f. rejector circuit at the video i.f. input. Look for open by-pass condensers if a common power supply serves both sound and video sections.
30. A pattern of fine lines or short diagonal bars appears on the picture at irregular intervals, and may or may not move.	30. Excessive diathermy interference. Carrier of police, amateur or aircraft station beating with video carrier. Intermittent high-frequency oscillation in video channel of receiver.	30. Trouble is external interference if it disappears when a television signal generator is connected in place of the antenna. Try new antenna position, or use a directive antenna oriented for minimum interference.
31. Moving white and black splotches or spots on picture and momentary loss of either vertical or horizontal synchronization.	31. Ignition interference due to automobile or other equipment employing a spark coil for ignition.	31. Move antenna farther away from street, and rotate for a maximum signal-to-noise ratio. Use a directive antenna.
32. Snowstorm effect on entire picture.	32. Signal strength at receiver input is too low; to get a picture, gain must be advanced so far that normal atmospheric interference and tube hiss affects picture.	32. If reception was normal at one time and television transmitter has not been changed, check antenna system. Check tubes, parts and voltages in preselector stage and mixer-first detector stage.
33. Dark brown or black spot in center of picture.	33. Bombardment of center of t.c.r. tube screen by ions which come from the electron gun but are not controlled by the deflecting systems, destroying the fluorescent material in this region.	33. Replace t.c.r. tube.
34. Ghosts images in picture.	34. Signals are arriving at the receiving antenna over two or more different paths from the telecaster. Signals are being reflected back and forth in the transmission line due to improper match.	34. Change the position of the receiving antenna, or use a directive antenna so as to pick up signals over only one path. Match the receiver input to the transmission line.
35. Picture appears momentarily, then disappears. Sound is unchanged.	35. Loose connection in a video signal circuit.	35. Look for loose connections, particularly in leads to t.c.r. tube socket.
36. Picture scrambles for a while without changing in average brightness, then returns to normal.	36. Loose connection or defective tube in the scanning system.	36. Look for loose connections in clipper or frequency separator if scrambling occurs.
37. Picture is trapezium-shaped (not rectangular).	37. Deflecting system is out of balance.	37. In a balanced electrostatic deflecting system, check the output tubes in each sweep channel. In an electromagnetic deflecting system, look for shorts between turns in a deflecting coil.

covered in this tabulation, however. You will note that many of the troubles are quite simple, and their remedies appear equally simple. Do not let this mislead you, for simple defects are oftentimes the most difficult to locate. Study this trouble-shooting chart carefully, item by item; observe how logical are the causes and remedies associated with each observed effect.

Alignment of Sight and Sound I. F. Channels

The alignment of the i.f. and preselector tuned circuits in a television receiver is essentially no different from the band-passing of corresponding circuits in a sound all-wave superheterodyne receiver. Of course, certain precautions must be observed in order to secure the required band-pass characteristics and keep out undesired signals, but these precautions are invariably given in the service manuals prepared by television receiver manufacturers.

Different models and makes of television receivers employ different types of i.f. coupling units and different circuits, hence only general alignment instructions can be given here. Since each television receiver manufacturer will have a preferred procedure for aligning his particular television receivers, it is always a good idea to study the service manual for a receiver before choosing an alignment technique.

Television receiver alignment will definitely be a service shop job, having as its goal the securing of response curves with the characteristics shown in Fig. *2*. Neither the v.f. amplifier nor the t.c.r. tube need be in operation during alignment; this is fortunate, for it permits disconnecting the t.c.r. tube power pack and thereby eliminating the danger of shocks.

Video Output Indicator. The first requirement for alignment of the video i.f. channel is a means for measuring the output of the video i.f. amplifier. If an unmodulated video i.f. carrier signal is to be fed into the video i.f. amplifier, the pulsating d.c. voltage developed across the load resistor of the video detector will give the best output indication. Since this load will have a very low ohmic value, any ordinary 1,000-ohm-per-volt voltmeter may be used as an output indicator. A vacuum tube voltmeter can also be

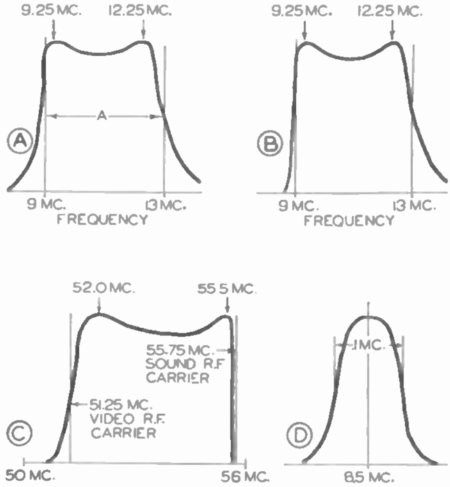


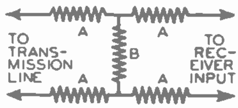
FIG. 2. **Typical response curves for a television receiver.** ***A*****—Response of last video i.f. stage alone when it has no sound i.f. rejector circuit;** ***B*****—Response of video i.f. amplifier having a sound i.f. rejector circuit which is tuned to 8.5 megacycles;** ***C*****—Response of preselector and entire video i.f. amplifier;** ***D*****—Response of sound i.f. amplifier.**

used, provided its series blocking condenser is shorted to permit passage of direct current. If a high-frequency vacuum tube voltmeter is used (one having a vacuum tube built into the test lead, with the top cap of the tube serving as the test probe), it may be connected to the input of the video detector.

Signal Generator. An all-wave signal generator (s.g.) can be used for video i.f. alignment if its fundamental frequencies cover the range from 7 mc. to 15 mc. Its output must be essentially constant over this range, and its frequency calibration should be accurate to within one-fourth of one per cent, for otherwise false resonant response curves will be obtained. Equally important is the requirement that it deliver at least .5 volt output, for use when testing a single stage.

