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Vol. 8 JULY, 1931 No. 7

The design of a complete television system‡

By C. E. HUFFMAN*

THE television system about to be described is a partial answer to an outstanding problem.

That problem is to provide a means by which visual representations may be sent broadcast from one point and received at many others. Several methods might be used in solving this problem.

It is conceivable that some combinations of lenses or mirrors might be arranged whereby this broadcast could be effected by purely optical methods.

By purely optical methods we mean the linking of an observer with an observed object by light from that object directly and without the interposition of any auxiliary system of transmission.

It is understood, of course, that lenses or mirrors would only modify the direction of light and would therefore not introduce any new system.

A purely optical system would be dependent upon atmospheric conditions and its operation would presuppose the absence of intervening obstructions. Its many other limitations are quite evident and the broadcasting of visual presentations by optical means alone is obviously impractical.

‡Presented before the Club, April 8, 1931.
* Television Engineer, DeForest Radio Co.

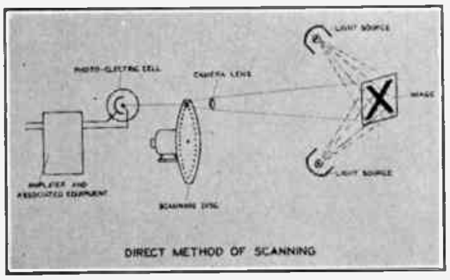

Fig. 1. Direct method of scanning.

It is necessary then for the practical solution of the problem to provide some auxiliary system interposed between the observer and the observed to effect visual broadcasting.

A system, electro-mechanical in nature, has been devised and today visual broadcasting is being effected by interposing that system between the observer and the observed.

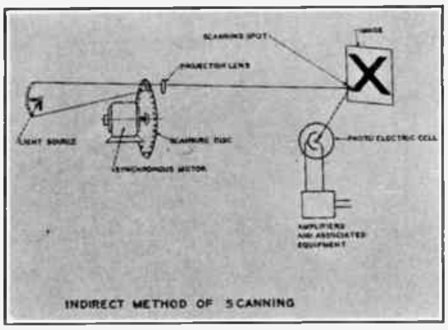

Fig. 3. One method of reduction of apparent brilliancy of light.

A simple optical system includes a source of light, an object to be viewed, light given off by the object, an eye to intercept some of this light and a nervous system wherein would be created the sensation of seeing.

That is, in order to be seen an object must give off light. This light may emanate from the object itself or from another source and be reflected by the object. The object radiates this light, some of which reaches the eye of an observer. Entering the eye it falls upon thousands of sensitive nerve ends stimulating them to send pulses to the brain.

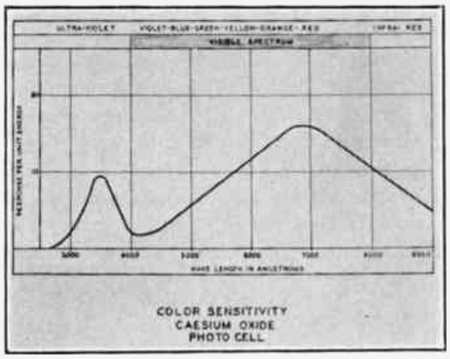

Fig. 2.

The brain integrates these pulses into a sensation peculiar to that object and forms a vision of it.

A television system includes a light sensitive device and an electrical circuit interposed in the path of the light waves to convert them to electrical waves which may be transmitted with greater facility. It also includes a device for reconverting the electrical waves to light waves at the receiving end.

Photocell

A device called a photoelectric cell is placed in the path of the light from the object. This cell allows current to pass in proportion to the amount of light falling upon it. More light more current and vice versa. This current is amplified and transmitted to the other end of the circuit where it excites a lamp to give off light in proportion to that intercepted by the photoelectric cell. Now, it is evident that if the light from all parts of the object were allowed to strike the photocell at one time the lamp at the other end of the

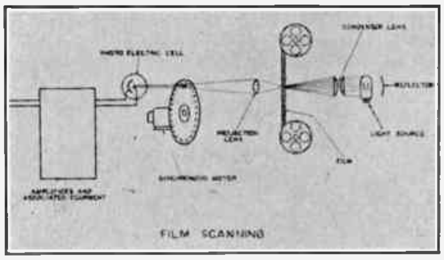

Fig. 4. Scanning motion picture type film.

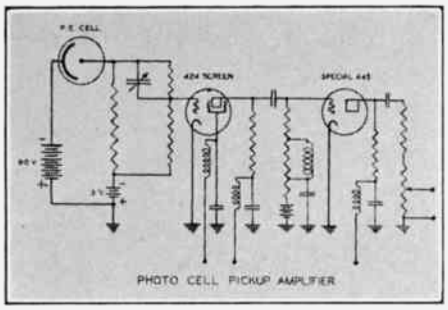

Fig. 5. Schematic of photocell amplifier.

circuit would light with an intensity proportional to the overall brilliancy of the object. Therefore, no details of that object would be transmitted and it is necessary to scan the object a step at a time and view the light at the receiving end so that light from it reaches the eyes from the same angle as it would if the object were being viewed directly.

The explanation of how this is done has been given so often that it will not be gone into here.

The purpose of this paper is rather to describe the component parts of a television system and show their relation to each other.

Referring to Fig. 1 we have what is known as the direct method of scanning. Here the entire object to be viewed is illuminated by light which reflects into the photocell. A lens collects as much of this light as possible and passes it through a hole in the disc a unit at a time in rapid succession. The photocell delivers current to the amplifier in proportion to the amount of light reflected from the successive units.

As only a small part of the light

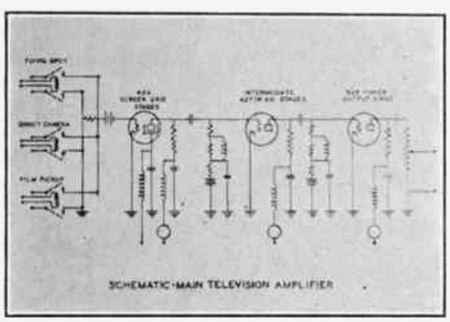

Fig. 6. Simplified schematic of amplifier.

thrown on the object reaches the hole in the disc, it is necessary that the object be illuminated strongly over its entire surface.

As shown in Fig. 2 the photocells in use are sensitive to invisible light as well as visible and by the use of proper filters a subject being scanned is unaware of the intensity of light thrown upon him.

It is possible, however, to reduce the apparent brilliancy of visible light by the method shown in Fig. 3. In this method the scanning disc is placed between the light source and the object so that only a small portion of it is illuminated at one time. The illumination can therefore be much more intense without causing discomfort when a person is being scanned. Also the photocells may be placed closer to the object and thus pick up more reflected light.

Motion picture films are scanned as shown in Fig. 4. Here the light passes through the film to the scanning disc. The holes in the disc allow light from each unit area to affect the cell in succession as in the other methods.

The discs shown rotate at a speed of 1200 r.p.m. and scan the object 20 times per second. There are 60 holes around the circumference of the disc so that the picture at the receiving end appears as an image constructed with 60 lines.

Scanning at this speed will cause the photocell to release currents varying at

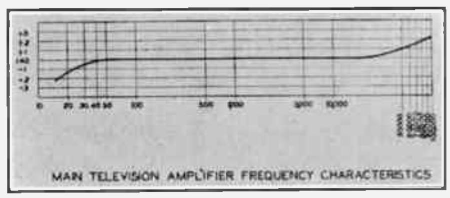

Fig. 7. Frequency characteristic of main amplifier.

a rate as high as 43,000 cycles per second.

Fig. 5 shows a schematic circuit of the amplifier associated with the photocell in each of the pickup scanners.

The network shown between the photocell and the grid of the first tube serves to equalize the response to varying rates of light fluctuation. The network shown at the grid of the second tube tends toward uniform transmission of the desired frequencies.

A special 445 type Audion is used in the output circuit so that signals are fed through a 75-ohm line to the main amplifier without undue attenuation at the higher frequencies.

Fig. 6 is a simplified schematic of the main amplifier which supplies signal to the modulator grids in the radio transmitter. Incoming lines remotely controlled by relay connect any of the photocell amplifiers to the input of this amplifier. One pickup may be faded out as the other is faded in.

Fig. 7 shows the frequency character-

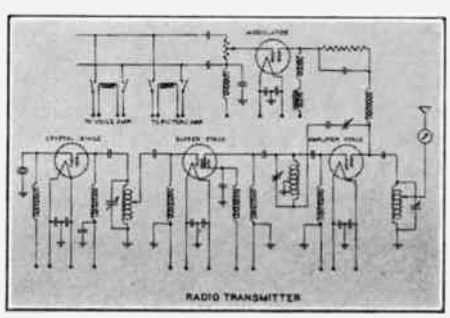

Fig. 8. Radio transmitter of 250 watts output.

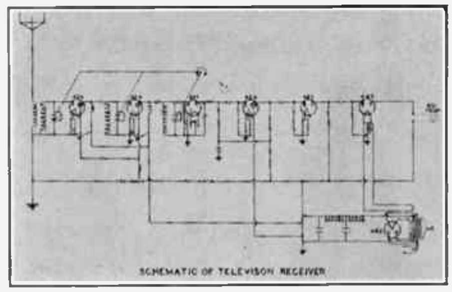

Fig. 9.

istic of the main amplifier. As shown the amplifier has an overall gain of 140 db. plus or minus 2 db. from 15 cycles to 80,000.

Fig. 8 is a schematic of a radio transmitter having 250-watts output. A crystal oscillator excites a radio-frequency amplifier through a screen-grid buffer stage. The output of the r-f. amplifier is modulated by a water cooled modulator controlled by the output of the main picture amplifier just shown.

A separate speech amplifier may be connected to modulator grids for station announcements.

At W2XCD in Passaic sound is broadcast with the television programs over a standard deForest radiophone transmitter located adjacent to the television transmitter. No cross talk is experienced when these transmitters are operated simultaneously. The picture

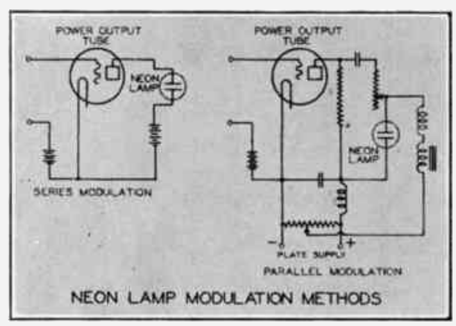

Fig. 10.

transmitter operates on a frequency of 2050 kc.; the sound on 1604 kc.

Changeover from one sound and picture pickup to another is effected by relays operated from a central control panel. Signal lights indicate in the studio and at the control panel just which pickup is connected with the transmitters and signal lights in the studio indicate when transmitters are on the air.

Monitor receivers for both picture and sound allow the quality of the transmission to be checked and adjusted from this control panel.

Fig. 9 shows the schematic circuit of the radio receiver used in picking up the picture transmissions. This consists essentially of four unit parts assembled as a whole.

The first is a power unit which provides power for all filament, plate and grid voltages as well as neon lamp current.

The second unit consists of two screen-grid audions operating between three tuned circuits to select and amplify the desired signals without discrimination against the side frequencies.

The third unit is a detector which recombines the carrier and side frequency to produce the picture frequencies at its output.

The fourth unit is a resistance capacity coupled amplifier for building up the level of these frequencies sufficient to supply the picture reproducer or radiovisor.

No attenuation of picture frequencies occurs between 50 cycles and 20,000 cycles. At 20 cycles and at 50 kilocycles the attenuation is 4 db.

Fig. 10 shows two methods of connecting the output of the radio receiver to the neon lamp. The usual arrangement is to connect the neon lamp in the plate circuit.

A more desirable arrangement is to by-pass the plate current of the output tube through an impedance and operate the neon lamp in parallel, as shown. The signal level and the biasing current through the lamp may then be varied by means of series resistors without affecting the characteristics of the output amplifier appreciably.

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CONTRIBUTORS to the Proceedings, by bearing in mind the points below, will avoid delay and needless expense to the Club.

1. Manuscripts should be submitted typewritten, double-spaced, to the Chairman of the Papers Committee.* In case of acceptance the final draft of the article should be in the hands of the Chairman on or before the date of delivery of the paper before the Club.

2. Illustrations should invariably be in black ink on white paper or tracing cloth. Blueprints are inacceptable.

3. Corrected galley proofs should be returned within 12 hours to the office of publication. Additions or major corrections cannot be made in an article at this time.

4. A brief summary of the paper, embodying the major conclusions, is desirable.

5. The Club reserves the right of decision on the publication of any paper which may be read before the Club.

* For 1931 the Chairman of the Papers Committee is Mr. F. X. Rettenmeyer, 463 West Street, New York City.

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Synchronization of Westinghouse Radio Stations WBZ and WBZA‡

By S. D. Gregory*

RADIO Station WBZ was installed on the roof of the Westinghouse plant in East Springfield, Massachusetts, in September, 1921. It was the first radio station in the United States to be granted a license exclusively for broadcasting, although Westinghouse Station KDKA had been operating a radio telephone transmitter since October, 1920, under a special authorization. WBZ's original license specified an operating wavelength of 360 meters and a power output of 1,500 watts—a comparatively high power for those days.

The studio for WBZ was located in Springfield and depended entirely upon local talent for program material. It was soon evident that those facilities were inadequate and a studio was installed in Boston, where a much more diversified array of talent was available. The new studio proved a boon to the listeners in and around Springfield, but at the same time it created an embarrassing condition in Boston. Signals from the East Springfield transmitter were not heard in that area at all well and the artists complained that their friends could not hear them broadcast.

In order to make the programs from WBZ available to the listeners in Boston it was decided to build a second station there. The new transmitter was installed in the Brunswick Hotel, where the Boston studio was located, and was first put in operation in November, 1924, under the call letters WBZA. It was a self-excited set, operating on 242 meters, with a power output of 250 watts, and, although it was a makeshift affair at the best, it remedied the situation in Boston.

Historical

An interesting fact in connection with WBZA is that it was the first broadcasting station to use a piezoelectric oscillator for controlling its frequency. This apparatus was first installed in March, 1925, and similar equipment was placed in service at WBZ shortly after.

During the following months the first attempts to operate both WBZ and WBZA on the same frequency (900 kilocycles) were made, using crystals ground to zero beat. The results were far from satisfactory, due primarily to the fact that no precautions were taken to keep either the supply voltages or the crystal oscillator temperature constant. The listeners in the suburbs of Boston were troubled with a heterodyne of varying frequency when both stations were operating. After a short trial the two stations went back to their original setups, carrying the same program on separate frequencies.

In April, 1926, true synchronization of the two stations was attempted. The land wire which ordinarily carried the program between Springfield and Boston was used to transmit the synchronizing frequency as well. In order to keep the number of frequency multiplier stages at a minimum, fifty kilocycles was chosen as the carrier frequency for the first trials. The line used was an ordinary telegraph circuit consisting of open wire with the exception of a two-mile section of cable and twisted pair at Worcester, and another fifteen-mile section of cable at the Boston end.

A schematic diagram of the original frequency multiplying equipment used at the two stations is shown in Fig. 1. At WBZ the 50-kilocycle piezo oscillator excited both the first harmonic amplifier and the line amplifier. At that time buffer amplifiers were unheard of. The harmonic amplifiers, of which there were three, utilized the second or third harmonic in each case, the frequencies used being 50 kilocycles, 150 kilocycles, 450 kilocycles, and 900 kilocycles. Two hundred fifty watt tubes were used in the harmonic amplifiers and a 250-watt power amplifier stage at 900 kilocycles excited the output stage. The 250-watt line amplifier supplied about 125 watts of 50 kilocycles energy to the line. The transmitter at WBZA was similar to the one at East Springfield, except that it used 50-watt tubes in the harmonic amplifiers and had a power output of 250 watts.

In spite of all the precautions taken to insure good transmission, in foggy or rainy weather the incoming 50 kilocycles at Boston invariably dropped off to below a useable level. At first the source of trouble was thought to be the section of cable and twisted pair at Worcester, but measurements of the synchronizing frequency at that point showed the same wet weather characteristics as at the Boston end. After making a thorough investigation it was

‡ *Delivered before the Club June 10, 1931.*

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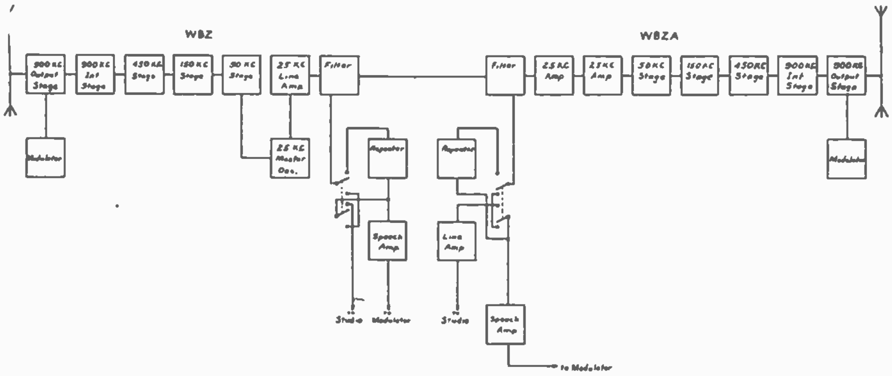

Fig. 1. Original Frequency Multiplying Equipment.

decided that the transmission frequency was too high. When the crossarms became wet the metal insulator pins were connected together by a high resistance path, and the water on the insulators greatly increased the capacity from line to pins. The resulting increase in charging current caused a corresponding increase in power loss along the line and accounted for the higher attenuation during damp weather.

The frequency was lowered to 25 kilocycles and an additional multiplier stage was added at both stations. At that time there were no 25-kilocycle crystals available, so a stable master oscillator was built, using a UX-210 tube. On May 20, 1926, the new synchronizing setup was tried out and the results were encouraging. Tests were continued until July 5, 1926, at which time the two stations commenced synchronous operation on regular schedules.

Brunswick Hotel Station

The setup just described was operated for more than a year with only minor changes. Very little difficulty was had with the synchronizing apparatus; what trouble occurred was due largely to the fact that the grounding system at the Brunswick Hotel was unsatisfactory, the building being of frame construction. As it was impossible to remedy this difficulty, arrangements were made to move to the top floor of the Statler Hotel. A complete new transmitter was constructed and was placed in operation in June, 1927. The new set differed from the Brunswick transmitter chiefly along constructional lines, the electrical details being substantially the same. Improved filters were installed for separating the radio and audio at the Boston terminal of the synchronizing line.

At several times during the transition period three transmitters—WBZ at East Springfield, and the old and new WBZA outfits at Boston—were successfully operated in synchronism—the first time that this had been done in this country. The new transmitter put a much stronger signal into Boston, due to the improved antenna system, to an increase in power to 500 watts and to the higher percentage of modulation of which it was capable. A few months later similar multiplier and low-power amplifier stages were built for WBZ. Both of the new transmitters gave satisfactory service and were operated for more than two years with no major changes in equipment.

On November 11, 1928, the new allocation plan for the broadcast spectrum went into effect and the frequency of Stations WBZ and WBZA was changed to 990 kilocycles. Shortly after the change was made listeners began to complain about interference from harmonics from WBZ. These harmonics were in reality combinations of the various multiplier frequencies resulting in modulated radiations within the broadcast band. Previous to the reallocation, these radiations happened to fall on broadcast channels in which reception was already ruined by cross-talk and heterodyning. The use of 990 kilocycles shifted the interference to frequencies occupied by cleared channel stations, and listeners immediately registered protests. A readjustment of the harmonic amplifiers helped the situation temporarily and new equipment, which will be described shortly, gave permanent relief.

Another effect of the frequency change was a marked decrease in signal from the two stations around the outer edge of their service areas. Even the comparatively small increase of ninety kilocycles was enough to cause a noticeably higher attenuation.

Frequency Multiplying Equipment

In December, 1929, improved frequency multiplying equipment was installed at WBZA, using UX-210 tubes in place of the larger power tubes. Three of the multiplier stages were replaced by a multivibrator, operating from 55 kilocycles to 990 kilocycles. As an additional precaution against the radiation of any harmonic frequencies a crystal filter was installed between the multivibrator and the 990-kilocycle power amplifiers.