Disconnecting the A.G.C. System. When the frequency of the test signal is varied (wobbulated) *manually*, the automatic gain control (a.g.c.) voltage in the television receiver will vary as the s.g. frequency is changed. In this case, it will be necessary to replace the a.g.c. system with a fixed C bias corresponding to the C bias for a normal signal level. This is done by disconnecting the lead going to the a.g.c. source, and connecting between this lead and ground a d.c. supply

A in Ω	B in Ω	ATTENUATION
18	82	2:1
27	47	4.5:1
33	33	9:1



Courtesy RCA Mfg. Co., Inc.

Circuit diagram and table of values for an H pad attenuator which gives the desired attenuation of an excessively strong input signal while still maintaining the proper impedance match between the transmission line and the receiver input.

voltage which will provide the correct fixed C bias for the a.g.c.-controlled tubes. Measure the a.g.c. bias while the receiver is tuned to a telecaster, using a high-resistance (high ohms-per-volt) voltmeter, then remove the a.g.c. voltage and adjust the fixed C bias to the measured value. The exact value of the fixed bias is not particularly important, so long as it remains constant during alignment.

Of course, if the s.g. output is automatically wobbulated over the entire video i.f. frequency range at a rate of 60 cycles per second, the a.g.c. system will be unable to follow the variations in output, and no changes in the a.g.c. circuit will be necessary. When a cathode ray oscilloscope (c.r.o.) is connected to the diode load resistor, an automatically wobbulated signal generator will give a reproduction of the entire response curve on the c.r.o. screen. The wobbulated s.g. should have controls which permit locating the sound and sight i.f. carrier values on the c.r.o. response curve.

Video I.F. Alignment Procedure. Having connected the output indicator and disconnected the a.g.c. circuit (if necessary), connect the all-wave s.g. between the control grid and chassis of the *last video i.f. tube.* Use well-shielded cable for this connection, so signals cannot get into a previous stage. As a further precaution, short the plate load of the previous stage (the plate tuning coil) with a wire jumper; this will not disturb voltage distribution in the circuit, but will serve to block undesired signals.

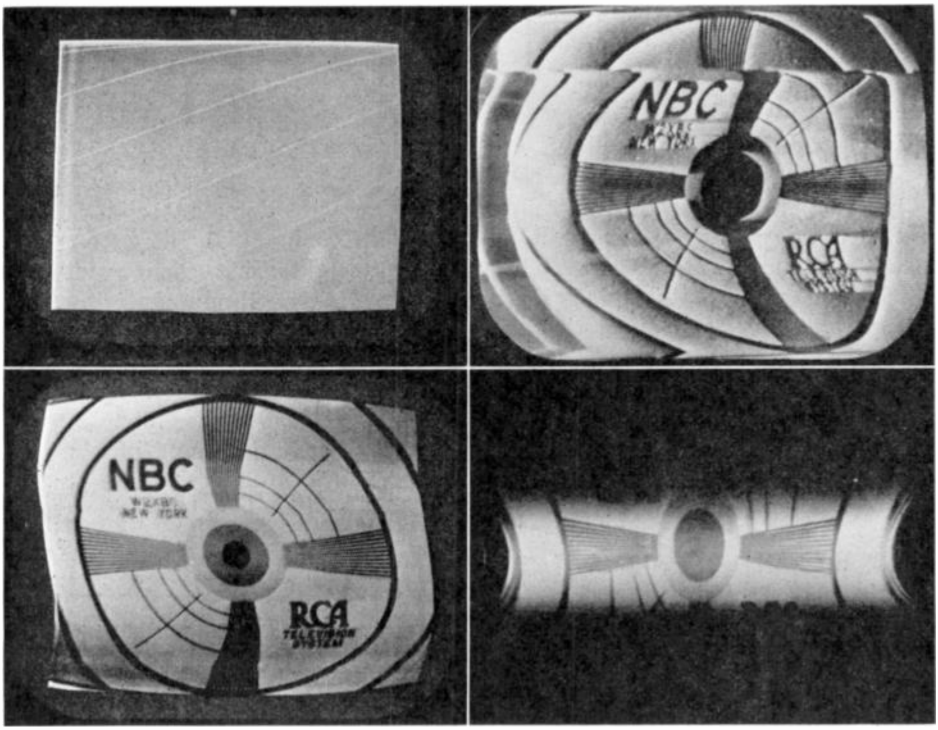
Tune the s.g. from 8.5 mc. to 14 mc. and note how the output varies. Two peaks will be observed, usually with a valley in between. As you vary the frequency and watch the meter pointer, trace the response characteristic in your mind and imagine how it looks; this is a technique which you must acquire if you employ manual wobbulation over the video i.f. range.

One peak in the output should be observed at a frequency just below the video i.f. carrier frequency. Thus, if the video i.f. carrier is 13 mc., its peak will appear at about 12.75 mc. The position of the other peak will depend upon the width of the pass band intended for the receiver in question. This information is given in the service manual prepared by the manufacturer, and is important. If we are working on a high-definition receiver having a 4-mc. pass band, the other peak will appear at about 9 mc.

With only a single stage between the s.g. and the output indicator, the output of the s.g. must be high, at least .5 volt. If the peaks do not appear under this condition, adjust the trimmer condensers for the last video i.f. coupling unit until the peaks are clearly noticeable. You will find that one trimmer has maximum control over the 13-mc. peak, while the other trimmer has more effect upon the 9-mc. peak.

Besides watching for peaks, be on the lookout for the attenuation characteristics above 13 mc. and below 9 mc. The attenuation at the 13-mc. end of the response characteristic should be gradual, with the response at 13 mc. somewhere between three-fourths and one-half of the response at the 12.75-mc. peak. The attenuation below 9 mc. should be quite sharp if a sound i.f. rejector is provided in this last stage. The rejector may need adjustment; set the s.g. at the sound i.f. value (8.5 mc. in our example), and adjust for minimum output. If there is no sound i.f. rejector, the attenuation below 9 mc. will be somewhat gradual, but no adjustment will be possible or necessary because previous stages will compensate for this lack of attenuation.

Having completed adjustments on the last video i.f. stage, remove the plate load jumper and advance the s.g. to the grid and chassis of the preceding v.f. tube. Leave the voltmeter



Courtesy RCA Mfg. Co., Inc.

Upper left: A raster like this, consisting of very fine horizontal lines and vertical retrace lines which slope diagonally upward from left to right, should appear on the screen of a properly operating television receiver if the brightness control is advanced but no station is tuned in.

Upper right: Too strong a signal at the receiver input terminals (over 50,000 microvolts) may overload the receiver circuits and cause a distorted and torn pattern like this, due to partial loss of synchronization. The remedy involves insertion of an H pad attenuator (made up from five ¼-watt carbon resistors as indicated on the opposite page) between the receiver input terminals and the transmission line.

Lower left: Effect of 60-cycle hum or ripple voltage in the horizontal sweep channel. The condition was exaggerated for illustrative purposes; the picture width is reduced here to show the wavy effect at the edges of the picture. Normal residual hum may cause a slight weaving of the picture if receiver and transmitter are on different power systems, but this is hardly noticeable at the proper viewing distance.

Lower right: Opening of both high-voltage filter condensers in the t.c.r. tube power pack gives this effect, equivalent to the combined effect of ripple in the video amplifier and ripple in the deflection circuits. Check filter condensers whenever pronounced ripple patterns like this appear.

connected across the video detector load. Again, short the plate load of the stage just ahead of the s.g. Repeat the entire adjusting process on the before-the-last video i.f. coupling unit. This coupling unit will probably have a sound i.f. rejector, hence sharp attenuation will be observed at the 9-mc. slope. In some cases, the sound i.f. rejector will have been adjusted at the factory, and its adjusting screw sealed to prevent readjustment. Ordinarily you should not touch these sealed screws, for the sound i.f. rejector also serves as the mutual coupling reactance for the i.f. coupling unit, and this reactance must not be varied too much.

Continue moving the plate load jumper and the s.g. toward the antenna one stage at a time in this same manner. As you move toward the first detector, you will note that the peaks become more prominent, and the attenuation at the slopes much more sharp. Furthermore, the adjustments become more critical, making it essential to exercise care in adjusting the trimmers.

After the plate load of the mixer-first detector has been shorted and the s.g. connected between grid and chassis of the first video i.f. tube for adjustment of the second video i.f. coupling unit, the s.g. must be moved to the input of the mixer-first detector. The preselector circuit now presents a problem. Since the preselector resonates at frequencies above 44 mc., a grid-chassis s.g. connection would attenuate the signal (the preselector would act as a short-circuit at the video i.f. value). This means that we must make a series s.g. connection to the grid of the mixer-first detector. If the s.g. has an internal d.c. blocking condenser, shunt its output with a resistance of about 10,000 ohms to permit application of the fixed C bias to the grid of the mixer. The video i.f. carrier signal can now be fed through the mixer stage into the first video i.f. coupling unit, and the trimmers in this unit adjusted in the manner previously described. This completes the adjustment of the video i.f. channel.

Sound I.F. Alignment Procedure. The s.g. and output indicator used for video i.f. alignment are also satisfactory for alignment of the sound i.f. channel. Connect the output-indicating voltmeter across the load resistor of the sound second detector. Leaving the s.g. connected to the input of the mixer-first detector, set it to the sound i.f. value (8.5 mc. in our example), and adjust each sound i.f. trimmer for maximum output. The order of adjustment does not matter. Having completed these adjustments, swing the signal generator frequency about 50 kc. in either direction to make sure that the sound i.f. channel has sufficient broadness. The output at 50 kc. off the video i.f. carrier value should not be less than one-fourth the output at the carrier value.

If the sound i.f. channel has a picture i.f. rejector of the adjustable type, set the signal generator at 9 mc. and adjust this rejector for minimum output.

Adjustment of the first sound i.f. transformer may affect the adjustment of the first video i.f. coupling unit, so it is wise to recheck the adjustment of the video i.f. channel input.

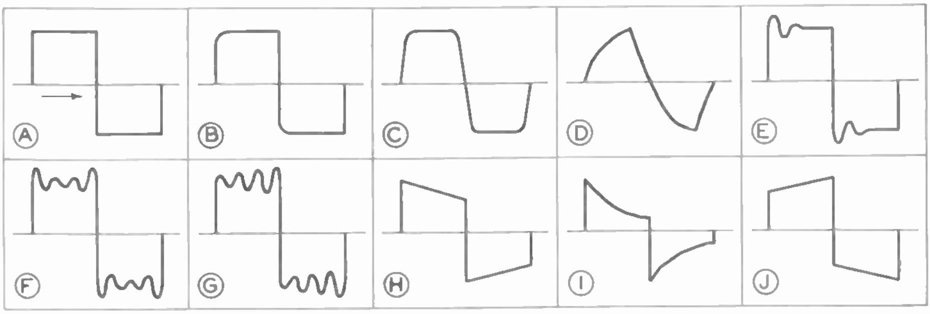
Preselector Alignment

For alignment of the preselector tuned circuits, an ultra-high-frequency signal generator covering the range from 44 mc. to 150 mc. is needed. Again, accuracy of frequency calibration and constancy of output voltage are essential requirements. If this signal generator is provided with a shielded cable for connecting purposes, connect it to the two antenna terminals (transmission line terminals) on the television receiver, without removing the transmission line. If the signal generator is provided with a radiating rod, the rod can be placed near the transmission line or can be connected directly to one of the receiver input terminals with a short length of wire. If the transmission line is not connected to the receiver, place a 100-ohm metallized resistor across the receiver input terminals to duplicate the effect of the line.