The multivibrator setup proved satisfactory and a few months later similar equipment was installed at WBZ. That is, the construction of the apparatus was the same, but the multivibrators, of which there were two, were used as frequency dividers. The WBZ transmitter operated from a 990-kilocycle crystal the same as a conventional broadcast installation. The crystal oscillator output was also used to excite a multivibrator, which divided the frequency to 165 kilocycles. The second multivibrator further divided the frequency to 27.5 kilocycles, which was fed to the synchronizing line through a power amplifier consisting of four UV-845 tubes in parallel. Parallel operation of this type of tube effected a very efficient transfer of energy to the line. Suitable filter systems were used to keep the synchronizing tone from feeding back into the audio system and the audio from getting into the multivibrators. A schematic diagram showing the multivibrator equipment and associated apparatus at both stations is shown in Fig. 2. As mentioned before, this new equipment remedied the interference caused by unwanted radiations.

Receiver Distribution

Although the synchronized operation of WBZ and WBZA gave satisfactory program service to Boston and Springfield, it was rather an illogical arrangement as the 15-kw. transmitter was located in the smaller of the two cities and the 500-watt set in the larger. On the other hand, it was not desirable to locate a powerful transmitter within the limits of a large city. Inasmuch as a large part of the population of the New England States is concentrated in the three cities of Boston, Providence and Worcester, it was decided to build a new station in some location which would adequately serve those cities and to move the WBZA transmitter to East Springfield to serve that area. After careful investigation as to elevation, accessibility to power and telephone lines, type of soil, etc., a location on Dover Road about two miles northeast of Millis, Massachusetts, was tentatively chosen for the new station. A 500-watt test transmitter was set up and several weeks were spent in taking field strength measurements, using a portable checking set installed in a light truck. The three cities mentioned before were thoroughly covered in the survey, and, in addition, readings were taken along six radials in order that field intensity contours could be plotted. Data was available from which the probable output in meter amperes of the proposed 15-kw. transmitter could be calculated, and a comparison of that value with the meter ampere output of the test transmitter gave the approximate coverage to be expected from the new station. As the three cities in question fell within the calculated good service area the Millis location was definitely decided upon and construction work was started immediately.

As the transmitter which was installed is an RCA coordinated set, Model 50-B, a detailed description is hardly necessary. Kaar and Burnside covered this type of transmitter in their paper, "Some Developments in Broadcast Transmitters," published in the Proceedings of the I. R. E. for October. 1930. However, there are a few points which it might be well to mention.

The usual duplicate crystal control units are incorporated in the transmitter. Additional equipment was installed for synchronizing the two stations as before, a new type of frequency multiplier being used. Fig. 3 shows the details of the multiplying equipment and the method used for tying it in to the main transmitter. The apparatus is connected so that the Millis transmitter automatically changes to its own crystal oscillator in case the synchronizing tone from East Springfield drops below a certain level. When the leven returns to normal the station automatically changes back to synchronized operation. A sensitive relay operated by the grid current in a low-power 990-kilocycle saturated amplifier keeps the plate circuit of the crystal unit buffer stage open as long as the level of the synchronizing tone remains high enough to keep the grid current of the saturated amplifier above a certain value. Below that value the regular crystal unit functions normally and the relay opens the plate circuit of the saturated amplifier.

Apparatus Units

The synchronizing apparatus proper is located in the room which houses the station audio equipment. The incoming *27.5* kilocycle frequency passes through a band-pass filter which keeps the audio and any line interference from getting into the multiplying equipment. A two-stage *27.5* kilocycle amplifier feeds a coupling tube, the plate of which is connected to the tank circuit of a special 165-kilocycle oscillator. The second *27.5* kilocycle stage, operating saturated, takes care of any small variations in the level of the incoming *27.5* kilocycles. The coupling tube, having its grid excited strongly by *27.5* kilocycles, has a high percentage of harmonics in its output; consequently, the 165-kilocycle oscillator, oscillating at a frequency which is the sixth harmonic of *27.5* kilocycles, locks in step with the exciting frequency. The oscillator could be made to lock in at any harmonic frequency within certain limits, but 165 kilocycles was chosen in order to arrive at the operating frequency in two steps.

The output of the oscillator feeds through a coupling tube into a second oscillator operating under like conditions at the sixth harmonic of 165 kilocycles, thus producing the desired frequency, 990 kilocycles. The output of the second oscillator passes through a double crystal filter as shown in Fig 3 and into a two-stage power amplifier, which feeds a transmission line running to the saturated amplifier located on the crystal control panel of the main transmitter. The transmission line, which is about 100 feet in length, is rather novel in that it consists of low capacity twin conductor lead cable running through an iron conduit.

The Audio System

In the original synchronizing setup it was possible to feed programs either way between Springfield and Boston. The erection of the Millis station introduced a new problem as the transmitter is situated between the two cities in which the studios are located. The synchronizing line, which also carries the audio, was re-routed through Millis at the Boston end, the section between those two cities carrying program only. Fig. 4 shows the present audio layout.

Two bridging amplifiers are used in the line terminating equipment at Millis. The output of one feeds the transmitter, the other acts as a repeater and feeds audio to the studio which is not furnishing the program. That is, to Boston when the program originates in the Springfield studio, and vice versa. The switching of amplifiers and lines is done by relays controlled by the announcer at the Boston studio. In this way the switching takes place automatically as the program source is transferred from one city to the other. The line terminal and switching equipment, including amplifiers, volume indicators, relays and rectifiers is provided in duplicate, so

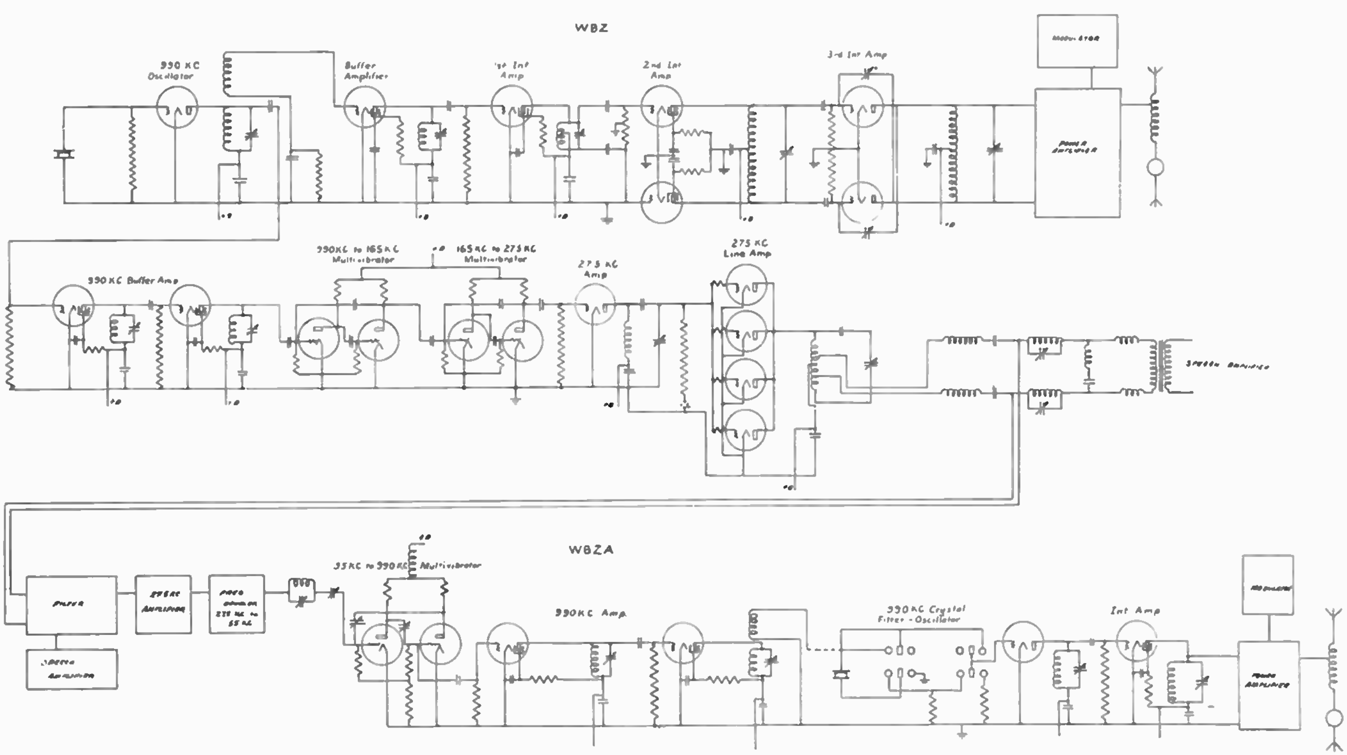

Fig. 2. Multivibrator Equipment and Associated Apparatus.

that in case of trouble the spare set may be used. The sub-harmonics of the synchronizing frequency are kept out of the audio equipment by means of low-pass filters which cut off at about 8,000 cycles.

Monitoring

Monitoring facilities are so arranged that the station operator can monitor the program on the line, at either stage of the speech amplifier, or, by means of a rectifier, at the output of the final radio-frequency power amplifier. A microphone control and amplifier are provided so that announcements can be made from the station during test work or in case of emergency. All amplifiers have separate rectifiers for plate supply, using 280 type tubes. Filament power for both the audio and synchronizing equipment is supplied from a 12-volt battery.

Low-level modulation is used, the last three power amplifier stages being operated as Class B amplifiers. The output stage has been modified to use six UV-207 tubes, three on a side, in place of two UV-862s, giving a maximum rated carrier power of 15 kilowatts. The transmitter is normally modulated 100 per cent, an oscillograph being used to check the modulation. The manufacturer's design specifications call for a frequency response flat within two decibels from 30 to 10,000 cycles, and within one decibel from 100 to 5,000 cycles.

Power is fed to the antenna over a two-wire transmission line terminated in a tuned tank circuit of the correct impedance to match the characteristic impedance of the line. The antenna is a vertical cage supported between two 300-foot insulated steel towers spaced about 700 ft. apart. Both a fan counterpoise and a buried wire ground are used, the combination of the two giving considerably better results than either one separately.

Important Developments

In reviewing the development of synchronizing of broadcasting stations as carried on by Westinghouse, it is evident that many problems have had to be worked out. A brief discussion of these might be of interest. Inasmuch as the backbone of any synchronizing system is the method or source of frequency control that subject will be discussed first.

The methods of control with which our engineers have experimented are master oscillator, piezo oscillator, and tuning-fork. As stated previously, a master oscillator was used for some time at Stations WBZ and WBZA. The circuit was a regular Hartley with a high-capacity tank, using a special Litz-wound inductance. It was found necessary to carefully filter the power supply in order to prevent the ripple from the filament machine from causing frequency modulation of the oscillator output. The frequency stability of the stations when operating from master oscillator control was well within the required limits. In fact, for several years WBZ was listed in the Radio Service Bulletin of the Department of Commerce as a constant frequency station.

Mention has already been made of the use of matched crystals for controlling the simultaneous operation of two stations. Westinghouse engineers gave the idea a trial in 1925, but the art of grinding crystals to narrow limits had not advanced enough to warrant further experimental work along that line. However, the use of a master piezo oscillator to control the synchronized operation of two or more stations has proven very successful so long as the usual precautions are taken against variations in temperature, load and supply voltages.

Crystal Filters

While we are on the subject of quartz crystals it might be in line to say a few words about crystal filters. Westinghouse engineers have been working on this problem for several years and were the first to make use of such a filter in connection with a radio transmitter. A crystal filter acts as extremely narrow band-pass and the use of two or more crystals in cascade results in practically a point-pass filter.

The use of a tuning-fork as the master control for synchronized operation was not found necessary at WBZ as the characteristics of the line between the two stations made possible the use of frequencies above the usual range of tuning-forks. However, in the experimental synchronization of KYW and KDKA in 1927 it was necessary to use a lower tie-in frequency and a tuning-fork was chosen as the logical source of control frequency. In that case a master fork operating at 5,000 cycles controlled the frequency of the KDKA transmitter through a system of harmonic amplifiers, and, in addition, was used to modulate a short-wave transmitter. At Chicago the short-wave signal was picked up and the 5-kilocycle tone was fed through a tuning-fork stabilizer into similar harmonic amplifiers. In case of fading of the short-wave signal the inertia effect of the stabilizer was sufficient to carry over until the end of the fade, then the incoming tone was automatically re-connected in the proper phase relation.

Another problem concerning which our engineers knew little when synchronizing was first attempted was the transmission of frequencies above the audio range over land wires. At the outset no extra precautions were taken

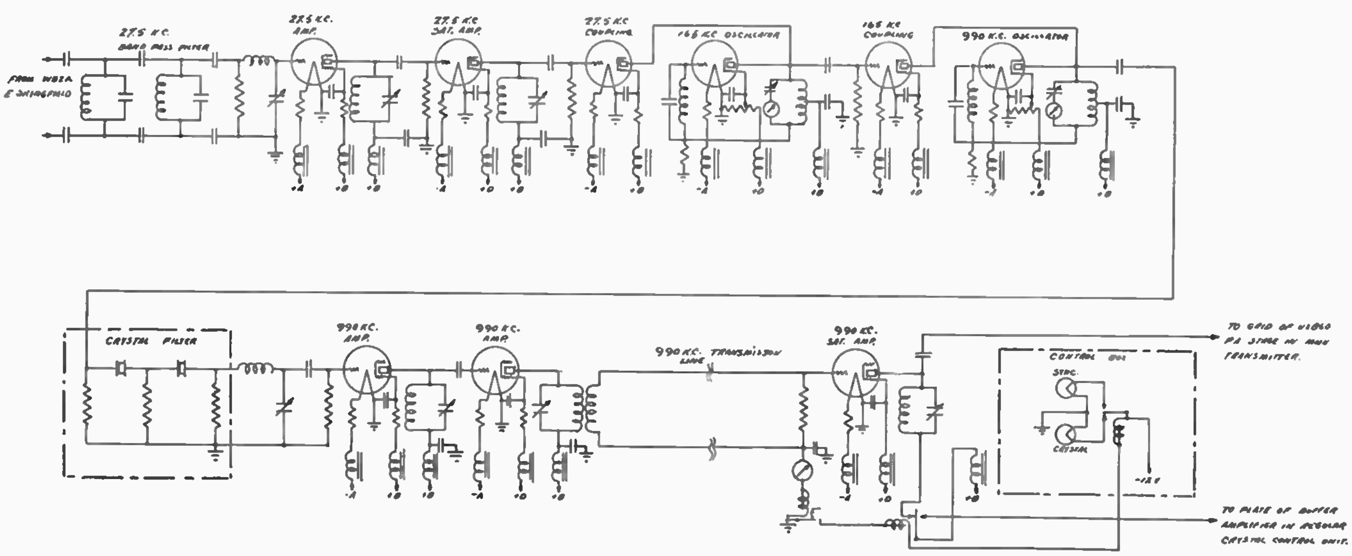

Fig. 3. Details of Multiplying Equipment, and Method of Tying it Into Main Transmitter.

to fit the lines for carrying the synchronizing frequency, but experience soon brought out the necessity of balancing the lines, using extra insulation, etc., in order to insure good transmission the year round. The problem was complicated in that the same line carried audio, telegraph, and telephone in addition to the tie-in frequency.

Over a long line such as the one between Boston and Springfield some difficulty due to electrical disturbances was to be expected. The trouble from that source proved to be slight, and has caused very little time off the air during almost five years of synchronized operation.

Synchronizing Systems

Continual research is being carried on in an effort to reduce the amount of equipment and number of tubes necessary for a synchronizing setup. To that end, several types of harmonic amplifiers, as well as the so-called multivibrator, has been experimented with. Each type of frequency multiplier or divider has its advantages and disadvantages, depending upon the conditions under which it is to operate and upon the order of harmonic or sub-harmonic necessary in order to arrive at the final frequency. If a comparatively low order of harmonic, such as the second or third, is desired the ordinary harmonic amplifier, in which a series of harmonics are produced in the output by strongly exciting a tube that is biased beyond cutoff, is to be recommended. Such an amplifier is also preferable from the standpoint of stability inasmuch as it does not require a regulated power supply.

The special harmonic controlled oscillator which has already been described in connection with the Millis station has the advantage of producing an output comparatively free from unwanted sidebands. If operated from regular power sources it can be used to obtain as high as the eighth harmonic.

A multivibrator such as shown in Fig. 2 has an output rich in harmonics due to the fact that the plate current of each

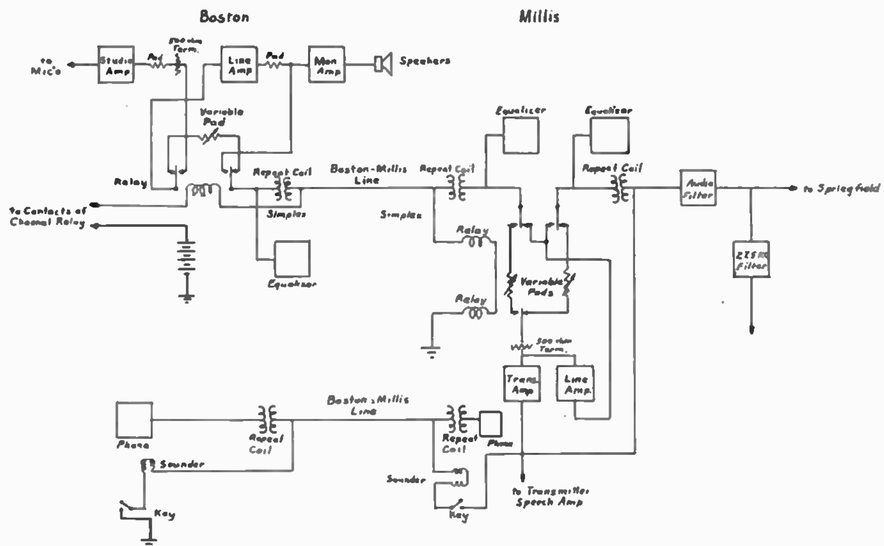

Fig. 4. Present Audio Layout.

tube goes from zero to saturation during alternate half cycles. The frequency at which the plate current changes is dependent on the time of charge and discharge of the coupling condensers through the bias resistors. Under ordinary conditions it will operate satisfactorily when using as high as the tenth harmonic and, with well regulated supply voltages, up to the fortieth can be used for special applications. The disadvantage in using multivibrators in a synchronizing setup is that they are easily affected by cross-talk. Either audio or modulated radio getting into them will cause frequency modulation in their output.

The problem in connection with synchronizing which has been most widely discussed is the interference pattern which results when two broadcasting stations operate on the same frequency. In the case of Stations WBZ and WBZA, the bad quality area resulting from synchronized operation has been found to be quite limited and at no place within the service area of the two stations has the reception been poorer than it was found to be with either station alone. With the original synchronizing setup the area in question fell on the outskirts of Boston, between that city and Springfield, but very few complaints of poor reception in that area were received.

In achieving success in the automatic synchronization of Westinghouse Stations WBZ and WBZA our engineers were forced to depart from prevailing practices in many instances and to carry on developments along new lines. Among the outstanding developments which have since come into more or less general acceptance were the first use of a quartz crystal for controlling the frequency of a broadcasting station, the use of matched crystals to control the simultaneous operation of two stations on the same frequency, the automatic synchronization of two or more stations by means of a tie-in frequency transmitted over land wires, the use of radio as a transmission medium for a synchronizing frequency, the use of a tuning-fork as a stabilizer in connection with the synchronized operation of two stations and the use of a quartz crystal in the role of a narrow bandpass filter. For the past eight years Westinghouse engineers under the supervision of Dr. Frank Conrad have been engaged in experimental work on these and other problems associated with synchronization.

BOOK REVIEW

SHORT WAVES. By Charles R. Leutz and Robert B. Gable. Published by Charles R. Leutz, Inc., Altoona, Pa., 1931. *Price,* $3.00 (384 *P. P.—cloth*).