Oscillator Alignment. Before aligning the band-pass preselector circuit, it will be necessary to adjust the local oscillator trimmer so that the oscillator frequency is above the incoming signal frequency by exactly the sound i.f. value of the receiver. Two conditions will be encountered: 1. Variable condensers are employed for tuning the receiver; 2. Push-button tuning with pre-adjusted trimmer condensers is employed for tuning the receiver.

Alignment of Preselector Having Push-Button Tuning. Considering the push-button case first since it is by far the more common, the local oscillator trimmer for each push-button should first be adjusted. Here is an example of how this is done.

If you are working on the push-button for the 50-56 mc. television channel, you know that the sound r.f. carrier will be .25 mc. lower than the upper end of the channel, or at 55.75 mc. Therefore, set the unmodulated s.g. to 55.75 mc., and adjust the oscil-



Patterns obtained on a cathode ray oscilloscope screen when a square-wave signal generator is used to check the damping, time delay and frequency response of a v.f. amplifier in a television receiver or transmitter. The square-wave signal voltage (a fundamental frequency of either 60 cycles or 13 kc. and many odd harmonics) is fed into the v.f. amplifier input, and the output voltage wave of the v.f. amplifier is reproduced on a special c.r.o. The resulting patterns, when properly interpreted, tell whether the v.f. amplifier circuits are properly damped, whether the time delay is sufficiently constant, and whether the frequency response is flat. Square-wave generators are used chiefly in design and research laboratories at present, for Teletricians rarely if ever find it necessary to check the performance of v.f. amplifiers so thoroughly. The patterns are presented here merely to give you some idea of how v.f. amplifiers are checked and adjusted at the factory.

At *A* is shown the square wave signal produced by the square-wave signal generator. For wave forms *B* to *G* inclusive, this signal has a frequency of 13 kc., and reveals amplifier characteristics at the higher frequencies in the v.f. range. For wave forms *H* to *J* inclusive, this square-wave signal has a frequency of 60 cycles, and reveals the v.f. amplifier behavior at low frequencies only.

Wave-form *B* shows that there is some high-frequency attenuation, and that the v.f. amplifier circuits are highly damped. Without damping, ripples due to high-frequency attenuation would appear at the top of each square wave; with damping (with a long time constant in the resistance-condenser circuits), these variations cannot take place. The rounding off of alternate corners indicates insufficient time delay at the high video frequencies.

The symmetry of each alternation in pattern *C* indicates a constant time delay. Absence of ripples tells that the amplifier is highly damped. We also have considerable high-frequency attenuation.

The extreme departure from a square wave at *D* indicates that there is considerable high-frequency attenuation. The amplifier is highly damped, for there are no ripples. The time-delay is insufficient at high frequencies.

Excessive gain at high frequencies is indicated by pattern *E*. Ripples appear, indicating that the amplifier is not damped sufficiently.

Lack of damping allows variations in response to show in the pattern at *F*. There is a sharp cut-off of signals below the desired high-frequency limit, indicating severe attenuation. The symmetrical wave indicates constant time delay.

The presence of waves at the top in *G* indicates excessive gain at high frequencies in the v.f. amplifier. The rising amplitude of these waves indicates regeneration in the amplifier. If the waves decreased in amplitude toward the right, slight damping without regeneration would be indicated.

The first 60-cycle pattern, at *H*, indicates that there is a small amount of low-frequency attenuation and below-normal time delay at the low frequencies.

Appreciable attenuation at low frequencies and insufficient time delay at low frequencies is indicated at *I*.

Pattern *J* indicates excessive time delay at low frequencies.

lator tuning circuit trimmer associated with this channel for maximum output across the diode sound detector load as indicated on the d.c. voltmeter used for sound i.f. alignment. Adjust the oscillator trimmer for each other push-button in the same manner, setting the s.g. each time to a value .25 mc. below the upper frequency in the channel assigned to a button.

Preselector Band-Pass Circuit Alignment. Study the circuit diagram for the preselector to determine whether one, two or three resonant circuits are employed.

If only one resonant circuit is used, set your s.g. to about a middle frequency in the television channel for which the receiver is to be adjusted first. Thus, if you are starting with the 44-50 mc. channel, set the signal generator to about 47 mc., without modulation, and adjust the resonant circuit trimmer or variable inductance for maximum output voltage across the *video* second detector load. Note that the output indicator is now measuring video output; we get a much higher voltage indication across the low-ohmic-value video detector load with an ordinary 1000-ohm-per-volt meter than we would across the high-ohmic-value sound second detector load. Adjusting the preselector trimmer for each other push-button in this same manner, with the s.g. set to a mid-frequency in the channel assigned to each button, completes the alignment adjustment for the preselector when there is only one resonant circuit.

In the case of a preselector having three tuned circuits, that resonant circuit which is by itself (not capacitively or inductively coupled to any other resonant circuit) is adjusted first, in exactly the manner just described.

A double or triple-tuned preselector will have one band-pass tuner. Both resonant circuits of this tuner may be loaded with resistance, or one circuit may be loaded and mutual coupling depended upon to reflect this loading into the other. That resonant circuit which is loaded the heavier (has the lowest resistance across it) will be the broader. In a double-loaded circuit, the antenna resonant circuit will be loaded more than the other.

The band-pass circuit in a preselector is intended to pass both the sound and picture r.f. carriers and their side frequencies. The most heavily loaded resonant circuit should be adjusted first in order to give this required broad response. Set the unmodulated s.g. to a frequency which is *.75 mc. above* the picture r.f. carrier frequency for a particular push-button (channel), so that the picture carrier will be on one slope of the response curve. For example, in the case of the button for the 50-56 mc. channel, where the picture r.f. carrier frequency is 51.25 mc., the s.g. should be set at 52.0 mc. Now adjust the trimmer condenser in the heaviest-loaded resonant circuit for maximum output voltage across the *video* second detector load.