During the past years high-frequency radio communication has taken the lead as a means of reliable communication between the four corners of the globe. This interesting and fascinating field has literally been growing by leaps and bounds and many have found it difficult to keep abreast with its progress. There has been no previous book explaining the work done in this short-wave field and it was only recently that such a work has been offered to the public.

In *Short Waves* the authors have taken into consideration the importance of this new field as is evidenced by the comprehensive text discussing the accomplishments which have resulted in recent years.

The book, itself, is presented in a concise and interesting semi-technical manner, being of value both to the radio fan and to the more experienced radio engineer. A historical review of pioneer radio development, considering the works of Maxwell, Hertz, and Marconi, introduces the general high-frequency developments down to the present day. The peculiarities of short-wave propagation are also considered with some of its strange effects.

Considerable space is given to transoceanic and long-distance telephonic radio systems, discussing much of the equipment employed in this field of transmission and reception. Numerous types of receivers, such as the superheterodyne, are discussed for the benefit of the interested reader.

Television, which is making rapid progress, because of short-wave facilities, is likewise discussed with views to further practical developments. A review of various systems employed, here and abroad, summarized the developments in research and experimental laboratories in this relatively new field.

A chapter is allotted to the use of ultra-short waves for medical and surgical applications wherein the production of artificial fevers is discussed.

We generally associate short waves with the amateur, better known as the "ham," who is perhaps the person that should receive most of the credit for their exploitation. To him a chapter is devoted. It appears that some of the material included in this work could well be omitted and the space given over to some of the apparatus employed in "ham" stations which is more in line with the subject.

Considering the book as a whole, the work is intelligently prepared and is certainly a valuable addition to one's bookshelf.

▲ ▲ ▲

The Radio Club of America regrets to announce the death, this month, of members, Daniel R. W. Murdock and John McCann.

SUGGESTIONS TO CONTRIBUTORS

CONTRIBUTORS to the Proceedings, by bearing in mind the points below, will avoid delay and needless expense to the Club.

1. Manuscripts should be submitted typewritten, double-spaced, to the Chairman of the Papers Committee.* In case of acceptance, the final draft of the article should be in the hands of the Chairman on or before the date of delivery of the paper before the Club.

2. Illustrations should invariably be in black ink on white paper or tracing cloth. Blueprints are inacceptable.

3. Corrected galley proofs should be returned within 12 hours to the office of publication. Additions or major corrections cannot be made in an article at this time.

4. A brief summary of the paper, embodying the major conclusions, is desirable.

5. The Club reserves the right of decision on the publication of any paper which may be read before the Club.

* For 1931 the Chairman of the Papers Committee is Mr. F. X. Rettenmeyer, 463 West Street, New York City.

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Condensers[†]

By R. A. Lane*

IN looking into the history of condenser development, we find that the pioneer investigators discovered the ability of a dielectric to store electrical energy, before they understood the principle which governed the apparatus. This is indicated by the name condenser, a misnomer arising from early misconceptions of the electrical principles involved. The more recently applied term "capacitor" is more truly descriptive.

Like many other important developments the first condenser, in the form of the Leyden jar seems to have been arrived at by two investigators at approximately the same time: Dean Von Kleist of the Cathedral of Camin in Germany in October, 1745, and Von Muschenbroek of Leyden in January, 1746. Von Muschenbroek's results were the first to become generally known, hence the name of the apparatus.

The names of Volta, Cavendish and Franklin stand out among the many early investigators of dielectric phenomena. Volta in 1782 observed that when a Leyden jar was discharged and left on open circuit for a time, a charge reappeared. This opened up a field of investigation which has occupied the attention of physicists up to the present time.

Cavendish, from the hissing sound he heard just before the discharge of a Leyden jar developed his fluid theory of electricity.

As Americans, we should be particularly proud of Franklin's investigations, which began soon after the discovery of the Leyden jar.

Franklin seems to have been one of the first to put forward the idea that energy was stored in the dielectric. In one of his letters to Peter Collinson, of London, with whom he carried on an extensive correspondence on a variety of subjects, he says: "Thus the whole force of the bottle and power of giving shock is in the glass itself, the non-electrics in contact with the two surfaces serving only to give and receive to and from the several parts of the glass, that is to give on one side and take away on the other."

He later demonstrated this by making a plate condenser out of glass and lead foil, removing the plates after charging the condenser, and discharging with a second set of plates.

Franklin also noted that dry air is a good insulator, but as the amount of moisture increased, the insulating value decreased. He mentions in one of his letters a Leyden jar which held at least a portion of its charge for seven months.

Like most of the investigators of his time, Franklin spent considerable time in working up electrical tricks. He arranged a picture of the King in such a way that anyone who attempted to dislodge the crown would be bowled over by the discharge of a few Leyden jars.

Franklin also was keenly interested in the effect of the "electrical fire" on living things. He found that two large Leyden jars would kill a hen, but turkeys were tough, and while two jars would knock them out, it required five to kill them. He reports that "meat" killed in this way was particularly tender.

Most of the work done by the earlier investigators was of a qualitative nature, but as knowledge was enlarged the more forward looking workers began to seek quantitative results.

Faraday, in particular, appreciated the desirability of this sort of investigation, as shown by the opening paragraph of his paper on "Induction," read before the Royal Society in December, 1837, where he said:

"The science of electricity is in that state in which every part of it requires experimental investigation; not merely for the discovery of new effects, but what is just now of far more importance, the development of the means by which the old effects are produced, and the consequent more accurate determination of the first principles of action of the most extraordinary and universal power in nature."

In his efforts to obtain accurate information Faraday built several pieces of apparatus with which he studied the properties of dielectrics. One of these consisted of two concentric hollow brass spheres, the inner sphere being insulated from the outer with a space of about ⅝ inch between the two. The outer sphere was made up of two hemispheres which could be screwed together. Two of these instruments were made and comparative tests made with air for insulation in one, and various other materials in the other. From this work Faraday arrived at the idea of specific inductive capacity, and gave values for several different substances. He also observed the phenomena of residual charge, at first finding that all dielectrics, including air, showed it; but finally deciding that the solid insulation used as a support for the inner sphere was responsible for the residual found with the air dielectric.

Maxwell, in 1873, gave out his theory of absorption, which later has been followed by other theories or modifications by Pellat, Boltzman, Van Schweidler, Wagner and others.

During the 125 years between the discovery of the Leyden jar and Maxwell's work on dielectric theory, the condenser was almost exclusively a laboratory device. Progress in the study of insulation had, of course, been made, but there had been no wide technical application of condensers to furnish the incentive for development.

First Used in Submarine Cabling

This incentive was furnished by the demand for condensers, first for telegraphy and telephony, later for ignition, radio and power factor applications.

The story of condensers is, to some extent, the story of the development of high grade insulation, and the condenser engineer is primarily concerned with the selection of materials and development of processes which will produce the most economical condenser to fit the need at hand.

The necessity for high grade insulation is apparent when the square relation between working stress and volume is considered. Suppose, in making a 200-volt radio by-pass condenser, we used instead of 1 mil of insulation, 10 mils, which can easily be found on other apparatus rated at the same voltage:

†Delivered before the Club, September 16, 1931.
*Consulting Engineer.

This by-pass condenser would then be 100 times as large as it is now.

Properties of Condensers

The electrical properties considered in selecting a condenser dielectric include dielectric constant, insulation resistance, dielectric strength and power factor. Since methods of processing affect most of these properties, process development must be carried on along with materials investigation. When enough information is available to determine probable safe working stress, cost of insulation per joule of energy stored may be determined, and the economic usefulness of the material considered. The ideal dielectric would have a high dielectric constant, negligible leakage and losses, and a high dielectric strength.

No ideal dielectric material has yet been developed, although almost every type of insulation has been tried for condenser dielectric at some time or other. For some, little or no commercial application has been found; others have properties which fit them particularly well for certain applications.

Some of the better known and more widely used dielectric materials are impregnated paper, mica, oil, glass and compressed gas.

The development of impregnated paper insulation is particularly interesting, since condensers insulated with paper impregnated with either wax or oil are widely used for a variety of purposes.

Early wax paper condensers, largely used on low, direct voltages, were, of course, far inferior to present condensers of that type, because neither materials nor processes had been highly developed.

A Bureau of Standards report, published in 1907, gives values of power factor from 1.3 per cent to 14.7 per cent for a number of condensers of various makes. In 1911 another set of tests was made on 13 condensers made by English, French, German, and American manufacturers. The minimum value found was .87 per cent, while most specimens ran many times this value. In 1912 the Bureau made some power factor and insulation resistance tests on paraffine impregnated condensers, some of which used metal foil as conductor and others metallized paper. Tinfoil condensers showed power factors from .4 to 4.1 per cent, Mansbridge type from .9 to 1.9 per cent. Insulation resistance in megohms per microfarad varied between 323,000 and 10 for the tinfoil type and between 74 and 100 for the Mansbridge type. Tests were made at room temperature at 100 cycles. It is interesting to note that the report that gives these values of insulation resistance states that while the values vary widely, even the lowest was satisfactory for the purpose for which the condenser was designed. Apparently the effect of leakage on the circuit in which the condenser was to be used was considered, rather than the leakage as an indication of the life of the condenser.

The Dielectric

The various types of paper, foil and impregnating compounds used in the manufacture of wax impregnated paper condensers were at first for the most part selected from available materials; later as requirements became better known special materials were developed.

The paper used in present-day condensers is the result of years of development by paper manufacturers in cooperation with condenser manufacturers. These efforts have produced an extremely thin closed sheet, practically neutral chemically, and remarkably free from conducting particles.

Materials in most general use as conductors include tinfoil, aluminum foil and metallized paper. Aluminum and tinfoil are both available in thicknesses of .0003 inch. Tinfoil makes a heavier condenser and is usually more expensive per sq. in. of coverage. Aluminum foil is more difficult to solder and condensers made with it do not press down as readily as those made with tinfoil. Some test results described further on seem to indicate, although perhaps not conclusively, a longer life for condensers wound with aluminum foil.

Metallized paper or Mansbridge condensers have not been used as extensively in this country as abroad. Instead of using a thin sheet of foil, metal is deposited on paper to form a conducting plate. One of the advantages claimed for this type of condenser is that when a failure occurs the metal around the point of failure is so thin it will be vaporized and the fault cleared. The disadvantages include high conductor resistance and difficulty of making a non-inductive winding.

Paraffine, probably the first material used for condenser impregnation, had when first used, widely varying characteristics due to different methods of refining and different places of origin. Characteristics are more closely controlled at present and the material is still quite widely used, either alone, in combination with other waxes such as carnauba, or with a certain amount of mineral oil. Other petroleum derivatives having higher melting points are also available. Most of these have a dielectric constant of 2 to 2.5. Halowax, a synthetic material, is widely used, because it combines good electrical properties with high dielectric constant.

Assembly

The steps involved in producing a condenser include putting the paper and foil in proper relation, either by winding or stacking, removing moisture from the paper, impregnating, cooling and sealing.

Stacking, that is, building up the condenser section with sheets of paper and foil cut to size, is very seldom used in making wax impregnated condensers, since the number of sheets of paper between foil is usually small enough to permit winding, which is a much cheaper operation.

Winding may be either inductive or non-inductive. Inductive windings use foil which is 3/8 to 1/2 inch narrower than the paper. The section is wound up with equal margin on each side and tinned copper strips laid in to enable a connection to be made. The non-inductive winding uses foil the same width as the paper, foils of opposite polarity protruding 1/4 inch or so on the opposite ends of the winding. Inductive windings require less weight of foil per microfarad, because all foil used is active. Winding labor is greater because connecting strips must be put in. For certain radio applications, the non-inductive winding is necessary, and it is desirable when the condenser is to be used on alternating current, because this foil arrangement facilitates heat dissipation.

Early methods of processing often did not involve the use of vacuum for removal of moisture from the paper, the sections being placed in the impregnating bath, kept there for a few hours, then removed from the wax and pressed. Sometimes vacuum was used on the impregnating tank, with no previous vacuum treatment of the wound sections. This, of course, made a better condenser than when vacuum was not used at all, probably as much due to the removal of entrapped air as to moisture removal.

One method of pressing was to remove the sections from the wax bath, a few at a time, and press in a hydraulic or compressed air press, in a water cooled die. One objection to this method was the rough treatment the section had to stand. Another was the fact that sections would cool rapidly on the outside, remain hot inside and open up when removed from the press.

In many cases the detrimental effect of exposure to moisture laden air during cooling and assembly was not thoroughly understood, which resulted in a product which was extremely variable in quality.

Details of present practice vary rather widely, due to different materials in use and different production apparatus employed. In general, the wound sections are stacked in clamps, separated by metal spacers. Loaded clamps are then placed in a drying oven, heated and evacuated. Since the amount of moisture drawn off during the first hour or so of pumping is large, two vacuum systems are often employed, one for primary and one for final evacuation.

In some cases wax is run into the vessel in which drying took place and the impregnation completed without handling the loaded clamps. Another method involves moving the clamps from drying oven to impregnating tank. A few systems, after vacuum impregnating for a period of hours finish up by putting the impregnating tank under air pressure of about 50 lbs. per sq. in. for a time.

Cooling starts in the impregnating tank when the heat is cut off. Since it is desirable to cool the condensers out of contact with any moisture laden atmosphere, the cooler they are when removed from the wax the better. Sometimes when steam jacketed impregnating tanks are used, the cooling is hastened by cutting off the steam and running water into the steam jacket.

When removed from the impregnating tank the clamps are cooled off in oil or in air from which the moisture has been removed.

To guard against penetration of moisture during the life of the condenser the section or group of sections is usually dipped in a bath of wax after the leads have been soldered on, and just before placing in the container. After the block is in the container, pitch is poured in to insure complete protection against outside atmospheric conditions.

Tests

Capacity and over voltage tests are made before assembly is started to eliminate faulty sections before any work is done on them. Preliminary tests of this type are often made at three times rated voltage. After assembly the capacity is rechecked, insulation resistance checked and a final over-voltage test made. On condensers for d-c. service power-factor tests are often not made on total production, tests being made frequently on a few samples selected at random.

The minimum value of insulation resistance specified as acceptable is often set at 1,000 megohms per microfarad at 25° C. Most carefully processed condensers run considerably higher than that.

Even a poorly processed condenser will often stand a 15 second breakdown test at a value far above twice or even three times its rated voltage, so that while the over-potential test will eliminate sections weakened by mechanical defects it is not a good check on process. The insulation resistance test is better in this respect, although by no means infallible. Best results by the manufacturer are obtained by combining routine tests with a very careful check on every step in the process of manufacture; and best results for an organization using condensers but not making them lie in patronizing a manufacturer known to do this.

Long time life tests at two or three times rated voltage are widely used to determine the quality of condensers. They are, of course, useful in the development of processes and materials rather than as a means of controlling production. 1,000 hours is often specified as the minimum time for operation at double rated voltage. There is considerable difference of opinion as to the interpretation of the results of these accelerated life tests. It is sometimes considered that the life of the condenser on d-c. varies as the fourth or fifth power of the voltage applied.

Thus, if a condenser operated at double voltage for 1,000 hours it would operate between 16,000 and 32,000 hours at normal voltage. In drawing conclusions from tests of this kind it must be kept in mind that "normal operation" means operation at varying temperatures, often with an a-c. component, and with the condenser subject to frequent surges.

Such tests are, however, valuable in making comparisons when materials or process have been varied. Some time ago, when working with both aluminum and tinfoil it appeared to me as though aluminum foil sections stood exposure to moist air much better than tinfoil sections. To find out if this was true when conditions were controlled, two sets of sections were made up and impregnated at the same time. Samples of both types were exposed to moist atmosphere at the same time for the same length of time, then assembled in the same way and put on double voltage life test. All the sections made up with aluminum foil remained on test well over 1,000 hours with no failures, while failures started on the tinfoil section in about 10 hours and very few lasted as long as 500 hours. Insulation resistance of the two sets of samples was about the same at the start of test. Unfortunately power-factor tests were not made on either set of sections.

Oil Impregnated Paper

The use of oil impregnated paper insulation has been largely in condensers for power factor correction, although some have been used in radio work, particularly in broadcasting apparatus.

Oil impregnated paper is superior to wax impregnated for a-c. service, particularly at the higher voltages when insulation is thicker. The combination of oil and paper is a much better conductor of heat than that of wax and paper, so that heat is passed out of the case for dissipation much more rapidly.

Several types of paper have been used in oil impregnated condensers, including Kraft, a combination of wood pulp and cotton and pure linen tissue. Processing must be modified to fit the particular material used, paper containing wood pulp being much more quickly affected by high temperature than pure linen tissue.

Mineral oil of about the same grade used in transformers is commonly used as an impregnating material. Some vegetable oils having high dielectric constants have been tried.

Process in impregnating paper with oil is similar to that used with wax, drying being completed before admiting the oil, and the oil preheated before being run into the condensers. Care must be taken to get any occluded air out of the oil before it becomes hot enough to damage it by oxidation. In many cases the condenser is assembled completely, then dried out and impregnated in its own container.

Condensers for a-c. service at 1,328 volts and above are tested for 1 minute, at twice rated voltage plus 1,000, sometimes at 2¼ rated voltage plus 2,000.

Dielectric losses are of particular importance in a condenser designed to operate on alternating voltage and must be kept at a low value, usually not so much because of the power cost as to insure long life for the condenser itself. Maximum allowable losses are set from .35 to .5 per cent of the normal operating KVA, measurements being made at 25° C.

Dielectric Losses

Many methods of measuring dielectric losses have been developed, but most of them require delicate apparatus, which takes considerable time to set up and adjust. A fair idea of losses may be obtained by preparing a dummy container identical outside with the condenser under test but containing a heating element instead of a condenser. By adjusting the input to the heater until the case temperature is the same as that of the condenser under test the condenser losses may be considered equal to the input to the heater.

One method which has proved successful in production testing is the use of an inductance of known losses with which the power factor of the condenser is corrected to approximate unity. Losses in the combination may be measured with an ordinary wattmeter and correction made for the losses in the inductance.

Book Review

"EXPERIMENTAL RADIO ENGINEERING." By John H. Morecroft. Published by John Wiley and Sons, Inc., New York City. 1931. Price, $3.50 (345 P.P.—illustrated—cloth).

Addressing the radio fraternity in general, no radio engineer needs an introduction to Professor Morecroft's *"Principles of Radio Communication."* His *"Elements of Radio Communication"* is likewise written in a similar workmanlike manner which makes this text especially valuable to radio students and beginners. And now comes the third of a trio of fine radio works written by this recognized author and teacher of experience.

The new book, *"Experimental Radio Engineering,"* is in the form of a laboratory manual compiled especially for the engineering student who is interested in knowing the "how" and "why" of radio principles. It is written in true Morecroft fashion and is direct to the point, considering in concise manner the various fundamentals necessary to understand radio frequency and operating phenomena. By use of illustrations and simple mathematical formulae, the work is clearly presented which in conjunction with the actual experiments to be worked out forms an interesting and instructive radio course for the serious-minded student.

The book consists of fifty-one experiments considering the principle and important circuit components employed in radio communication. The experiments are preceded by an introduction wherein various instruments of electrical measurement, used in conducting experiments, are described and reviewed in general. The choice of material for the fifty-one experiments is worthy of comment since all of the subjects are of common nature whose idiosyncrasies one encounters in the usual routine of radio practice or study covering the broad field of the radio art. The information proves effective even if merely read over. For actual benefit, however, the experiments should be conducted in the form of progressive problems by which routine of study the reader will most appreciate the work outlined in this radio engineering course.

Among the experiments included in this work are measurements of the fundamentals constituting the simple tuned electrical circuit and a study of their characteristic properties, followed by various considerations of circuits comprising instruments for electrical measurement. Succeeding this material the student is then introduced to the study of the thermionic valve; considering its various forms of construction and its applications in radio circuits. In addition there is an interesting study of antennae, the oscilligraph, filters, rectifiers, super-sonic reception, and modulation, etc. From this brief list it may be seen that the book considers both the receiving and transmitting phases of radio communication.