Next, set the s.g. to the sound r.f. carrier frequency for the channel being aligned (to 55.75 mc. in our example), and adjust the trimmer in the remaining resonant circuit for maximum output voltage across the *audio* second detector load.

The two band-pass resonant circuit trimmer adjustments just described are repeated for each other push-button. Remember the order of adjustment in the case of a triple-tuned preselector: first, the single resonant circuit, then the more heavily loaded band-pass resonant circuit (the antenna circuit), and finally the less-loaded band-pass resonant circuit.

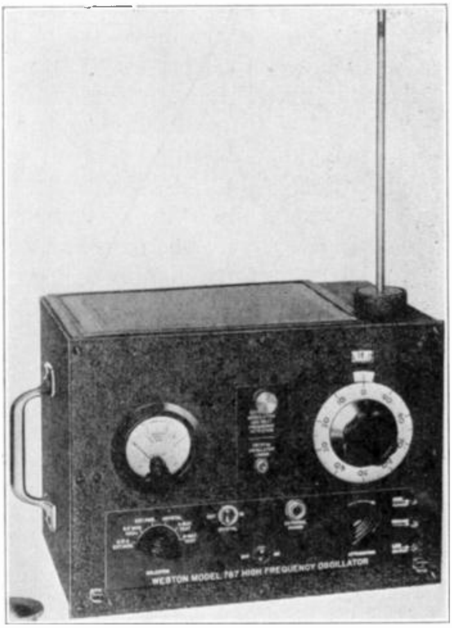
Alignment of Preselector Having Variable Tuning Condensers. Connect the s.g. to the receiver input terminals just as before. Rotate the variable tuning condenser plates until the first serrated segments just mesh, and set the s.g. to the frequency indicated on the station tuning dial. With the output indicator connected across the load resistor of the *sound* second detector, bend the meshed segment of the *oscillator variable condenser* to the position which gives maximum output. Now rotate the variable tuning condenser until all plates are meshed (maximum capacity), set the s.g. to the new receiver tuning dial reading, and adjust the oscillator padder condenser for maximum output voltage across the sound second detector load. Re-check the first adjustment, then rotate the tuning condenser until the second segments mesh, tune the s.g. to the new dial reading, and bend the second *oscillator* variable condenser segment for maximum output. Repeat for each other oscillator segment in this same manner.

The preselector will usually have a band-pass resonant circuit. The technique for adjusting this is the same as was used for push-button tuning, except that now the rotor plate segments are bent to give maximum output across the load resistor of the *video* second detector. This lines up the entire r.f. system.

Sometimes a vernier tuning control affecting the oscillator tuned circuit is provided on receivers having push-button or station-selector switch tuning. During alignment, this vernier control should be set at a mid-position; otherwise, the alignment procedure is exactly the same as for conventional push-button or switch type tuning.

For a final check on alignment, tune in a telecaster and adjust the pre-set controls for the best possible image. If the low-pass filter in the video detector output has an adjustable condenser, set it for best detail in the image. This condenser affects the high-frequency response of the receiver, and also controls the amount of time delay.

If a picture signal generator is used for the final test, tune the receiver to a telecaster frequency, then tune the s.g. until an image appears on the t.c.r. tube, and adjust the pre-set controls as before.



Courtesy Weston Electrical Instrument Corp.
FIG. 3. Weston model 787 ultra-high-frequency oscillator.

Television Test Equipment

The test equipment required for installing, aligning, and servicing television receivers has already been mentioned, but now let us analyze this equipment problem a bit more carefully.

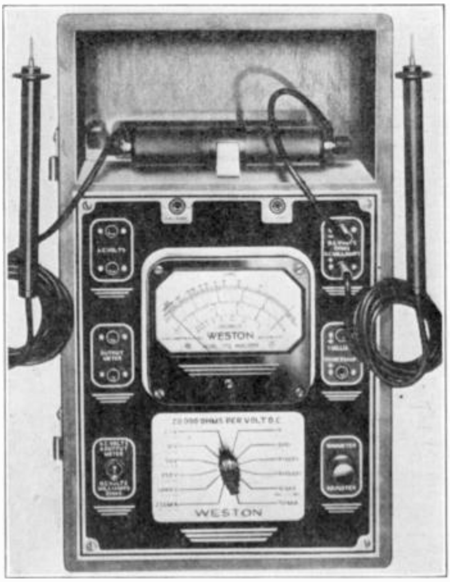
Weston Model 787 Ultra-High-Frequency Oscillator. A typical well-designed ultra-high-frequency signal generator for television purposes is shown in Fig. *3*. The tuning coil consists of bare wire wound in grooves on a coil form, with a contact sliding on the wire. Rotating the coil varies the effective length of the coil, changing the output frequency. The unused portion of the coil is automatically shorted. This arrangement gives a high *L* to *C* ratio (normally a high Q factor), which means high output and good frequency stability. The coil has sixteen turns, covering the range of frequencies from about 30 mc. to about 150 mc.

Referring to Fig. *3*, the tuning dial is at the upper right on the front panel. An indicator above the dial reads in terms of effective coil turns, while the tuning dial itself reads in fractions of a turn. Reference to a calibrated chart mounted on top of the instrument gives the correct frequency. Also on top of the instrument is the radiating rod. The meter at the left on the front panel normally indicates the oscillator plate current and shows that the unit is in operation.