Prof. Morecroft's new work is recommended to all readers having an interest in radio principles and there is no doubt but that it will receive the same respect accorded to the other previous works of this series.—*Reviewed by Louis F. B. Carini.*

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OBITUARY

DONALD F. WHITING of Port Washington, N. Y., a Fellow of the Radio Club of America since 1926, was killed in an accident at his home on September 7, 1931.

He was born April 13, 1891, at Lowell, Mass. After attending the public schools, he entered Worcester Polytechnic Institute, from which he obtained his Bachelor of Science degree. During his sophomore year he became a member of the Worcester Polytechnic Institute Wireless Association, of which he was president during his junior and senior years. During these years he collaborated in the design and installation of the Worcester Polytechnic Institute wireless transmitter. Immediately after graduation he entered the employ of the Marconi Wireless Telegraph Company of America as assistant engineer, which position he occupied until 1916, when he entered the engineering department of the Western Electric Company. From 1916 to 1927 he served as technical consultant and supervisor of the engineering department of the Western Electric Company and its successor, Bell Telephone Laboratories. During this time he invented numerous transmission circuits and devices, on which some 15 patents have been issued, and was responsible for a number of valuable contributions to the communication art. A number of Mr. Whiting's inventions made during this period are now being utilized in radio receivers and public address equipment. In 1922 he submitted a thesis on "Measurement of the Transmission Efficiency of Telephone Apparatus" to Worcester Polytechnic Institute and during the same year received the degree of Electrical Engineer from this institution. During 1927 Mr. Whiting became staff engineer in charge of testing and research for the Fox Case Corporation, and in 1930 was appointed technical director of Fox-Hearst Corporation, a position he held until a few weeks before his death. Mr. Whiting was an active member of many technical organizations, having served on the:

Membership committee of the Radio Club of America, papers committee of the Radio Club of America, projection committee of the Society of Motion Picture Engineers, and standardization committee of the Institute of Radio Engineers.

He was a Fellow of:

The American Institute of Electrical Engineers, the Radio Club of America, and the American Association for the Advancement of Science, also a member of the Institute of Radio Engineers.

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PROCEEDINGS
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RADIO CLUB OF AMERICA

Vol. 7 DECEMBER, 1931 No. 12

Sound absorption balance in the acoustics of auditoriums†

By V. A. Schlenker*

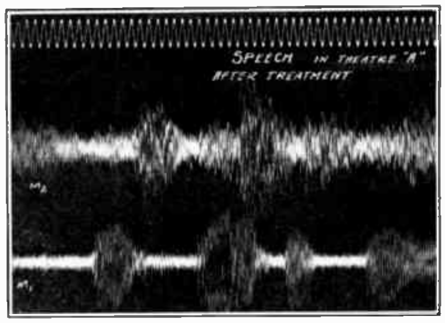

Fig. 2. Effect of reverberation on speech.

A REGRET expressed by engineers now delving into architectural acoustics is that the father of modern acoustics is no longer living. Professor Wallace Clement Sabine was never content to consider any phase of acoustics a closed book. He was always willing to reopen and continue with any investigation where there was hope of extending experimetal data in a practical way.

Unfortunately, many of his successors have shown a tendency to assume that his contributions were sufficient for the solution of practically all acoustical problems which the engineer encounters. Without detracting in the least from the monumental pioneer work of Professor Sabine, it can truthfully be said that his contributions are not entirely adequate to arm the present engineer to successfully cope with the acute conditions caused by sound pictures, radio, and television. Had Sabine lived he would no doubt still be the leader in experimental investigation with our present electro-acoustical instruments. That he was able to make such accurate and intricate measurements with the crude equipment available in his time is beyond the comprehension of most of us.

The most common assumption made by the young acoustician is that his job is done when he adjusts the reverberation of an auditorium to the so-called "optimum." Just what or why there is or should be an optimum period of reverberation has always been somewhat obscured with a veil of mystery. That music is enhanced with some reverberation is well known and it follows that a definite period, not too long and not too short, can be determined by the sensing of artists who react positively to the variation of the reverberation as it is adjusted. Professor Sabine reported that "a difference of five per cent in revereberation is a matter for approval or disapproval on the part of musicians of critical taste." (P. 80) Collected Papers on Acoustics.)

In the case of speech, however, it is not so simple. In a general way, the clarity should increase as the reberberation is reduced. At the same time the intensity at the ear of the listener is reduced by the introduction of acoustic absorption which is employed to reduce the reverberation. In small auditoriums the attenuation is not especially objectionable so long as the intensity is well within the limits of audibility. Therefore, if there are no other factors in control no optimum period of reverberation can be determined.

In the case of the large auditorium we have two essentially opposite effects on the quality of speech—one tending to increase, the other tending to reduce the reverberation. If there were no other important factors, naturally, a compromise or optimum would result.

It is quite apparent, in the small inclosure, at least, that some other important factor must be in control to

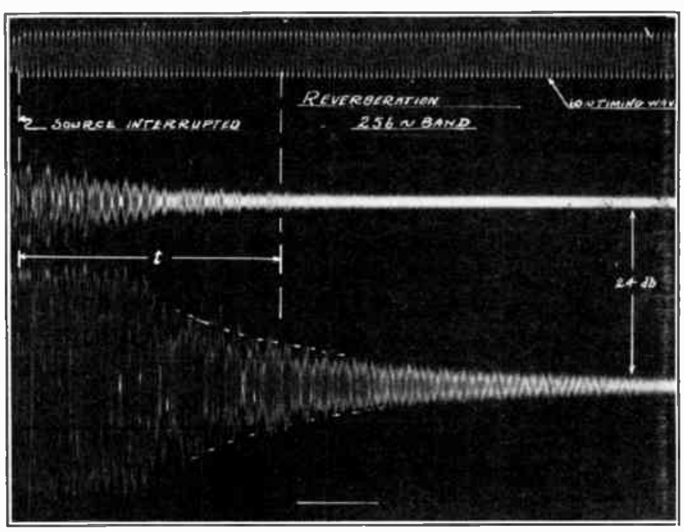

Fig. 1. Oscillographic trace of decay of sound.

†Presented before the Club, November 11, 1931
*Consulting Acoustical Engineer, Chanin Bldg., New York City.

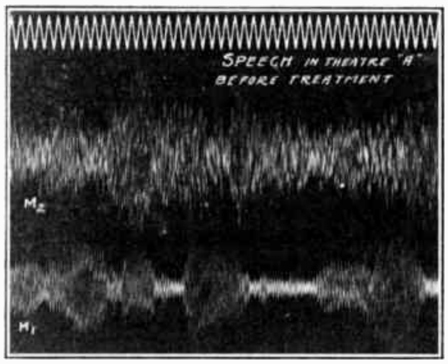

Fig. 3.

account for the optimum period of reverberation.

The reverberation of a room is usually measured by timing the decay of sound. Present methods involve a microphone to pick up the sound and a chronographic means of recording the time required for the sound intensity to drop a certain number of decibels. The number of seconds required for a 60 decibel reduction in level is universally designated as the period of reverberation regardless of frequency.

An oscillographic trace of such decay of sound can be seen in Fig. 1. The two traces are recorded simultaneously —the lower one is monitored on the upper channel electrically but set at an adjustable number of decibels above it in gain. In this particular case, the lower trace was recorded at 24 db. above the other. The distance between the points of equal amplitude on the two traces is a measure of the time for the sound to decay 24 db. By multiplying this figure by 2½ the period of reverberation is obtained. The difference of level chosen is determined by the noise level and the maximum intensity level of the test tone which is available.

The method just described was developed by the writer to avoid the possibility of error which is apt to enter when other methods are employed which involve the operation of marginal relays. Furthermore, the exact manner in which the decay takes place is at all times known when the oscillographic trace is made. This facility is very important for the research worker who must be on the look-out for new and unexpected phenomena.

The effect of reverberation on speech is shown in an interesting way in Fig. 2. In this case, two microphones were set up in a particular theatre. One was placed about four feet in front of the loudspeaker behind the picture screen giving the lower trace, while the other was positioned out in the auditorium, giving the upper trace. In this way a direct comparison between the sound as it comes out of the horn can be made with the sound as it is received by the listener out in the audience. The last three syllables are "VI-TA-PHONE."

Although the distortion is abundant because of reverberation it was worse before this house was acoustically treated, as will be seen in Fig. 3. The reverberation is so great that the individual syllables are scarcely discernible.

When the reverberation is measured in the auditorium the investigator at once discovers that there is a considerable variation, depending on the frequency. Some typical curves are given in Fig. 4. The curve marked T-1 has an excessive period of 4.0 seconds at 128 c.p.s., while at 4096 c.p.s. the period is only 1.5 seconds, which is a ratio of almost 2.7. The curve T-3 from a theatre which has been treated acoustically has a period of 3.5 at 128 c.p.s. and 1.0 at 4,096 c.p.s. Here the ratio is even greater—3.5. Curve T-2 has the smallest ratio—3.2 to 1.8 seconds, which is approximately 1.8.

At once, one is led to the suggestion that perhaps the relative slope of the reverberation curve may be of considerable importance. In other words, the fact that low-frequency sound is absorbed less efficiently than the high frequency may be most valuable in determining the degree of intelligibility with which speech is understood.

In Fig. 5 (lower right portion), is

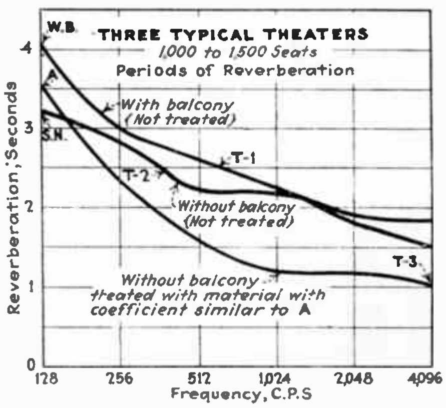

Fig. 4. Reverberation curves of three typical theatres with different acoustical treatment.

given the reverberation curve of a particular average theatre with a seating capacity of 1,800. It will be noted that the reverberation at the higher frequency depends upon the relative humidity of the air. Recent investigation by Dr. Knudsen and others have established the absorption of the air at different values of relative humidity. Their findings have been quite startling but entirely in accord with the experimental as collected by competent observers. Professor Sabine, himself, recognized the fact that the moisture content of the air is a factor in the dissipation of acoustic energy but he concluded that (to quote from p. 171 of his Collected Papers), "this form of dissipation instead of being an important factor, is an entirely negligible factor in any actual auditorium." If the bounding surfaces of this auditorium were perfect reflectors the reverberation at 4,000 c.p.s. would be 4.4 seconds due to the absorption of the air at a relative humidity of 20 per cent and room temperature of 70° F. On the other hand, if the humidity is 70 per cent the period is almost twice as great—the absorption at 4,000 c.p.s. being almost negligible for all practical purposes. In fact, this no doubt accounts for Sabine's failure to detect

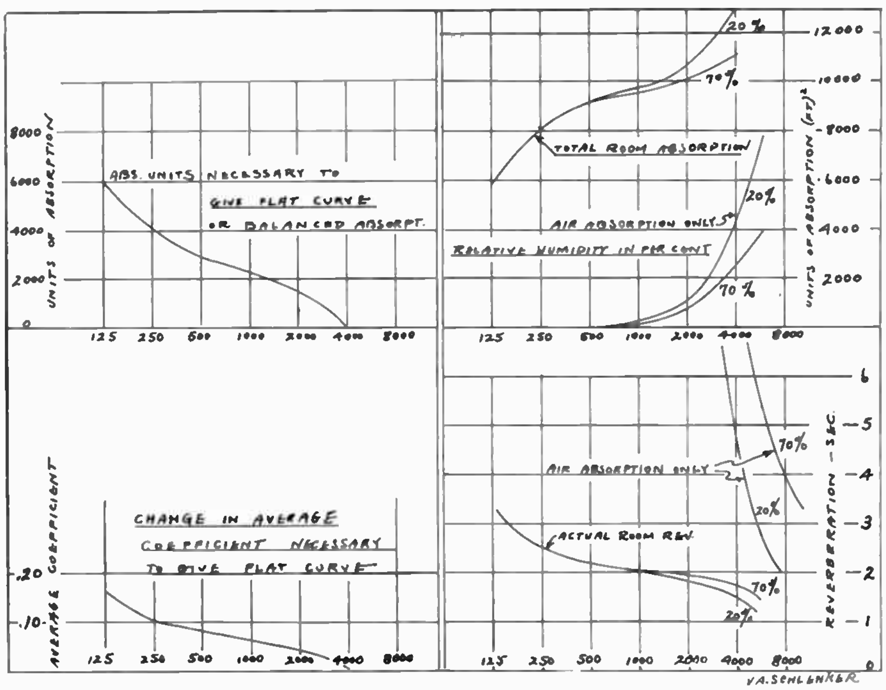

Fig. 5. Reverberation curves.

the effect of humidity, since he may have done practically all his work in humid air.

The effect of dry air must be taken into consideration since most of the theatres have very dry air in the winter time. I have been informed by the Carrier Engineering Corporation that the humidity will run as low as 25 per cent in the winter where no air conditioning is provided. The practical ideal for winter is 35 to 40 per cent as is maintained by the air conditioning equipment. It can be concluded that at frequencies above 2,000 c.p.s. the relative humidity must be considered in determining the acoustical absorption and its effect on reverberation.

In the upper right-hand portion of Fig. 5 is given the absorption as calculated from the reverberation given in the curve immediately below. It will be noted that the curve has an alarming slope at a relative humidity of 70 per cent. At an average humidity of 45 per cent the total absorption is 12,000

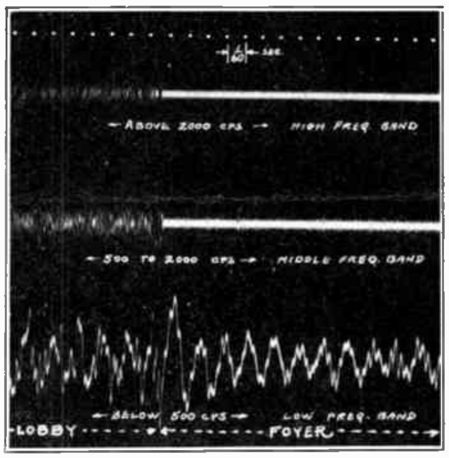

Fig. 7. Records of street noises.

units at 4,000 c.p.s. and only 6,000 units at 125 c.p.s—a ratio of 2.0. For purposes of later consideration the units of absorption required to give a flat curve are given in the left portion. In other words, if a balanced condition is desired in this theatre the absorption must be added in largest amounts at low frequencies.

In the last analysis of the acoustic problem, the final judge which must be satisfied is the human ear. It is well known that the ear is limited in tonal range or frequency. It is also limited in the range of intensities. The very faintest sound is sensed at the "threshold of audibility" while the very loudest sound is sensed at the "threshold of feeling." Both the frequency and intensity ranges can be represented on a chart by a certain area as shown in Fig. 6.

A smaller area can be used to represent average or normal speech. The

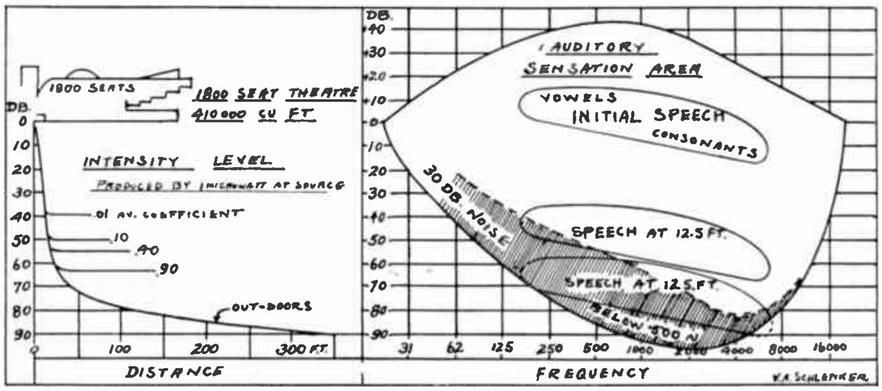

Fig. 6. Frequency and intensity ranges.

average extends from 200 c.p.s. to 8,000 c.p.s. for the important components. The speech area, then, will extend from 200 to 8,000 along the frequency axis and about 25 decibels along the intensity axis. The speech area can be further divided into the vowel and consonant portions. The vowels occupy the region of low frequency and high intensity while the consonants are found in the region of high frequency and low intensity.

Taking the total speech power as 10 microwatts for average speech (p. 67, Fletcher, "Speech and Hearing"), the speech intensity is 1 microwatt per square centimeter at a distance of one-half inch from the mouth of the speaker, since the power is divided over the 10 sq. cm. of surface of the hemisphere whose radius is .5 inch. The intensity of 1 microwatt per sq. cm. is taken as zero level.

If sound continues to radiate into unconfined space the intensity will diminish according to the inverse square of the distance. At a distance of 12.5 feet the intensity will be 50 db. lower than the "initial level" which is taken at a distance of .5 inch by definition.

On the auditory chart the effect of the listener moving from .5 inch to 12.5 feet can be represented as a 50 db. vertical drop of the speech area. When the listener moves to a distance of 125 feet a further drop of 20 db. is experienced. At this distance, the speech area is then touching the minimum audibility level.

Some idea of what this means in terms of the dimensions of a theatre can be gained by the curve and sketch shown in the left portion of Fig. 6. It will be seen that if a person spoke on the stage with a speech power of 1 microwatt, it would be just audible in the rear of the theatre, assuming that no reflections took place from the walls, ceiling, and floor. If there is noise present a portion will be masked. In the shaded portion of the auditory sensation area is represented the space occupied by a 30 db. level of noise which has its components below 500 c.p.s. The masking extends well up in the higher frequency range as has been determined at the Bell Telephone Laboratories. If this noise were present as is frequently the case, the speaker could not be heard in the remote portion of the balcony. In other words, the one microwatt voice with an initial intensity level of —10 db. would have to be raised 30 db. to 1,000 microwatts to give an initial level of +20 db. This would insure a —50 db. level at a distance of 125 feet without the aid of reflections.

In the actual theatre the reflections raise the level of sound, immensely. For the purpose of comparison the intensity levels have been calculated for different absorption conditions. For an average coefficient of absorption of 0.10 the intensity level of approximately 50 db. below 1 microwatt per sq. cm. (zero level) would be established by a sustained sound.

The nature of the room noise which is ever present should be known with some degree of accuracy. Not only the intensity should be known, but its frequency distribution as well. Fig. 7 gives a record of the street noise which filtered into the theatre which we have

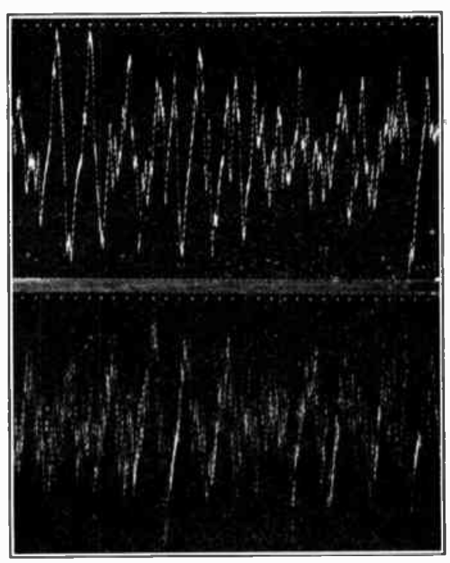

Fig. 8. Traces made in an acoustically treated theatre.

been considering as typical. The electrical circuits were arranged with special filters so that the entire frequency range was divided into three bands—low, middle, and high. The distribution of the noise is fairly uniform over the three bands when picked up on the street. After finding its way into the lobby the middle and high frequencies are attenuated somewhat as can be seen in the left half of the traces. A special switching device automatically switches the circuits over to another microphone located in the foyer. This switching is accomplished in much less time than it takes the sound to travel from one microphone to the other. The traces from the noise in the foyer show an entirely different distribution of energy over the three bands. In the foyer, which is really a part of the orchestra itself, the noise is almost entirely made up of frequencies below 500 c.p.s. This fact is important in determining the characteristics of any acoustical treatment which is prescribed for noise abatement. The type of auditory masking which it causes is also determined by its frequency characteristics.

Fig. 8 shows an interesting comparison of two traces which were taken in a studio which was heavily treated acoustically. The upper trace shows the room noise which runs as low as 30 c.p.s. up to 200 c.p.s. The lower trace shows the same room noise with high frequency noise of a motion picture camera superposed. These traces were taken separately but within 15 minutes of each other. Once more the room noise is found to be made up of low frequency components.

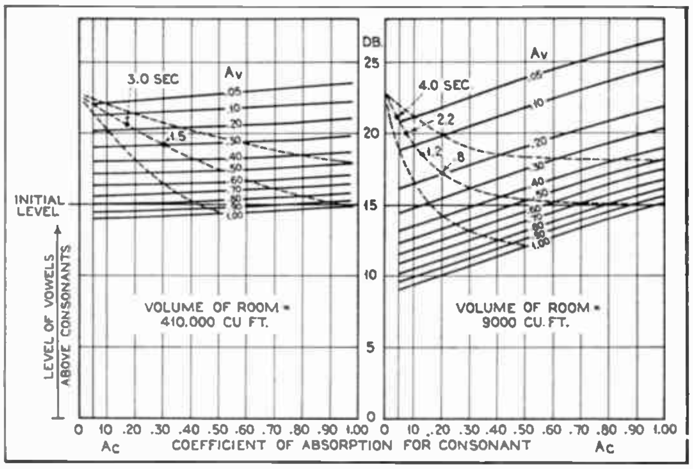

Fig. 10. Intensity level of vowel above intensity level of consonant:
tv = .30 sec.
tc = .05 sec.

It has been noted how multiple reflections build up the sound intensity when a single tone is sustained long enough for a steady state condition to be established. In dealing with speech, however, the duration of the individual component is very short. The time of the average vowel is 0.3 second while the average consonant can be taken as 0.05 second. Inasmuch as the vowels and consonants are entirely different in frequency, duration, and intensity, it seems reasonable that each should be considered separately. For purposes of diagnosis, the writer has developed an electrical syllable which can be used to simulate a component of speech. If its frequency is set at, say, 250 c.p.s. with a length of 0.30 second, it will represent a vowel. If its frequency is set at, say, 4,000 c.p.s., with a length of 0.05 second, it will represent a consonant.

In this way an auditorium may be tested by acoustically projecting the vowel and the consonant separately and recording the sound as it is picked up in various parts of the house by a microphone.

Four different oscillograms are reproduced in Fig. 9. These were taken as suggested in the last two paragraphs. In fact, they were all taken in the same theatre but in different positions. The traces on the left were taken in the center of the orchestra while the ones on the right were taken on one side of the orchestra. Space will not permit more than a glance, but it is obvious that a great wealth of information may be gained from a careful study of such soundings in an auditorium. The particular orientation of the horns will also control to some degree whether the high frequency projection will "clean cut" like the one at "M-2" or ragged like the one at "M-5."

After a careful consideration of the properties of speech and its interpretation by the ear, the writer has finally concluded that the true relation between reverberation and articulation can be traced to the short length of the fundamental speech sounds. If the vowels are assigned a duration of 0.3 second and the consonants 0.05 second with a difference of 15 decibels in power we will have a good average representation. The vowel can have a frequency of 250 c.p.s. while the consonant can be assigned 4,000 c.p.s. The intensity to which each will build up can then be calculated where the average coefficient of absorption of the room is known for each frequency. It is at once apparent that the consonant will build up to only a small fraction of the steady state value because it is so short in duration. On the other hand, the vowel which is six times longer will attain a much greater fraction of its steady state value.

As has been seen, the vowels are about 15 db. higher than the consonants. One can then proceed to calculate the difference in level as determined by the duration of the sound, the absorption at the particular frequency of the vowel or

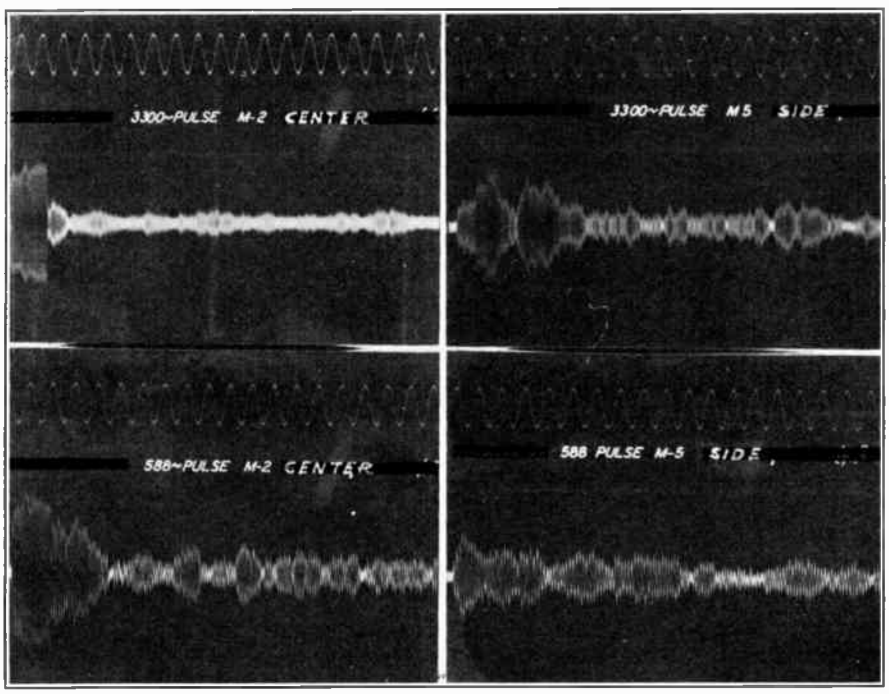

Fig. 9. Traces made in an acoustically treated theatre.

consonant, the volume, and total surface of the room.

Fig. 10 shows the results when all the possible coefficients of absorption are assigned to the vowels and consonants, respectively. The true vertical distance represents the intensity level of the vowel above that of the consonant for any particular value of the consonant coefficient. For example, take the point marked 0.8 second on the chart for the room with a volume of 9,000 cubic feet. This represents a consonant with a coefficient of 0.20 and a vowel with a coefficient of 0.20 also; the level of the vowel being 17 db. above the consonant. The 0.8 second is the reverberation for this particular coefficient. The dotted line passing through this point is a locus of all conditions in which the vowels and consonants have the same coefficient. In other words, this line represents a balanced absorption with respect to frequency.

The upper dotted line represents the condition in which coefficient of absorption for the vowels (Av) is only one-half that for the consonants (Ac). Likewise, the lower dotted curve contains all the points in which the vowel absorption is twice that for the consonant. In brief, the area above the middle dotted line represents unbalanced absorption of the usual kind while the area below represents a reversed absorption unbalance which is most unusual.

Many interesting deductions can be made from this chart. Perhaps the most interesting thing to note is that the condition of unbalanced absorption causes the vowels to rise far above the normal level for initial speech which is bound to decrease the articulation. On the other hand, the reversed unbalance causes the vowels to be much lower in level and in some cases to be below the normal level. Further experiment will show that the articulation will be improved in a corresponding way.

The effect of the size of the room is strikingly shown when the same calculations are made for a room with a volume of 410,000 cubic feet. Here there is less opportunity to keep the level of the vowels at or below the normal level of initial speech. However, the reversed absorption condition is far superior to even the balanced condition.

In the application of acoustical treatment, one must not lose sight of the fact that coefficients of absorption which are available, are painfully limited. Practically all the materials on the market have absorption curves similar to those which are shown in Fig. 11. The slopes of these curves are of special interest in view of the data given in the chart presented. The absorption at high frequencies which controls the consonants is between twice and three times that at low frequencies which controls the vowels. These curves have the usual unbalance which results in the vowels being intensified in excess of the consonants. The net effect is to lower the articulation.

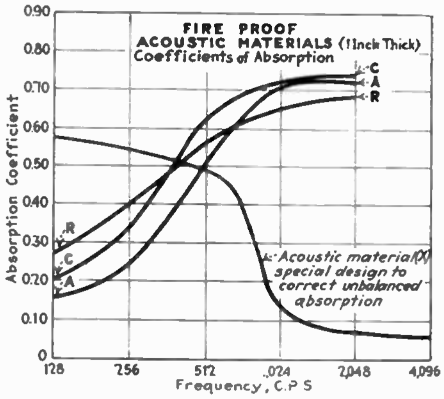

Fig. 11. Coefficients of absorption curves of well known materials for different frequencies, also one material of special design to correct unbalanced absorption in acoustic treatment.

The new acoustic treatment which is indicated by the curve "X" in this figure is designed to aid in the correction of the unbalanced condition. The cost of treatment which will give the extreme slope of one-fifth is considerably more than a modified treatment on the same principle which has a slope of one-half.

Referring again to Fig. 10, the smaller room gave an articulation of 79 per cent when the reverberation was adjusted to a period of 1.2 seconds for a sensation level of 72 db. (J. C. Steinberg, J. A. S., Oct., 1929). In this room (whose dimensions were 20 x 30 x 15 feet), the coefficients Av and Ac were approximately equal to 0.12. Reading the chart, it will be noted that the vowels are about 3 decibels above the normal, or a total of 18 db. above the consonants. If this room were treated with the new material with a reversed absorption curve, the average coefficient for the vowels Av could be adjusted to 0.30 keeping the A c at 0.12. The result would be to bring the vowel level completely down to the normal for initial speech, thereby enhancing the intelligibility.

In conclusion, the method of acoustic treatment of auditoriums which employ a new material with maximum absorption at low frequencies has unusual possibilities for improving the articulation of speech. That there is a sound scientific basis for such a conclusion in addition to experimental confirmation is most reassuring to the engineer who desires to determine the specifications of acoustic treatment to give a certain percentage of articulation at a prescribed acoustic intensity level.

▲ ▲ ▲

Club Notes

Harry W. Houck has joined the Kolster Radio Corp. as assistant chief engineer, after having been connected with the Dubilier Condenser Corp. and its predecessor for ten years. He will be stationed at the Kolster Company's engineering laboratories in Newark, New Jersey.

C. E. Brigham, chief engineer of Kolster Radio, Inc., Newark, N. J., has been appointed director of the engineering division of the Radio Manufacturers' Association. Mr. Brigham is chief engineer of Kolster Radio, Inc. He is a Fellow and a Member of the Board of Directors of the Radio Club of America, a member of the Institute of Radio Engineers and on the Committee of Papers and Standardization of the I. R. E.

Homer G. Tasker, now connected with United Research Corp., 41-39 38th Street, Long Island City, N. Y., as chief engineer. Formerly in sound department of Warner Bros. Pictures, Inc., Hollywood, California.

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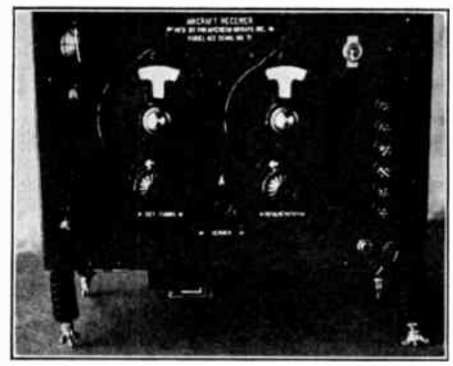
Radio communication on the international airlines of the United States†



Model ACC aircraft receiver. View of front panel, set closed.

By H. C. LEUTERITZ*

Route Traffic Between Airports

Where an organized air route between fixed points is established, it is of the utmost importance that an efficient system of communications should exist, in order that messages concerning the departure and arrivals of aircraft, instructions to land at intermediate air ports or emergency landing fields, information regarding transport of passengers and goods, and the thousand and one messages which are a part and parcel of an efficient air transport organization may be rapidly and accurately communicated without unnecessary delay.

The Department of Commerce under the Air Commerce Act of 1926 has undertaken to handle part of these details, using wire line facilities where they exist and radio service in other locations. However, the service which is rendered is rather limited in extent so that all the points covered in the above paragraph are not handled by them, particularly on international routes, in which cases the airline operator is necessarily compelled to provide his own facilities.

Experience has shown that the circulation of all meteorological information and all route traffic messages, is best handled by means of radio telegraphic signals.

Meteorological information is usually circulated in the form of code messages, while the normal route traffic messages consist of information concerning number of passengers, letters defining the airplane and such details regarding the aircraft in particular. It is generally agreed that this class of service is more easily dealt with when using the telegraph code. This insures a permanent record being kept of the actual text of the messages dispatched and received for future reference.

The location of any aircraft on an airway at any particular instant must be available to the flight control officer usually designated as the operations manager. This is most important so that he may keep in close touch with the meteorologist at all times to be in a position whereby he can issue the necessary advice to cancel any flight if in his opinion such flights will jeopardize the safety of the passengers and crew.

Aircraft Communications

Turning to the question of the system to be employed from and to the planes while in flight, it is now accepted that where the pilot of the machine himself has to operate the radio equipment, then the *only* system that can be efficiently operated is radio telephony. The pilot of a modern airplane has so much to occupy his mind while flying the plane and watching the multitudinous "gadgets" which are an integral part of all modern types, that he cannot possibly be expected to concentrate on the reception and writing down of telegraph signals. Consequently the spoken word is essential for such cases.

In the case of large transport planes carrying passengers, it becomes necessary in most cases when employing telephony, to repeat a message two or more times before it is clearly understood. This delay is normally due to static and other contributing noises. This statement is based on experience both here and abroad and on more than one occasion the use of telegraphy copied by an operator aboard the plane has demonstrated that the speed of transmission is greater by use of the telegraph code. On several tests conducted, using both types of communication, it was possible to deliver a message pertaining to the safety of life and property in one-twelfth the time required by telephony.

In our operations, we not only have to contend with the inherent noise which exists on all aircraft, but the problem of static is decidedly more prevalent and over greater portions of the year in the tropics than elsewhere. This is only natural as the climatic conditions

†*Presented before the Club, January 13, 1932.*
**Chief communication engineer, Pan American Airways, Inc.*

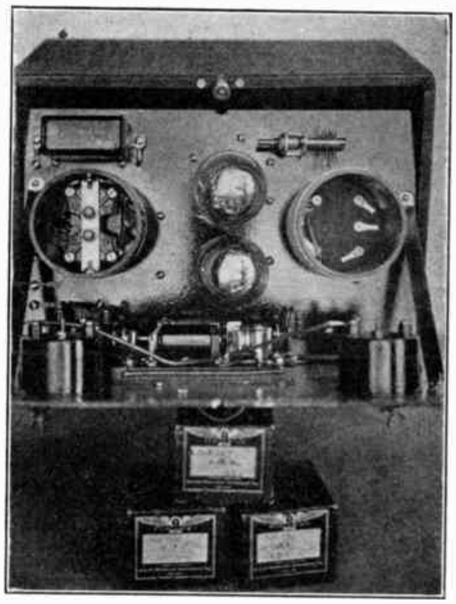
are such as to be conducive to development of electrical storms, etc.

Aircraft communications are carried out in the following manner. The pilot is required to send a message every half hour giving his position on the route. This position uses for its basis given landmarks where same are visible, or a latitude and longitude position when flying over water routes. This report is based on a dead reckoning and is dependent for its accuracy on the experience of the pilot. It is rather surprising to note the accuracy attained by pilots as checked against direction finder bearings. The radio operator, however, is required to contact airport stations every fifteen minutes and maintain a continuous watch so that ground stations and aircraft can contact each other instantly. As an illustration of how this works, a plane on the ramp at Washington heard the Miami station working an airplane in flight between Havana and Key West. When the contact was finished, he called Miami on the same frequency and got an immediate answer to his call and several messages were handled. This was done without any preliminary schedules or advice to the Miami station. This method of operation insures service to all aircraft so that in cases of emergency the situation can be met.

Direction Finding and Radio Beacon Operation

One of the prime uses of radio for aircraft is the possibility it affords of ascertaining the exact position at any instant of an aircraft in flight. While the ordinary methods of navigation can be used with a reasonable amount of success in the air, yet certain conditions of weather may be encountered where these methods may not only become almost totally useless, but actually misleading and in some cases dangerous.

For instance, suppose an airplane is flying in bad weather and is suddenly surrounded by thick fog which can neither be flown over or under. It is evident that the ordinary methods of flying by visual observations on the sun, stars or beacons immediately become useless, and reference has to be made to the compass and on dead reckoning. The aircraft compass, as is well known, is liable to be misleading, since under certain conditions it begins to swing, due to the yawing of the aircraft, and owing to the lag due to mechanical inertia, the pilot may over compensate again until the compass card may actually begin to spin. A turn and bank indicator helps here, but no other method of navigation will enable the pilot to determine his exact position except by radio direction finding, as if there is either a wind causing a drift, or an error on the compass, the machine may become many miles off its course, without the pilot having any indication. If the fog belt extends for many miles over the course, it is quite evident that the pilot may become totally lost under such conditions.



Transmitter.

Several methods of direction finding for aircraft have been employed to date, viz., (a) Direction finding systems on the ground. (b) Direction finding equipment carried on the plane. (c) Directional transmitter on the ground (radio range system).

A certain amount of discussion has taken place as to which method is preferable, and as a matter of fact there are many pros and cons for each system. Therefore, let us briefly summarize the advantages and disadvantages of each system.

Direction Finding on Aircraft

Advantages. (a) Secrecy; (b) Responsibility for correct position rests with the pilot or navigator on the plane.

Disadvantages. (a) Extra training and work of navigator; (b) Extra weight of apparatus; (c) Wind resistance in the case of a rotatable loop on the plane; (d) Turning of plane in flight when using fixed loops in order to check correct position; (e) Lack of direct contact with ground stations; (f) Lack of check with known ground points; (g) Lack of ground control; (h) Interference from ignition, etc., due to high sensitivity of receiver.

Direction Finding on the Ground

Advantages. (a) Saving of weight of equipment; (b) No extra wind resistance; (c) No extra personnel required; (d) Greater accuracy of bearings due to absence of noise and ignition interference; (e) Direct contact with ground stations at all times; (f) Direct control by ground stations; (g) Accurate check from ground points; (h) Accurate means provided for keeping aircraft on a predetermined course between airports; (i) Installation cost very low; (j) Air crashes avoided.

Disadvantages. (a) The pilot has to rely on bearings from the ground stations; (b) Slight delay between time of request for position and the time it is received from the ground station. However, this time can be reduced to less than one minute by efficient operation and training of ground crew.

Radio Range

Advantages. (a) Pilot flies a given course; (b) Theoretically any number of planes can follow same course; (c) No extra wind resistance; (d) No extra personnel required.

Disadvantages. (a) Lack of direct contact with ground stations; (b) Lack of direct control by ground stations; (c) Installation costs high; (d) Air crashes are possible between planes following the same course; (e) Responsibility of correct position rests with pilot; (f) Turning of plane in flight in order to check correct position; (g) Confusion of course due to noise and ignition interference; (h) Confusion of course due to other interfering ground transmitters caused by ships, etc.

Although much stress has been laid on the necessity of rapid communication between airports and airplanes in flight, the aid to navigation rendered by directional means is no less important.

Due to the many advantages by the use of direction finders on the ground the Pan-American Airways has adopted this system in preference to all others. A system has been worked out which is very economical and efficient in operation.

Aircraft Telegraph and Telephone Apparatus

The design and manufacture of aircraft radio equipment is an art in which the radio problems are complicated by the restriction of weight and space. Definite limitations are placed on these two facts and it is only by careful design and arrangement of the circuit parts that it is at all possible to combine compactness with efficiency.

1. The following data is compiled as a result of experience gained in the equipment and operation of radio apparatus on many commercial planes. It is intended to serve as a guide to the technical engineer well acquainted with modern radio practice.