The controls on the panel strip below the dial and meter are, left to right: rotary *SELECTOR* switch; *CRYSTAL OUT-IN* toggle switch; *OFF-ON* power toggle switch; *EXTERNAL POWER* jack; *ATTENUATOR* control; *HIGH OUTPUT*, *GROUND* and *LOW OUTPUT* jacks.

Turning the selector switch in a clockwise direction, the first position is for *continuous wave output*. When a picture signal along with impulses is fed into the *EXTERNAL MODULATION* jack located on the small panel between the meter and the tuning dial, this oscillator will radiate a duplicate of the television signal radiated by a telecaster. The next position on the selector switch is that in which a 400-cycle audio modulation is placed upon the output carrier frequency. The third switch position is the same as position *1* except that now a 180-volt battery can be plugged into the *EXTERNAL POWER* jack in order to increase the r.f. carrier power.

In the fourth switch position, a crystal having a frequency somewhere between 5 mc. and 10 mc. is introduced into a crystal oscillator circuit which is tuned by means of a *CRYSTAL OSCILLATOR TUNING* control located between the meter and the tuning dial. By beating the oscillator output with either a fundamental or a harmonic frequency of the crystal oscillator, the oscillator calibration can be checked to a high de-



Courtesy Weston Electrical Instrument Corp.

FIG. 4. Standard Weston model 772-2 analyzer, converted for measurement of high voltages in t.c.r. tube circuits by the addition of the special multiplier resistor in the upper compartment, along with heavily-insulated test leads and special probes.

gree of precision. Headphones can be plugged into the *EXTERNAL MODULATION* jack to listen for zero beat. The fifth and sixth switch positions connect the meter to the internal *A* and *B* batteries respectively for a check of their voltages. The output *ATTENUATOR* controls the r.f. output voltage.

Multimeters. Voltages, currents and resistances in any of the signal circuits, synchronizing circuits and associated power packs in a television receiver can be checked with an ordinary all-purpose multimeter such as is used for testing all-wave sound receivers. Of course, the voltmeter section of the multimeter must have a high ohms-per-volt rating if voltages which are fed through high-value resistances are to be measured.

High-Tension Voltmeter. In those cases where it is found necessary to measure the high voltages supplied to the anodes of the t.c.r. tube in a television receiver or to measure the output voltage of the t.c.r. tube power pack, a suitable high-tension voltmeter is required. Figure *4* shows how a standard multimeter can be converted to measure high voltages safely. A special multiplier resistor which is designed to withstand at any point the maximum voltage to be measured is used in series with the multimeter, and special heavily insulated test leads and probes are used. The probes have guard discs which prevent fingers from accidentally slipping down to the probe points. Special precautions must be observed when connecting the multiplier resistor to the multimeter and when using the resulting high-tension voltmeter, in order to maintain the meter and its case near ground potential and minimize the danger of shock. Voltmeters designed especially for measurement of the high voltages present in television receivers are also available, but as a rule are not required by the average Teletrician. Dangerously high voltages should be measured only as a last resort.

Picture Signal and Synchronizing Impulse Generators. As you have already learned, proper adjustment of the pre-set controls in a television receiver requires the presence of a television signal with its synchronizing impulses. Of course, the best source for this signal is an actual telecaster, but there will be occasions when no station is on the air at the desired time. A picture signal and synchronizing impulse generator will provide a fixed (stationary) image which serves practically all purposes except the adjusting of antenna position to eliminate reflection effects. This can be purchased by the Teletrician as soon as business warrants, making him independent of telecasting schedules.

Various pictures are produced for test purposes. A portrait such as is shown in Fig. *5* is widely used in picture signal generators, and is entirely

Courtesy Allen B. DuMont Labs., Inc.

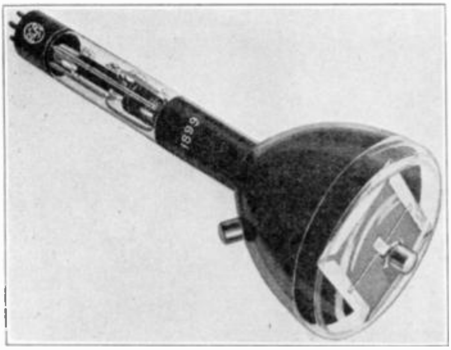
FIG. 5. Portrait of Abraham Lincoln as produced on the screen of a t.c.r. tube by a Phasmajector tube feeding into a picture signal and synchronizing impulse generator. Considerable detail in the image has been lost in the process of photographing it and reproducing it in this lesson.

satisfactory. Some engineers prefer the portrait of an Indian chief in full headgear, for there are many geometrical patterns in the headgear which give a check on image definition. Special geometric patterns are also employed, particularly for transmitter tests.

The production of a television signal corresponding to a particular pattern is made possible by a special cathode ray tube known under various trade names; the *monoscope* is the RCA version; the *monetron* is made by National Union, and the *phasma-*

jector is made by Dumont. A typical RCA monoscope tube is shown in Fig. *6*.

The operating principle of a picture-producing tube is relatively simple. When electrons strike a surface with sufficient velocity, secondary electrons are emitted. Different materials emit different amounts of secondary electrons for a given initial electron velocity. By using aluminum foil as the screen and printing the desired pattern on it with carbon ink in such a manner that the carbon will represent white portions of the picture and aluminum the black portions (just as in a photographic negative),



Courtesy RCA Mfg. Co., Inc.

FIG. 6. RCA type 1899 monoscope tube.

a satisfactory source for a television picture signal is available. The resulting picture signal in its electrical form will have a negative picture phase. A signal with a positive picture phase can be obtained simply by reversing the relative positions of the carbon and the aluminum.

The electron beam in a picture-producing cathode ray tube is generated in the usual manner by means of an electron gun. The electrons emitted by a heated cathode are focused into a beam by an electrostatic lens system and are deflected horizontally and vertically by electrostatic deflection plates to sweep the entire picture imprinted upon the aluminum sheet.