2. Aircraft radio communication has many problems associated with it which do not come into prominence in connection with ground or ship stations. The various systems employed have been developed by no means because they

were the simplest and easiest to apply to aircraft communications, but because it is not always economical or practical to carry a radio operator capable of giving his undivided attention to the transmitting and receiving of messages, except on very large passenger machines such as we use in our own services. In the case of single pilot mail or express planes or in the case of limited payload machines and under favorable conditions it is essential to employ telephony, since it forms the only solution to the problem, for it provides a practical means of linking the airplane with the ground or with another machine and can be used by a pilot or navigator without special training.

3. The destructive effect of constant vibration, and the conditions of extreme noise under which telephony has to be carried out, coupled with the fact that in most cases the apparatus is not available for inspection under working conditions except when a test flight is made, constitute the chief difficulties which are experienced. In the new large cabin planes the pilot does not wear a helmet and this further handicaps the use of telephony.

4. The efficiency of the radio installation on an airplane will depend largely on how the initial fitting is carried out, and too much attention and care cannot be given to this subject. Unfortunately provision is not always made in the modern airplane for radio equipment, consequently the disposal of the apparatus (including, as it does, the main set, controls, generator, antenna reels and fairlead) is a matter which often taxes to the utmost the ingenuity of the radio engineer.

In March, 1929, work was started on the construction of a 200-watt transmitter for airport operation and which utilized one UV-204A tube in an oscillating circuit feeding a doublet antenna.

The plate power supply was furnished by a full-wave rectifier using two UX-866 tubes and delivering from 1,500 to 2,500 volts. The plate voltage transformer was arranged with taps in the primary circuit for voltage control. The entire unit operating from either a 110 or 220 volt, 60 cycle, single phase supply.

These transmitters were later equipped with a wavechange switch to permit operation on two frequencies, and erected at each of the airports along the route for communication both with airplanes in flight and between airports.

In April of 1929 some of the new 100-watt transmitters were delivered and installed aboard aircraft and operated on telephone by pilots. Telephone tests in regular scheduled operation again demonstrated the need for better and more efficient service as the length of time required to deliver messages was considered too great for safe operation. By July 1 these transmitters had all failed from one fault or another and the entire lot were therefore rejected.

On the basis of this experience, complete new aircraft apparatus was designed including both transmitter and receiver.

The aircraft equipment can be divided into the following classification and each part will be considered separately:

(a) transmitter; (b) power supply; (c) receiver; (d) antenna systems.

Aircraft Transmitter

The output of the transmitter is 12 watts cw. telegraph only. The circuit is a standard master oscillator-power amplifier connection employing one 7.5 watt type UX-210 tube as the oscillator and one of the same type tubes as a power amplifier. The amplifier circuit is neutralized and the oscillator circuit is a straight "Hartley." All resistors are of the moulded type to insure reliability.

Plug-in inductances are used so that a quick change of wavelength can be made. The tank circuit capacities are constructed as integral parts of the plug-in coils so that in changing wavelengths, no adjustment is required in the transmitter other than retuning the antenna (by increasing or diminishing its length) for maximum radiation at the new frequency. Standard installations contain plug-in coils for 32, 54, 97, 600 and 900 meters. The latter waves being necessary because of our international flights part of which are over water. Keying is accomplished by biasing simultaneously both the grid of the master oscillator and the power amplifier.

The set is mounted in an aluminum

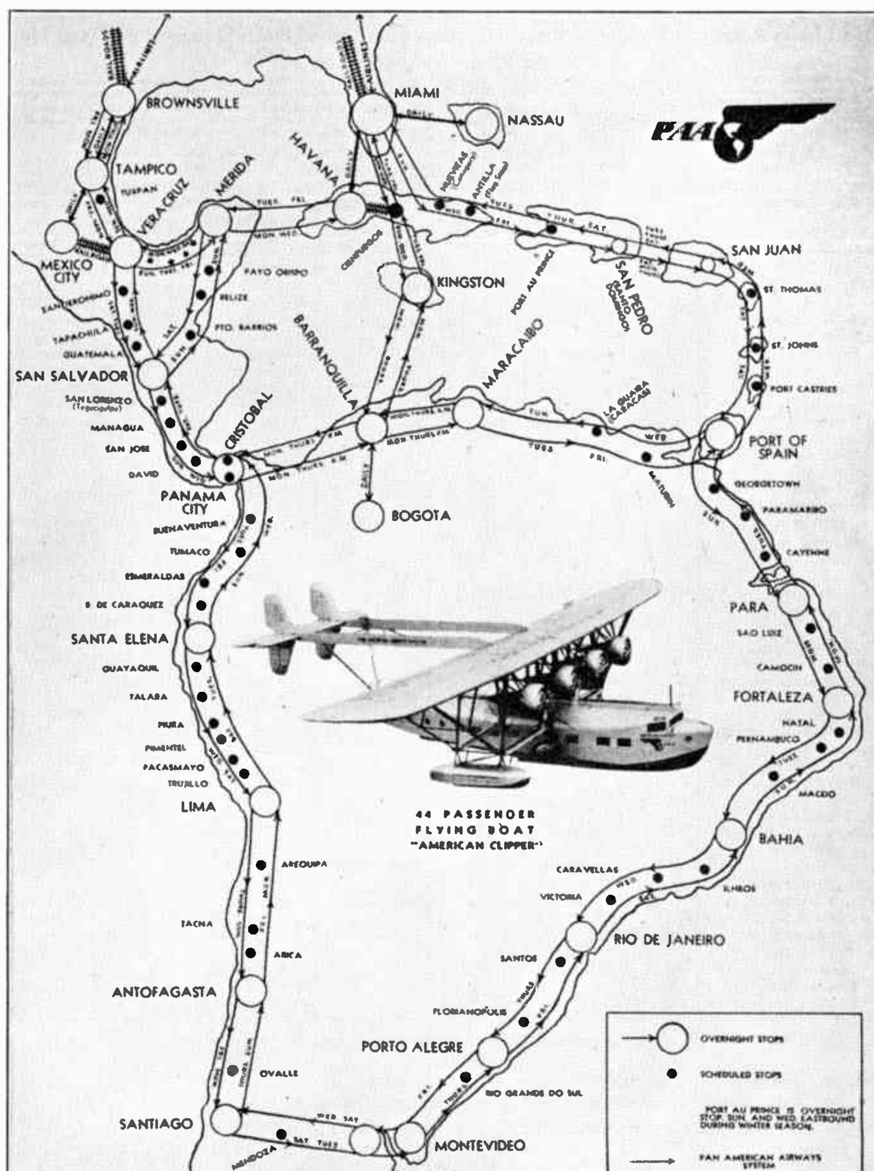
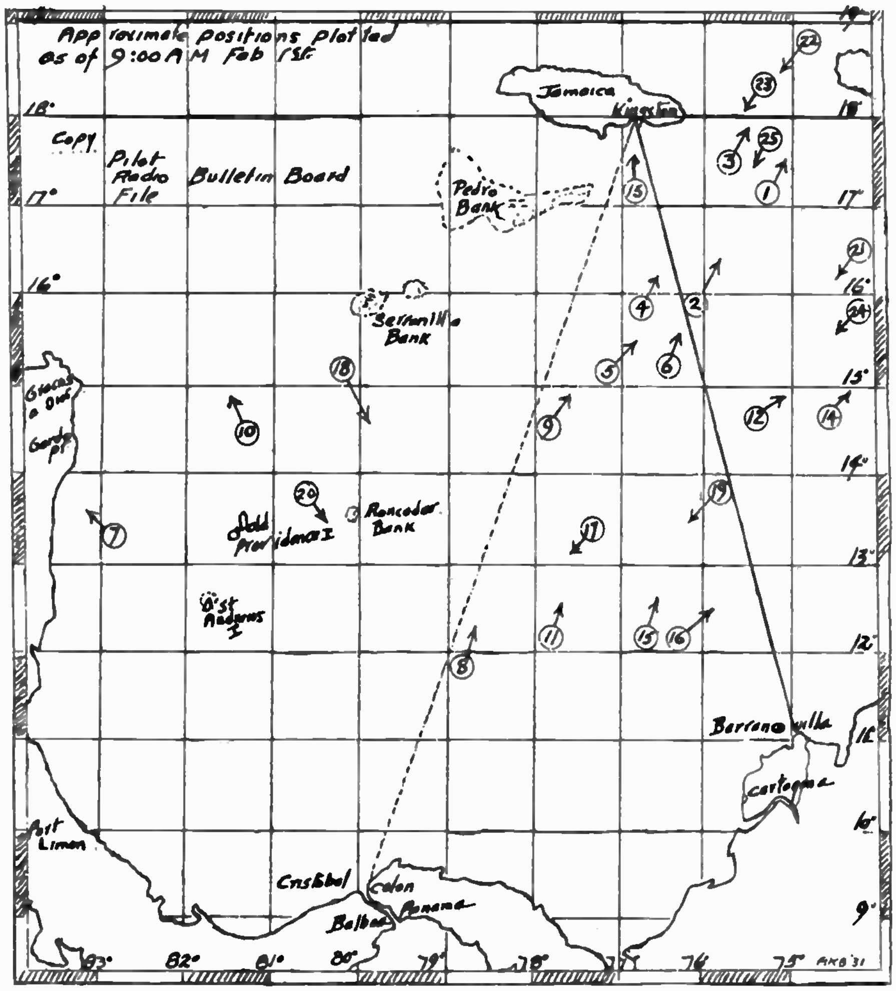


Fig. 1.



Chart, Fig. 2.

cabinet with a hinged front panel which tips outward disclosing in full view all of the component parts which are mounted either directly on the front panel or on a sub-panel. The front panel contains three meters; a plate current meter showing total plate current for both tubes, an r-f. ammeter for antenna current and a zero center ammeter showing the charge and discharge current in the main storage battery. The cabinet dimensions are: width 13 inches, height 9¼ inches, depth 8⅛ inches. A special break-in relay is also incorporated in the cabinet which permits faster communication between the plane and the airport stations. All resistors are of a moulded type and the entire transmitter assembly, including the cabinet, are especially treated with a coating impervious to heat and moisture. The set is also equipped with an antenna tuning arrangement consisting of a tapped inductance and a variable condenser in order to permit rapid tuning of the fixed antenna on amphibion and boat type aircraft. The radio transmitter complete with coils, vacuum tubes and cabinet weighs 12 pounds.

The filaments of the tubes are fed from a 12-volt aircraft storage battery while the plates are supplied from a small dynamotor rated at 400/12 volts, 70 MA/8-A. No filtering is required.

Aircraft Power Supply

It was at once realized that communication would be necessary in the event of forced landings. To accomplish this, the 12-volt, 65-amp. hour aircraft storage battery was standardized as the source of power instead of a wind-driven generator. With the 8 amp. input into the transmitter dynamotor and also feeding the filaments of the transmitting and receiving tubes, it is possible to maintain continuous communication for at least eight hours (and longer if used sparingly) without recharging the battery. On aircraft not equipped with engine driven charging generators, a wind driven generator rated at 6,500 r.p.m. 14 volts 5 amps. is used to continually charge the battery so that the source of power is kept up to full capacity at all times. The storage battery also supplies lights for the instrument board and cabin of the ship.

The dynamotor weighs 16 lbs.

The storage battery weighs 59 lbs. and the W/D charging generator 11 lbs.

Aircraft Receiver

The aircraft receiver is enclosed in an aluminum cabinet of the same construction and black crackle varnish finish as the transmitter. The exterior dimensions are: width 13 inches, height 9¼ inches, depth 6½ inches. The circuit consists of one screen-grid stage of radio-frequency amplification with tuned output only; a screen-grid detector; one space charge screen-grid audio tube and a low impedance output tube. All of the tubes are of the a-c. heater type and all of the filaments are in series. This receiver has a fairly high gain permitting the reception of weak signals over long distances. Ignition interference is not so bothersome as to preclude the reception of airport station signals over distances of four and five hundred miles even though shielded spark plugs are not employed.

The front panel of the receiver contains two dials, the right one for controlling oscillation and the left for tuning. The dials are indirectly lighted each with a small six-volt lamp. One inductance composes the tuning circuit. This inductance is of the plug-in type and each receiver is supplied with coils to cover the 32, 54, 97 and 600 meter wavebands.

The input to the receiver is controlled by means of a variable potentiometer and oscillation is controlled by a condenser. The plate voltages are supplied by a 135-volt aircraft "B" battery tapped at 67½; 22½; —4½volts. A six conductor cable supplies all the battery connections required.

In the audio-frequency circuits all the coupling resistors are of the moulded type and all grid resistors likewise. The entire assembly is coated to make it impervious to heat and moisture.

The receiver complete weighs 10½ lbs. and the plate battery 9½ lbs.

Antenna System

Due to international regulations and flights, the frequencies of 500 and 333 kc. must be available. Therefore both the transmitter and receiver are equipped with plug-in coils for operation on these frequencies. Each airplane therefore must necessarily be equipped with a trailing wire antenna of sufficient length which can be resonated to these frequencies.

The airplanes (Fokkers-Fords) are equipped with trailing antenna only and in case of forced landings on safe ground, communication can be maintained by unreeling the antenna to the correct resonance point and suspended a few feet above ground by anchoring it to a stick or tree. In cases of this kind, communication has been maintained with airport stations by using the frequency on which the last contact was made.

In the case of amphibions and boats, both a trailing wire and a fixed antenna were utilized. In most cases, the fixed antenna is suitable for all communication and also permits contact while on the surface of the water. As an illustration of the efficiency of this type of antenna, communication has been maintained between a boat on the ramp at the Naval Air station at Anacostia and the Miami station using 5680 kc.

Direction Finders

During the early period of tests on frequencies in the order of 2500 kc. an attempt was made to construct a conventional loop type direction finder together with suitable receiving equipment for taking bearings on aircraft in flight. While the results obtained were fair, it was necessary to split some twenty or thirty degrees to obtain an approximate bearing. The accuracy of the device was such as to prevent its adoption as standard equipment. This unit, however, was used for a period of some six months and the results were carefully analyzed.

It was found that during the period of December corresponding to the shortest daylight time, erratic and rapid shifting of minima were noted at sunrise and sunset. During certain periods of the day, depending on cloud formation and weather condition, minima were entirely lacking, or shifting very rapidly.

On the basis of this work, it was decided to conduct further tests on frequencies lower than 2500 kc. and not lower than 1500 kc. The results of these tests showed conclusively by using a frequency between 2000 kc. and 1500 kc. that accurate bearings could be obtained and the signal strength indicated the possibility of obtaining bearings on signals for distances up to 400 miles.

The first unit constructed was installed at Kingston, Jamaica, for the purpose of taking bearings on aircraft flying over the largest over-water route in the world. The distance between Kingston, Jamaica and Barranquilla, Colombia, is 540 miles. This location was selected for three reasons. First, for the necessity of navigational aid; second, over water transmission, and third, possibility of making observations on signal propagation over mountains.

The City of Kingston is located on a large sheltered bay and mountains towering 4000 feet encircle the town with the exception of the seaward side. Bearings have been taken on aircraft while they were flying between Kingston and Cienfuegos, Cuba, with the results that the mountains above mentioned were intervening. Observations disclosed that reflection by the mountains affects the aircraft bearings only while the plane is in close to the island of Kingston. On the over-water route, a slight shift in signal minimum is noticed only during sunrise and sunset periods. No extensive night observations have been made, although during the short periods of darkness when bearings were attempted, fairly good results were obtained.

Bearings are taken both while regular transmission is taking place and at other times when particularly requested by the pilot. Eventually this system of D. F. will be installed on board the aircraft, in which case the operator can take his own bearings and plot instantaneous positions. The unit has now reached the stage of development where the apparatus can be installed aboard the aircraft adding only 12 pounds additional weight for the loop and its tuning unit.

In addition to this means of navigation, I wish particularly to call attention to the chart, Fig. 2. This chart with its accompanying list shows the number of steamers in this area together with all pertinent data regarding call letters, frequency, where bound for, ship's name, and its approximate position on the day of the flight. These charts are compiled each morning and supplied to the radio operator whose responsibility it is to check these reports while en route. In this way, ships are contacted on 600 meters and weather reports obtained while en route in many cases 150 miles before the aircraft arrives at and actually sights the steamer.

It is by careful attention to such details that this route has been flown with the same regularity and safety as any domestic route. Not so long ago one of the aircraft on this route between Colon and Barranquilla sighted some wreckage and persons from the S. S. Baden Baden and prompt means of communication resulted in the rescue of the unfortunates.

LIST OF STEAMSHIPS ON CRISTOBAL-KINGSTON ROUTE

Date—January 31, 1931

Nr.	Steamship	Company	Knots	D.F.	Sails	Bound For	Radio Call Let.
			Out-Bound From Cristobal				
1	Point Breeze	At;-Refg.	12	Yes	3PM-30th	Philadelphia	KJEI
2	Henderson	U. S. S.	14	...	10PM-30th	H. Roads	NESD
3	Pear Branch	F. & W. Ritson	13	No	4PM-30th	S. Thomas	GDZJ
4	Arizonan	Williams	12	Yes	9PM-30th	New York	WACX
5	Hendon Hall	Inter-Frtg.	13	Yes	3PM-31st	Norfolk	GMZL
6	Albion Star	U. C. S. Ltd.	12	...	Mdt.-30th	Norfolk	GCBD
7	Amapala	S. F. & SS. Co.	14	...	2PM-31st	New Orleans	......
8	Baracoa	U. F. Co.	15	No	12M -31st	Kingston	KEDN
9	Volendam	Holl.-Amer.	16	Yes	3PM-31st	Kingston	PIHP
10	Tela	U. F. Co.	16	No	1PM-31st	Castilla	HRAM
11	Buchanness	W. R. Smith	12	No	7PM-30th	London	GKXY
12	Monique	Cie. Aux.	12	Yes	5PM-30th	Le Havre	FOEG
13	Barrwhin	C. Cront. Co.	13	Yes	6PM-30th	Jamaica	GDYK
14	Queen Maud	E. I. DuPont	12	No	5PM-31st	Baltimore	GKFR
15	Bolivier	Cie. Mar. B.	12	Yes	5PM-31st	S. Thomas	ORVA
16	Serantes	Cie. Nav. V.	12	No	5PM-31st	S. Thomas	EAKT
			In-Bound for Cristobal				
					Due*	From	
17	Trojan Star	Amer.-Hawa.	12	No	12M -2nd	Liverpool	GKMV
18	Caledonia	Cunard	16	Yes	9AM-2nd	W. Indies	GFJY
19	Canada	Johnson L.	15	No	7AM-2nd	Stockholm	SDQN
20	Heredia	U. F. Co.	15	Yes	7AM-2nd	New Orleans	KDAH
21	Parrakoola	Tr's.-Atl'c.	13	Yes	9AM-3rd	Europe	SMLA
22	Gisla	Can. Trans.	12	No	9AM-3rd	Philadelphia	LCLD
23	Hakushika Maru	N. Y. K.	13	No	7AM-3rd	New York	JBXD
24	Welsh City	W. R. Smith	13	No	9AM-3rd	U. K.	GKWD
25	Triton	W. W. Line	12	No	7AM-3rd	Baltimore	DDIT

*Approximate.

Conclusion

The application of radio to aircraft is of special nature and requires considerable thought and planning in order that a suitable network of stations can be erected to serve the particular demands. This must also be done as economically as possible.

It is the policy of the Pan-American Airways to maintain contact with all planes in the vicinity of any particular station at all times, plotting its course and advising the flight office of the location of any one plane on the various routes.

It is demanded that aircraft radio operation be made as reliable as engine operation and is only possible because of rigid inspection before and after each flight.

The system in use is the largest of its kind in the world and an endeavor is being made to make it the most efficient as well.

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Recent developments in radio-frequency control practice of precision frequency controls†

By D. E. REPLOGLE*

THE high quality of broadcasting, increasing the interest of the public has made the importance of satisfactory reception of radio broadcasts increase greatly month to month and year to year.

The work of the Federal Radio Commission has already resulted in clearing up much of the interference on adjacent radio channels and there is still much they are now working on. In order to clear up such interference and in order to put as many stations on the air as possible, there is urgent need for every existing station to operate accurately upon its assigned frequency with the least possible deviation. Any deviation will use space in the ether which is wanted and can be used advantageously by others.

Accurate frequency control is essential in many other fields beside that of broadcasting. The transmitters for service other than broadcasting have increased in number and in importance much faster than new channels have been opened for them. Aviation, fixed point to point telephone, moving vehicles, communication, press transmission, fixed point to point telegraph communication, and the growing need of large corporations with wide flung interests for inter-communication, educational broadcasting, governmental, marine and civil services, all have increasing need for more wavelengths and for great use of the ether.

The space each service requires in the air is determined by the audio frequency bands to be transmitted and the degree of selectivity that can be obtained in the reception of these wavelengths. The obvious means of inserting more stations in a given ether spectrum is to prevent the use of a wider area in that spectrum by a given transmitter than is necessary. This again calls for precision in the control of the carrier frequency.

Frequency Control Up to Manufacturer

With a given piece of equipment no station could, beyond a certain limit, do much to hold its frequency closer than the original design of the transmitter permitted. Hence, all Federal agencies connected with radio transmission have been following with mounting interest the development of frequency control units. In fact, it is understood that so desirous has the Radio Commission been for greater precision in carrier frequency control in the broadcasting field that as soon as an accurate frequency control at a reasonable cost could be assured, General Order No. 119 was put into effect. It is reasonable to expect that even better control units will be developed with stricter requirements. This is definitely up to the manufacturers of the transmitting equipment, with the problem of meeting the requirements of the art, in both original installations and also in installations now in operation.

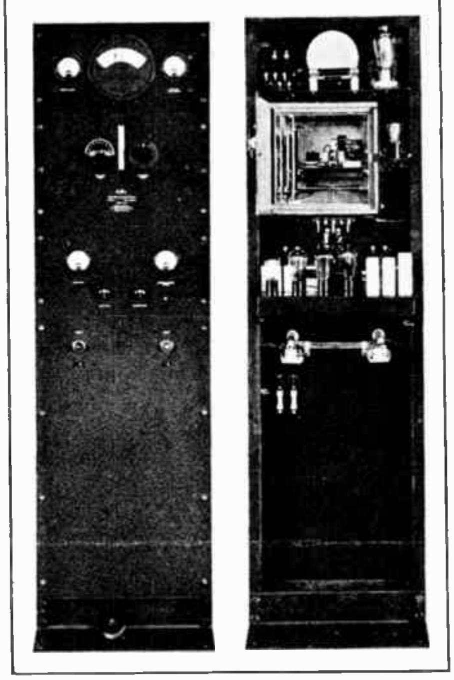


Fig. 1. Fig. 2.
Fig. 1. Front of DeForest frequency monitor Type A.
Fig. 2. Back view of DeForest frequency monitor Type A.

When the De Forest Company first started to build transmitters, we used a crystal control unit made by a well known manufacturer and which, from our experience, was the best obtainable. Trouble immediately developed with this unit so that the frequency control problem became the most difficult one in our design.

In sending transmitters to various parts of the United States, with different temperatures and different conditions of operations, we ran into an unusual amount of frequency control difficulty which proved very costly. We then decided to investigate the control field ourselves and with the aid of the Radio Research Laboratory in Washington, have developed what we believe to be one of the most reasonable and highly perfected control units yet

† Presented before the Club, February 10, 1932.
* Vice-President, in charge of engineering, De Forest Radio Co.

known commercially. This unit has already gone through some very exhaustive and conclusive tests which have been passed satisfactorily.

Monitors Desirable for Station Operation

The first step in attempting to obtain greater precision of frequency control is to set up and consistently operate a monitor which will as accurately as possible tell the deviation of the carrier frequency from the assigned value. There are a number of places in the United States where checks on frequency can be made. A call to a local United States radio supervisor will usually bring a frequency check on the carrier. A telegram to the Department of Commerce, central monitor station at Grand Island, Neb., will always bring a response on frequency precision, but it is highly desirable that a monitor be in continuous operation so that the operator can check from time to time on the frequency deviations. Hence, the requirement of the Federal Radio Commission that such a monitor be in operation in every broadcasting station. The most successful form of a monitor is the use of a local precision oscillator which beats against a carrier frequency, the beat note being indicated by some accurate method.

Monitor Requirements

The following characteristics should be met in such a monitor if the best practice is used:

1. The local oscillator should be of the highest precision, if possible to be maintained within 4 cycles.
2. It should have precision heat control.
3. It should have a continuous means of indicating the beat note.
4. It should be entirely independent of temperature variations.
5. It should be independent of supply voltage variations as far as possible.
6. All the meters or indicating devices employed should be corrected for temperature variations.
7. It should be capable of operating through wide extremes of temperature.
8. It should be capable of being set up in the station to be monitored without complicating adjustments.
9. The indicating means, if possible, should be continuously and easily visible through months of operation without attention and without adjustment.
10. It is undesirable that the precision and accuracy of the monitor be dependent upon adjustments which must be made by an operator from time to time.

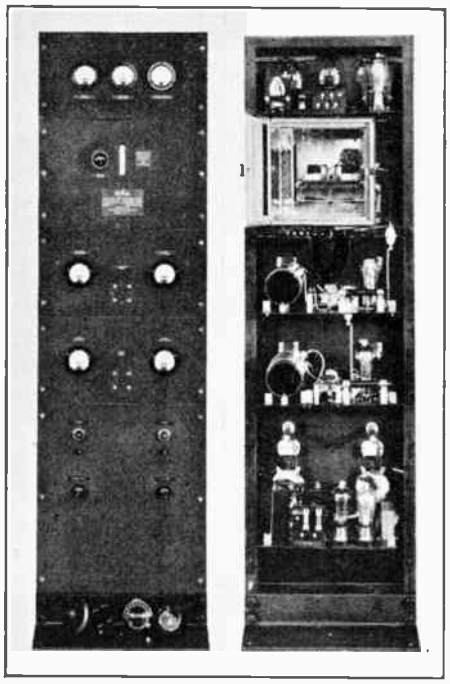


Fig. 3. Fig. 4.

Fig. 3. Front of DeForest Type B crystal control unit. Note removable adjustment dials.
Fig. 4. Back view of DeForest Type B crystal control unit.

In the De Forest monitor the precision frequency control is the first and outstanding development which merits attention.

Precision Frequency Control for Transmitters

The definition of "precision frequency control" has changed rapidly during the past few years. Not so long ago any vacuum tube oscillator was notable because of its excellent frequency stability. Later, a master oscillator circuit was regarded as the acme of perfection in frequency control, and even today any transmitter equipped for crystal control, whether or not the crystal is in actual command of the situation, is regarded with respect by a respectable percentage of the radio engineering talent.

The precision of any method of frequency control lies largely in the degree of engineering effort spent in the design of the circuits and in the care expended by the operating personnel in maintenance and supervision. It is a recognized fact that many self-oscillators are more stable in their frequency characteristics than some master oscillators, while a fair percentage of crystal controlled circuits are inferior to some well designed master oscillators.

While crystal control has in general led to better frequency stability with greater ease of operation there have been, and still are, many installations in which the frequency control is still poor and this despite the fact that the crystals are operated within cabinets supposedly maintained at a constant temperature. This paper deals with frequency control employing quartz crystals held at a constant temperature, as the frequency stabilizing means.

Crystal Cuts

There are two common cuts of quartz crystals known as the zero angle cut and the 30° cut. In the zero angle cut the crystal is manufactured from a quartz plate which has been cut through the plane, perpendicular to the X-axis of the natural quartz crystal. The 30° crystal is, as its name implies, made from a quartz plate cut from a natural crystal along a plane 30° from the X-axis.

Each cut has its advantages. The zero angle crystal is less likely to have spurious frequencies, while the 30° crystal is more active. From the manufacturing standpoint, the 30° crystal is the best product where immediate profit is concerned, since these crystals will generally oscillate readily and without a great deal of effort on the part of the grinder. These crystals, however, will frequently and without apparent reason shift their frequency of oscillation several kilocycles. This is particularly true if the load on the crystal changes or if the temperature of the crystal is subject to change.

Zero angle crystals are considerably more difficult to manufacture but when properly made will have little tendency to spurious frequencies and can be obtained with a guarantee that spurious frequencies will not show up during a 30 per cent. change in plate voltage, a 10 per cent. change in filament voltage or a 10° change in temperature. The specifications under which crystals are purchased should by all means include these items as a safeguard against crystals having "doubles."

The size of the crystal has some influence on its desirability and in general, for power purposes, the crystal should be substantially square and of not less than 1 inch in surface area.

It should be stated here that the matter of zero angle crystals and 30° crystals is one in which there is still controversy between many radio engineering organizations. While the proponents for 30° crystals admit that the possibility of spurious frequencies exists, they claim that the spurious frequencies can be removed by proper treatment. It is for the purchaser to decide whether he cares to risk a type of cut which is only slightly cheaper and may have spurious frequencies as against a cut which probably will not have spurious frequencies at only a slight increase in cost.

Causes of Frequency Drift in Crystal Controlled Oscillators

The change in temperature of the crystal is probably the best advertised of the several factors which lead to frequency drift in a crystal controlled oscillator. This change, due to temperature, is caused by the fact that as the crystal becomes warmer it expands and therefore its natural frequency of vibration is retarded and vice versa. This shift in frequency may be from ten to twenty-five parts in a million; that is, ten to twenty-five cycles at 1000 kcs. for each Centigrade degree change in crystal temperature. The entire change is, however, not due to the crystal expansion alone but also to the type of mounting and kind of cut of crystal. A second factor which may cause frequency drift is a change in capacity or inductance of the tuned circuit to which the crystal is connected. By adjusting the tuned circuit it is often possible to shift the frequency as much as 50 cycles and if the components of the tuned circuit are such as changing temperature, aging, etc. or undergoing a process of expansion or contraction, the frequency must inevitably shift. Other factors leading to frequency drift are changes in the loading on the crystal due to shifting plate or filament voltages, reactions from amplifier circuits, or other similar causes.

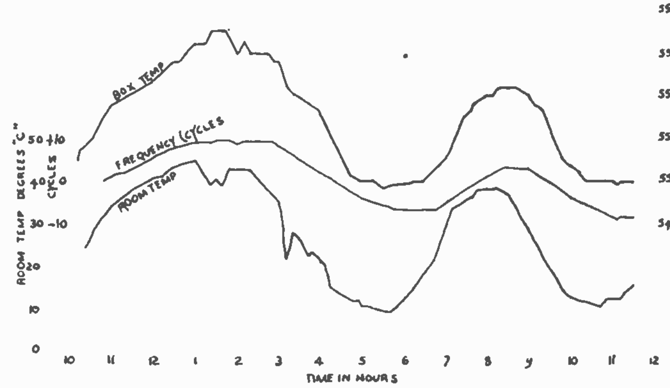
Most of the causes which underlie frequency drift in oscillating crystal circuits have been known for some time but the means by which they may be eliminated have either been neglected ot not sufficiently worked out to be incorporated in commercial designs.

Crystal Temperature

The temperature of an oscillating quartz crystal is dependent on two things: first the ambient temperature of the atmosphere immediately surrounding the crystal, and, secondly, upon the heat generated by the crystal itself.

The common way of maintaining the ambient temperature at a fixed value is to mount the crystal within a constant temperature cabinet. There are many types of constant temperature cabinets employed for maintaining constant crystal temperatures. Unfortunately, however, most of the cabinets have certain defects in design which make them of little or no value from the standpoint of crystal temperature regulation. The heart of a constant temperature cabinet is the thermostat by which the temperature is regulated. In the usual design of cabinet the thermostat is located at a point relatively remote from the crystal. The temperature at the thermostat may be constant but the temperature even an inch away from the thermostat may vary within considerable limits, as much as several degrees. Where a high capacity heater is employed together with insufficient insulation and where the room temperature of various points within a "constant temperature cabinet" will jump up and down a surprisingly large amount. This variation is noticeable when the thermometer is mounted with its bulb close to the crystal or where the bulb is in some part of the cabinet other than close to the thermostat, but such variations in indicated temperature do not improve sales so the practice has been to mount the thermometer close to the thermostat but to let the crystals remain at some point several inches away from the thermostat. With one exception the correct design of a constant temperature cabinet requires that the crystal, the thermometer and the thermostat be jammed as close together as is mechanically possible in order that the point of regulation shall be at the crystal and not at some point removed therefrom.

Fig. 5. Variations of frequency in oscillation with room temperature and with box temperature.



The exception referred to is where the crystal is mounted in an inside box having several attenuating layers between the crystal and the thermostat and between the thermostat and the heaters. This scheme will give extremely even temperature control, especially if two heaters and two thermostats are used in a series arrangement whereby the wide changes of room temperature are largely taken care of by the outside heater-thermostat-attenuating layer, while the finer temperature control is exercised by the inside heater-thermostat-attenuating layer. We have then two methods for obtaining the desired constant temperature; first, to confine the thermostat and crystal within a small area in a well insulated box and, second, to have the crystal mounted within a series of attenuating layers in a box whose temperature is regulated by a thermostat in one of the outer layers.

The second arrangement, while ideal from the standpoint of maintaining constant the temperature of a non-oscillating or very weakly oscillating crystal, does not satisfy the requirements where the crystal is being operated under considerable load. During the development of constant frequency apparatus it was noticed that despite the most careful regulation of temperature with the crystal non-oscillating a rise of several degrees in crystal temperature as evidenced by frequency drift would take place during the first hour the crystal was in operation. By substituting a resistance element of small size in place of the crystal it was ascertained that the particular crystal involved would rise 3° in temperature when operated under a comparatively light load. The task of eliminating this rise in temperature due to molecular friction within the vibrating crystal proved to be rather difficult. It is obvious that the second type of cabinet mentioned (attenuating layers) would not be suitable since the transfer of heat from the crystal to the thermostat would take several hours and the entire system would not be stabilized unless the constant temperature cabinet were kept operating and the crystal oscillating continuously. Such an arrangement is neither satisfactory nor economical. By employing rapid circulation, properly designed crystal holders and mounting plates, and correct thermostat location, the temperature of the crystal may be held constant within a very small fraction of a degree whether oscillating or non-oscillating, and a state of equilibrium can be established from the cold, non-operative position to the 50° oscillating frequency within a few minutes.

With this description of the local oscillator, the next point of interest in the De Forest monitor is the method used to indicate the beat note. An amplifier is used to amplify the beat frequency, and this is fed directly into a temperature compensator, a highly accurate Weston frequency meter which has a large scale which can be seen for some distance. It will be noted that this meter is driven by frequency only, and if ample safety factor on output voltage is provided the indication meter will be independent of the strength of the beat signal. Hence, changes in voltage in the amplifier will relatively be unimportant with little or no effect on the indicating device. Thus, a visual indicator at all times is accurately available to the operator without a single adjustment.

We find that in these frequency control units the oscillator tube must be thoroughly seasoned in order to obtain a high degree of precision.

The frequency control units herein described are run for a week's period or until such time as there is no further deviation in the frequency due to possible changes in tube characteristics.

Chances for error in the frequency change of the local oscillator may be due to the following:

Temperature shift of 35° Centigrade may cause a maximum change in the oscillator of 12 parts in a million.

Change in oscillator tubes may cause a change of 4 parts in a million.

Ten per cent. plus or minus in the supply voltages will affect the local oscillator frequency less than 1 cycle.

Change due to heavy pounding or vibration will affect the frequency less than 2 parts in a million.

A change of ambient temperature 1° Centigrade in the outside of the heater box will cause 100° change in the temperature inside of the heater box, which is roughly one-half cycle change for each degree centigrade in the ambient temperature.

Hence, for temperature changes a calibration chart is furnished which will give an absolute frequency value with the local oscillator in any degree of ambient temperature. The normal operating temperature in a heater is 55° Centigrade.

Crystal Control Units for Transmitters

The same type of crystal control units manufactured by the De Forest Radio Company in their transmitters are for use separately for other transmitters. This control is capable of precision up to one part in a million. It is possible to use these crystal controls for synchronization of broadcast stations. A very successful experiment is now in progress between stations WATC, Rochester; WAK, Albany; WHP, Harrisburg; WCAH, Columbia, Ohio, all operating sychronously on 1430 kc. These stations have been checked within two cycles for a period of a month, and for several months no station has been away ten cycles from the others. It might be of interest to note that the precision obtained here is even greater than at times obtained with wire synchronization from master frequency. One of the leading stations has recently been measured more than ten cycles off from its fellow synchronizing station.

In connection with the degree of precision which has just been mentioned it may be interesting to note that the best of astronomical clocks is built with no better precision than one part in 10,000. Average observed accuracy shown on this crystal controlled unit of one part in a million can be regularly expected. The units as built, even with rough treatment, can be expected to hold within three parts in a million.

Every unit is made with a thermometer so that the oven temperature is observable at all times, and if desired, a meter can be put in that will indicate any change in over temperature by audible means. At present we use a fusable link in the heater box to protect the heater from over-heating in case of thermostat failure.

In the crystal controls a ceramic holder is used with a very low temperature coefficient. The holder of the crystal itself is uniquely done, which facilitates slight changes of frequency, but maintains a given setting indefinitely. In the frequency control units ample power is allowed so that we tune considerably away from resonance for greater stability. Crystals are guaranteed to arrive very near their absolute frequency. A selective service with proper control units allows measurements of all important circuits. Monitors and frequency controls are checked a long period of time before shipment. There are no buttons to push, no incorrect effects from temperature, nor voltage variations in any of the units.

Conclusion

Precision frequency controls of this type are making much easier the development of satisfactory transmitters for operation on the ultra high frequencies. Particularly is this desirable in the wide acceptance of the super-services for television where doubling and tripling is desirable and frequency errors are multiplied accordingly. Even aviation demands a crystal control unit with the result that greater accuracy in crystal units must be developed.

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SUGGESTIONS TO CONTRIBUTORS

CONTRIBUTORS to the Proceedings, by bearing in mind the points below, will avoid delay and needless expense to the Club.

1. Manuscripts should be submitted typewritten, double-spaced, to the Chairman of the Papers Committee.* In case of acceptance, the final draft of the article should be in the hands of the Chairman on or before the date of delivery of the paper before the Club.

2. Illustrations should invariably be in black ink on white paper or tracing cloth. Blueprints are inacceptable.

3. Corrected galley proofs should be returned within 12 hours to the office of publication. Additions or major corrections cannot be made in an article at this time.

4. A brief summary of the paper, embodying the major conclusions, is desirable.

5. The Club reserves the right of decision on the publication of any paper which may be read before the Club.

* For 1932 the Chairman of the Papers Committee is Mr. F. X. Rettenmeyer, 463 West Street, New York City.

Book Review

"AIRCRAFT RADIO," by Myron F. Eddy, published by the Ronald Press Co., New York City, 1931. *Price,* $4.50. (284 *P. P.* 68 *figures. Cloth.*)

Have you ever stopped to think of the great importance that radio plays in the aeronautical field? Most of us who are not directly concerned with this branch of radio do not realize the extent that radio communication has been applied to this growing form of transportation. Until the recent appearance of *"Aircraft Radio"* there was no suitable manual containing complete information about this application of wireless.

"Aircraft Radio" is written by a former naval instructor in aircraft radio and is in the form of an elementary-semi-technical book prepared for the average student desirous of further investigating this particular field of radio. The work considers all methods of communication based on the applications of radio principles to aircraft. It is assumed that the reader of this book has had previous knowledge of the elementary principles of electricity as taught in public schools. For this reason the introductory chapters contain a brief review of the history of radio in aircraft and a discussion of elementary electricity as applied to radio practice. Although this introduction is somewhat superficial, its inclusion proves of value and serves as a suitable preparation for the more complete study included in the following chapters that directly concern radio equipment of more complex construction.

Following an explanation of the operation of the thermionic valve and its various applications in radio circuits, the reader is next introduced to radio telegraph and broadcast communicating equipment and a discussion of radio aids to aerial navigation. Here we learn more about the radio compass systems as applied to aeronavigation, rotating, radio range, and marker beacon systems: considering both the aural and visual forms, and the deviometer which is described and explained for the benefit of the interested reader. The text further explains how to solve problems regarding the installation of radio equipment in an airplane and contains an instructive discussion of bonding and shielding together with information on the installation of antennae. Sources of power supply for the operation of aircraft radio apparatus are likewise considered.