Two sweep generators are needed for a monoscope, one generating a 60-cycle saw-tooth sweep voltage for the vertical deflecting plates, and the other a 13,230-cycle saw-tooth sweep voltage for the horizontal deflecting plates. These sweep generators must be controlled by blocking oscillators, which in turn are kept at their correct frequencies by a primary frequency source. The blocking oscillators must also furnish the line and frame synchronizing pulses which are to be mixed with the video signal. Of course, a multi-vibrator type circuit here would combine the functions of the blocking oscillator and sweep generator. Additional pulses must be generated and fed to the grid of this cathode ray tube so that retraces will be blanked out.

The schematic circuit diagram for a typical picture signal and synchronizing impulse generator is shown in Fig. *7*. The special picture-generating cathode ray tube just described is designated as *PCR*. R_{24} and R_{25} are beam-centering controls, R_{22} is the focusing control and R_{20} is the beam intensity control. Tubes *1* and *2* form the multi-vibrator producing the vertical saw-tooth sweep voltage and the vertical synchronizing impulses. When charging of condenser C_7 begins, point *c* is driven suddenly in a negative direction with respect to point *a*, thus creating the line synchronizing impulse. Condenser C_7 discharges through R_9 and L_1, so that a saw-tooth sweep voltage is produced across C_7. This voltage is applied through C_{10} to the vertical deflecting plates of the picture-producing tube (across R_{18}), sweeping the beam vertically.

The vertical synchronizing impulse is developed across R_{11}. This voltage is applied to resistor R_{13} through diode *5*, and is then amplified by two r-c coupled amplifier stages having tubes *7* and *8*, so that the negatively swinging impulses across R_{13} are also developed across R_{31} and fed to the output terminals. The impulse voltage across R_{13} is also fed to the grid of the PCR tube, to extinguish the beam during retraces.

Diode *5* is necessary because there is a positive swing in voltage at point

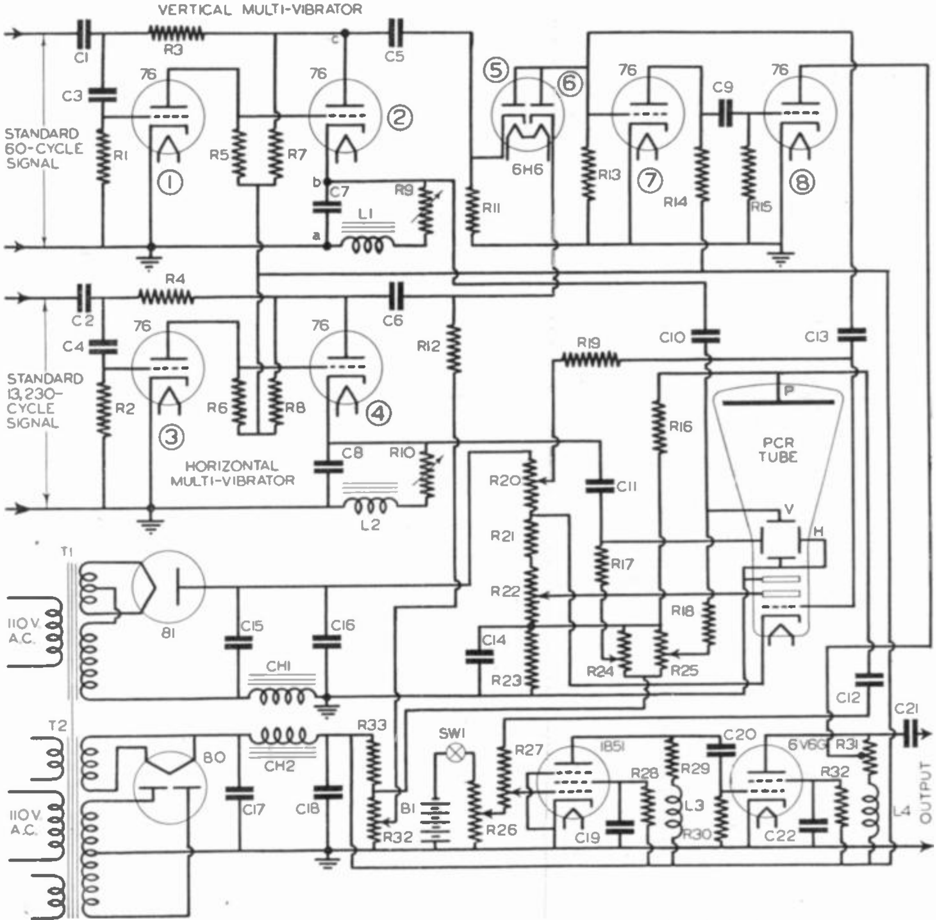


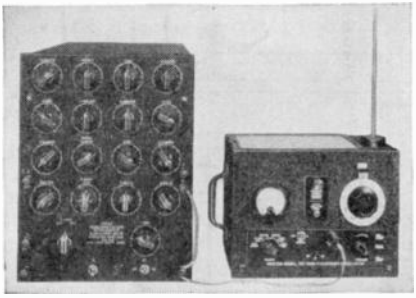
FIG. 7. Schematic circuit diagram for a typical picture signal and synchroniznig impulse generator.

c during discharge of C_7. The diode conducts only when point *c* swings in a negative direction, and hence serves as an automatic switch which allows only the desired negative-swinging pulses to pass.

Tubes *3* and *4* constitute the multivibrator which produces the horizontal saw-tooth sweep voltage and the horizontal synchronizing impulses. The horizontal saw-tooth sweep voltage developed across C_8 is applied to the horizontal deflecting plates of the PCR tube through d.c. blocking condenser C_{11}. The horizontal synchronizing pulses developed by tube *4* are fed through condenser C_6 and diode *6* to resistor R_{13}. From here they act on the grid of the PCR tube, and act through amplifier tubes *7* and *8* on resistor *31* in the output circuit.

The picture signals produced by the PCR tube are developed between the collecting plate (*P*) and the cathode. They pass through d.c. blocking condenser C_{12} to potentiometer R_{27}, and from here are fed into a two-stage v.f. amplifier which is capable of passing a wide range of frequencies. The output of this amplifier feeds directly to R_{31} and the output terminals. By varying R_{27}, the proper amplitude relationship between the picture signal and the synchronizing impulses can be obtained.

Since the impulses across R_{31} swing in a negative direction, the picture signal across this resistor must therefore swing in a positive direction. This means we have a positive picture phase at the output. If a negative picture phase is desired, one additional



Courtesy Allen B. DuMont Labs., Inc.

The type 202 Phasmajector television signal generator at the left supplies a high-definition television picture signal with synchronizing impulses, and has sufficient video output to modulate an ultra-high-frequency signal generator such as the Weston model 787 unit shown at the right. The picture signal source is a DuMont Phasmajector cathode ray tube having a suitable test pattern or picture imprinted on the pattern plate. This portable equipment provides a complete television signal. the characteristics of which can be controlled by the operator independently of telecasters. It is intended for use in servicing, routine production testing and development of television receivers.

v.f. amplifier stage may be added between R_{31} and the output terminals of this signal generator unit.

Other features of the circuit in Fig. 7 are more or less like conventional circuits used in television receivers, and hence need not be discussed here. No circuit values are given in this diagram, it being presented merely to show you the general operating features of this type of test instrument.

The signals which control the horizontal and vertical multi-vibrators should be supplied by a definite source, not shown in Fig. 7. In order to get 441 lines per frame, 30 frames per second and 60 fields per second so that interlaced scanning will be obtained, we must have a constant-frequency 26,460-cycle source. This can be either a crystal-controlled oscillator or a temperature-compensated conventional oscillator. One multivibrator is used to step this frequency down to 13,230 cycles for control of the horizontal sweep multi-vibrator in Fig. 7, and a chain of four multivibrators is used to step 26,460 cycles down to 60 cycles (by utilizing the third, third, seventh and seventh subharmonics respectively) for control of the vertical sweep multi-vibrator in Fig. 7.

The standard signal for the vertical or field frequency is fed through C_1 while the line or horizontal standard signal frequency is fed through C_2. This arrangement gives an output signal sufficiently close to that produced by a television transmitter to serve for all normal testing purposes.

The output of this picture and synchronizing impulse signal generator can be fed into the v.f. amplifier anywhere ahead of the clipper stage. Since the phase of the test signal must be correct for the particular stage into which it is fed, it is important that there be provisions for changing the picture phase at the output of the signal generator.

When the test signal has a negative picture phase, it can be fed into the modulating section of an ultra-high-frequency test oscillator like that shown in Fig. 3. The modulated output of this oscillator can then be fed directly to the input terminals of a television receiver, for a check-up of side band attenuation in the preselector or r.f. system. This equipment can also be used to radiate a standard television signal to a television receiving antenna. The signal-to-noise ratio can be estimated by watching the stationary pattern on the receiver screen, and various antenna locations can be tried until the noise is reduced to an acceptable level.

To check the effectiveness of a transmission line, connect the picture-modulated oscillator first to the receiver input and adjust its output until a satisfactory picture is obtained, then connect the oscillator to the antenna end of the line. If line loss is more than you would normally expect, adjust the matching transformers, line length and line loading for best results on the most-used television channel. This will eliminate phase cancellation and ghost images due to repeated reflections at the transmission line terminations.

TEST QUESTIONS

Be sure to number your Answer Sheet with the *number* appearing on the front cover underneath the title of this text.

Place your Student Number on every Answer Sheet.

Send in your answers for this lesson immediately after you finish them. Doing this insures that the graded answers will reach you while the subject matter is still fresh in your mind, and you will get the greatest possible benefit from our speedy personal grading service. *Never hold up a set of lesson answers.*

1. When the sound portion of a telecast is heard but only a vertical line is seen on the screen, where would you look for a defect?
2. What visible effect indicates that a t.c.r. tube is gassy?
3. In making a circuit disturbance test in a dead television receiver after the t.c.r. tube power pack is disconnected, what would you use as an output indicator?
4. Can a television receiver operate improperly even when no circuit defect exists?
5. Which pre-set control should be adjusted when the picture is continually moving up or down on the screen?
6. In a television receiver employing electromagnetic deflection, which control would you adjust if the left side of the picture was blurred and excessively bright?
7. Describe briefly the changes which should be made in the a.g.c. system before the video i.f. channel of a television receiver is aligned with a manually wobbulated signal generator.
8. Where would you look for a defect if a normal raster appears on the t.c.r. tube screen, but no picture can be obtained and no sound is heard when the receiver is tuned to a telecaster known to be on the air?
9. What adjustment is required when two images of normal height are seen side by side on the t.c.r. tube screen?
10. Where would you expect to find the trouble if the picture scrambles at irregular or regular intervals, then returns to normal each time? Neither the average picture brightness nor the sound program changes when scrambling begins. Adjustments of the hold controls have no effect upon the scrambling.

1. In the horizontal sweep channel or in its connection to the horizontal deflecting plates.

2. A blue glow in the neck of the tube, surrounding the electron gun.

3. An ordinary cathode ray oscilloscope or an audio amplifier with loudspeaker.

4. Yes.

5. The vertical hold control.

6. The damping control.

7. Replace the a.g.c. system with a fixed C bias corresponding to the C bias for a normal signal level.

8. In and ahead of the mixer-first detector.

9. Increase the frequency of the horizontal blocking oscillator by adjusting the horizontal hold control.

10. In the scanning system (either a loose connection or an intermittently-defective tube).