In addition there is included in the latter portion of the book the regulations of the U. S. Federal Radio Commission pertaining to aircraft operation and also a glossary of radio nomenclature together with a list of standard circuit symbols for the drawings relating to radio schematics as discussed in the foregoing chapters.

In general this work is more descriptive than theoretical and it appears that the text could have been more thoroughly illustrated to further enhance its value to the reader. Nevertheless, *"Aircraft Radio"* proves to be very instructive and is a timely work that should be included as a part of the radio library.

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"FOUNDATIONS OF RADIO." *By Rudolph L. Duncan. Published by John Wiley & Sons, Inc., New York City.* 1931. *Price* $2.50. (246 *pp. Illustrated-Cloth*).

Here is a timely work of recent publication written by one of our fraternal members who is an acknowledged authority on the subject. Students, and instructors as well, have long voiced their desires for a complete and easily comprehendable treatment of the elements underlying radio principles for use in mastering the radio science. The majority of popular radio books now in use are generally devoid of a complete treatment of elementary electricity such as forms the foundations of radio. For this reason there are numerous persons who learned radio through the self-study method and who are now engaged in various fields of the industry in practical work that have only a superficial knowledge of these basic facts. Such persons consequently have a vague conception of what actually occurs in various electrical circuits comprising radio apparatus. Mr. Duncan's new work now fills a gap in radio literature that will be appreciated by beginners and the like.

Nine chapters compose *Foundations of Radio* each of which is written in the author's well known style giving in plain language an understandable consideration of the principles involved. This treatment throughout the book is simplified by the use of suitable analogies and other pictorial diagrams to assist the reader in his study of electrical laws and theories that may otherwise leave the students somewhat clouded by technical explanations as commonly employed in such work. The use of intricate mathematical formulae has been entirely eliminated and only simple arithmetical calculations are employed in examples necessary to give the reader a working knowledge of the subject under discussion. The last chapter is devoted to preparatory mathematics wherein a review of elementary arithmetics and square root is included to familiarize the reader with problems involving such treatment and which are commonly employed in actual radio practice.

Foundations of Radio is an excellent "first book" for radio instruction prepared particularly for the student to whom it will prove most valuable.——*Review by Louis F. B. Carini.*

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The application of permeability tuning to broadcast receivers †

By R. H. Langley*

THE chief difficulty with condenser tuning is that it is inherently incapable of producing uniform performance. By the use of compound couplings it is possible to secure reasonably uniform gain, but no arrangement so far proposed will give uniform selectivity and fidelity except at the expense of a large decrease in the efficiency of each circuit. It was realized as early as 1922 that inductance tuning offered decided advantages in the solution of this problem.

Inductance tuning is a general term for any method in which the total effective inductance in the circuit is varied. The variometer, which enjoyed a considerable vogue in 1922-1924, was a device for securing this variation. The reason it did not succeed was because its resistance varied with frequency in exactly the same way as the resistance of the fixed inductance of the condenser tuned systems, and it was therefore equally incapable of producing uniform performance.

There have been other suggestions for varying the inductance. One proposed to decrease the inductance by introducing a copper shield. The eddy currents in this shield effectively decreased the inductance, but they simultaneously increased the losses and, therefore, the effective resistance, at a rate even greater than in the variometer. Here again there was no possibility of securing uniform performance over the range.

The problem, however, is not to produce a variation of inductance, but to produce a simultaneous and proportional variation of inductance and resistance. The recognition of this fact has come only recently. This is the result secured in the new tuning method which we are examining tonight. It is called "permeability tuning" first to distinguish it from other methods of inductance variation, and second, because this term is adequately descriptive of its mechanism.

With permeability tuning, it is not only possible to secure uniform performance over the broadcast range, or any other range, on all three counts, with a degree of mechanical and electrical simplicity quite beyond anything so far suggested, but other new and valuable results can be secured.

It now becomes necessary to direct attention to a fact which has been too much neglected in the study of the problem of selectivity. The channels on which broadcasting, as well as all other radio services are carried out are equally spaced in frequency. The published mathematical investigations deal exclusively with per cent frequency difference, which has no practical interpretation in terms of actual receiver performance. Even the current statement of selectivity in terms of bandwidth has no physical meaning as an indication of the signals that will be successfully rejected. What we desire to know is not the width of an inverted resonance curve, but just what signal strength, for signals on the channels immediately above and below resonance, can be tolerated without producing audible interference.

The situation with respect to selectivity can be summarized in a diagram, as is shown in Fig. 1.

This diagram represents the performance of five different types of receivers. The horizontal scale in all four graphs is frequency, and the divisions are the actual channels of broadcasting. Graph A is for a tuned radio-frequency receiver in which straight-line capacity condensers are used. The spacing of the channels on the dial of such a receiver will be as shown, that is, very

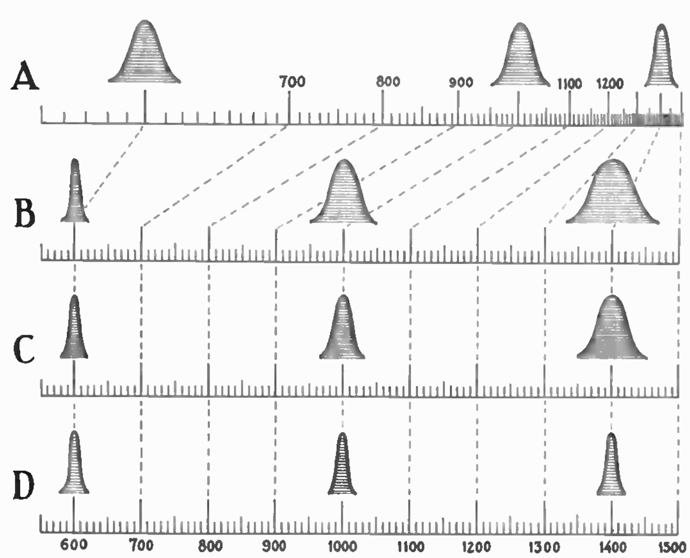


Fig. 1. Selectivity of five types of radio receivers.

*Consulting Engineer.
†Presented before the Club, March 9, 1932.

$$\frac{E_r}{E} = \sqrt{K^2 + Q^2(K^2-1)^2} \qquad K = \frac{\omega}{\omega_r} \qquad Q = \frac{\omega_r L}{R} \tag{1}$$

$$k^2 + q^2(k^2-1)^2 = K^2 + Q^2(K^2-1)^2 \tag{2}$$

$$q = \sqrt{aQ^2+b} \qquad a = \frac{(K^2-1)^2}{(k^2-1)^2} \qquad b = \frac{K^2-k^2}{(k^2-1)^2} \tag{3}$$

$$\frac{Q}{q} = \frac{\Omega L r}{\omega l R} \qquad \frac{Q}{q} = 2.73 \qquad \frac{\Omega L}{R} = 2.73\frac{\omega l}{r} \tag{4}$$

$$\frac{L}{R} = \frac{l}{r} \qquad \frac{l}{L} = 7.43 \qquad \frac{r}{R} = 7.43 \tag{5}$$

Fig. 2. Selectivity equations.

badly crowded toward the high frequency end. The black curves on this graph represent the apparent width, on the dial, of three signals of equal strength at three different frequencies. Note that, although the actual selectivity of the receiver is much worse at the high frequency end, the *apparent* selectivity is much better at the high frequency end. It shows how completely one fault masked another. It makes clear the fact that the straight line capacity condenser, because it crowded the high frequency channels, completely covered up the glaring fault of the system in which it was used.

Let us now put straight-line-frequency condensers into this receiver. The channels will now be equally spaced on the dial, as in graph B, but the broad tuning at the high frequency end will be strikingly obvious, as indicated by the width of the band covered by the high frequency signal. Such a receiver would meet definite sales resistance because of the lack of apparent selectivity, although the actual selectivity would be the same as in type A, thousands of which were successfully sold. Thus we see the reason the straight-line frequency condenser, otherwise an entirely logical and desirable improvement, was so slow to find its way into broadcast receivers.

If, by some method not yet suggested, we could arrange so that the actual per cent selectivity, the selectivity of the mathematical treatments, were constant over the frequency range, we should have the situation shown in graph C. Still the apparent selectivity would be noticeably worse at the high frequency end, and so would be the actual selectivity, so far as ability to reject undesired signals is concerned.

Graph D may be taken as representing a superheterodyne receiver, or a properly designed receiver of the permeability-tuned type. In either case the actual channel selectivity is constant over the range. In the superheterodyne, there would be some slight deviation, depending upon the amount of condenser-tuned-radio-frequency amplification employed. In the permeability-tuned receiver there would be substantially no deviation, and, incidentally, it would not be necessary to employ special mechanical arrangements to secure the equal spacing of the channels on the dial. There can, of course, be no question that the performance of graph D is superior to A, B or C, and that it is the ideal result.

To understand why permeability tuning can accomplish this result, with less tubes and fewer tuned circuits than a superheterodyne, it is necessary to examine the mathematics of the situation.

The usual expression for selectivity is given in equation (1), Fig. 2. This states the ratio of the voltages developed across the tuned circuit by a resonant signal and a non-resonant signal, in terms of K which is the ratio of the two frequencies, and Q which is the ratio of the inductive reactance at resonance to the resistance. Q has been called the figure of merit of the circuit. Note that both K and Q vary with frequency.

In order to determine the conditions for constant selectivity, we use small letters to represent quantities at the low frequency end of the range, and large letters for the high frequency end, and we write equation (2) directly from equation (1). Upon simplification this yields equation (3) which gives, implicitly, the ratio which the values of Q, one at the low frequency end, and one at the high frequency end, must have for constant selectivity.

Numerical substitution in equation (3) for the broadcast case, and for the actual 10 kc. separation for the broadcast signals, justifies the writing of equation (4) with the assurance that it is correct, at least to a very close order of approximation. Equation (4) gives the important conclusion that for constant selectivity the ratio of inductance to resistance must remain constant.

In normal condenser tuned circuits, and in inductance tuned circuits of the variometer types, the resistance increases approximately as the square of the frequency. Thus Q (equals omega L over R) decreases as the frequency is increased. If R could be made directly proportional to frequency, then Q would be constant, but even then the selectivity would not be constant, because K, the ratio of the frequencies, is also changing. Selectivity, in terms of actual ability to reject signals on undesired channels, can only be constant over the range when the ratio of inductance to resistance does not change.

In condenser tuned circuits, the inductance is held constant and the resistance increases as the square of the frequency. Such a circuit, therefore, cannot have constant selectivity, except by the expedient of artificially increasing the resistance at the low frequency end. A good tuned circuit has a resistance of about 4 ohms at 550 kc. and 30 ohms at 1,500 kc. If we can contrive to keep the resistance up to 30 ohms throughout the range, then we can have constant selectivity over the range, and it will be just as broad as 550 kc. as it now is at 1,500.

In inductance tuning, the inductance must change inversely as the square of the frequency. For constant selectivity, the resistance must also change inversely as the square of the frequency. This is expressed in equation (5) which states that the resistance and the inductance are to be approximately eight times as large at the low frequency end of the range as they are at the high frequency end.

How can we design a variometer, for use in an inductance tuned circuit, such that the inductance and the resistance will increase together, and their ratio remain constant? By a very simple expedient. We will design our circuit at the high frequency end, at 1,500 kc., to have whatever properties we desire to get, high gain and a high order of selectivity. We will use a relatively small inductance and a relatively large fixed condenser. Naturally both of these will have to be designed so as to have low losses.

Variable Inductance

We will then tune this combination down to 550 kc. by gradually inserting an iron core into the inductance. This will increase both its inductance and its resistance, and we may expect that they will increase together, since both depend upon the amount of iron which is actually inserted in the magnetic field. It will, of course, take a very special form of iron. No form that we have known in the past can be brought anywhere near a tuned radio-frequency circuit without increasing its apparent resistance out of all proportion to the gain in inductance.

Before we examine the material and the core, let us see what some of the other consequences of this method of tuning are going to be. We are not increasing the inductance of the coil itself. What we are doing is to increase the permeability of the surrounding medium. We are actually inserting a new factor in the equation for the frequency of the system. This factor is the effective permeability of the space around

Porcelain	2150×10^{12}
Glass	990×10^{12}
Bakelite	36×10^{12}
Polydoroff iron	50
Carbon (filament)	.004
Nichrome	.000 109
Steel	.000 045 6
Iron (pure)	.000 008 85
Copper	.000 001 589

Fig. 3. Comparative resistivity in ohms per centimenter cube.

the coil. This is the reason for calling the system permeability tuning.

We should assume, from the nature of the method, that if we have two coils of different inductances, but of the same physical dimensions, and if we insert two identical cores into them, the percentage change in inductance would be the same. If we tune these two coils, with different fixed condensers to the same frequency, then as the cores are inserted they should remain in step with each other.

This result can easily be secured, and it has tremendous consequences. It means that for the first time we have a method of tuning the antenna circuit of a broadcast receiver, and keeping it exactly aligned with the other tuned circuits. It means that we can thus secure a gain ahead of the first grid, due to resonance in the antenna circuit, which gives a very noticeable and valuable decrease in the amount of subsequent amplification necessary. But the most important result, so far as the user is concerned, is the marked improvement in the signal-to-noise ratio. This, more than any other feature of the performance of a permeability-tuned receiver, is its outstanding advantage over other present types.

Another result, not quite so obvious, perhaps, is that the frequency to which the system is tuned at any time is almost exactly proportional to the distance to which the core has been removed from the coil. By a slight correction in the shape of the core the relation may be made exact, and this gives, without additional mechanical gear, a uniform or "straight-line-frequency" distribution of the channels on the indicator. Thus the result so difficult to secure with condenser tuning is easily and naturally accomplished in the permeability method.

Since the resistance and the inductance increase at the same rate, an oscillator can be built in which the output is very nearly constant. And, by the use of a series inductance, not affected by the core, such an oscillator can be kept at any desired absolute frequency difference from other tuned circuits on the same uni-control system. Such an oscillator would have wide usefulness in superheterodyne receivers.

If it is desired to build a receiver having two or three ranges, each as wide as the present broadcast range, this can be accomplished by using as many taps on the fixed condensers in each tuned circuit. These taps can be selected by a gang switch without appreciable increase in losses, and the arrangement is mechanically convenient and simple. The ranges in such a receiver will not have quite the same performance, but the difference can be minimized by proper choice of the inductance and the capacity steps. Here, therefore, is a new and simple answer to the problem of an "all-wave" receiver for European service, or for any other service requiring an extremely wide range.

In a condenser tuned system there is a certain minimum capacity, represented by the maximum spacing obtainable between the rotor and the stator, and by the various capacities which exist in the circuits. This minimum capacity determines the value of inductance to be used, since the two together must produce resonance at 1,500 kc. The maximum value of the condenser is thus also determined, since this value taken with the same value of inductance must tune to 550 kc.

With permeability tuning, there is no such limitation. The inductance may have any value desirable to produce the required performance. Whatever the value of the inductance may be, it will be increased approximately eight times by the insertion of the core. Whatever the resonant frequency of coil and condenser may be, it will be decreased to approximately one-third this value, when the core goes into the coil. Thus we really have a new, an independent variable. It is not the inductance of the coil itself that we are varying: it is the effective permeability of the medium surrounding the coil.

When the research to find a form of iron that could be successfully used at radio frequencies was first undertaken, it was appreciated that the task was no small one. In fact, quite a group of scientists had said that it could not be done, and this same statement was repeated after the work was well under way. The core material that we have today is no chance discovery. It is the result of a carefully planned and adequately financed research.

Core Material

Iron sulphate is reduced by hydrogen to a metallic powder. The sulphate is rhombic in crystalline form, the iron cubic. In passing from rhombic to cubic the material must go through atomic or at least molecular dimensions. By proper control of the process it is pos-

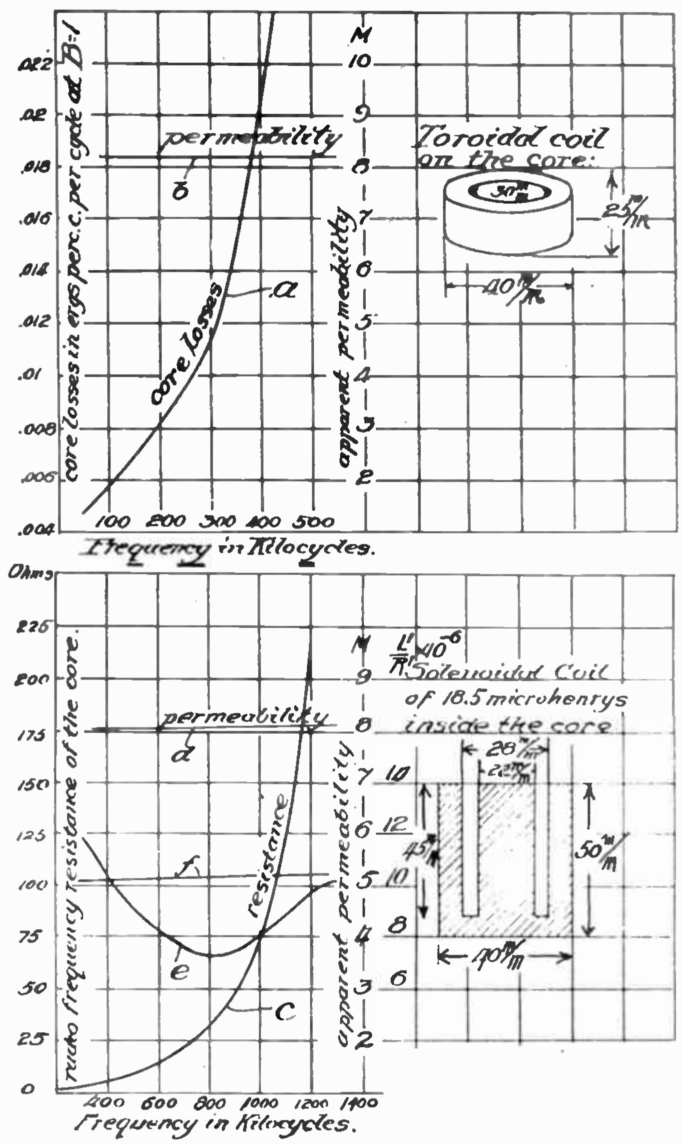


Fig. 4
Characteristics curves.

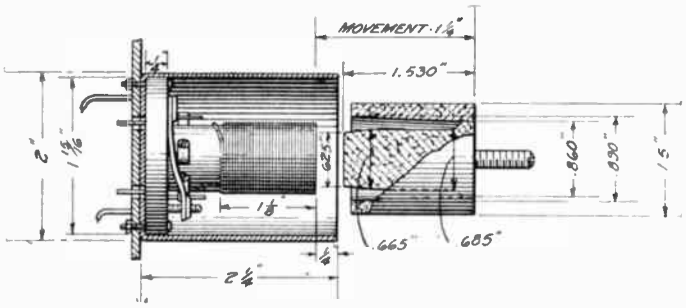


Fig. 5. Overall dimensions of tuning unit.

sible to obtain the powdered iron in any desired degree of fineness. Iron dust so fine that it will float in the air can be produced. The particle size which has been chosen for this use is 10 microns, approximately 0.00039 inch. The powder is, of course, of very high purity.

Before this powder is allowed to come into contact with air, the individual particles are insulated. This requires an entirely new insulator, especially developed for the purpose. None of the existing insulating materials was suited to the work. The film surrounding each particle is approximately one micron thick. This amount of insulation is adequate for the minute voltages generated in the particles by the magnetic field. Current is therefore effectively prevented from flowing between particles. The eddy current loss is therefore limited to the energy that can be dissipated within the particles, and this loss, in particles of the size mentioned, is low enough to permit successful use at the frequencies used in broadcasting.

This insulated iron powder is now molded with bakelite in much the same way that any other dry powdered filler, such as wood flour, would be molded. The molds are made of steel, as usual. Any desired form that is capable of molding in any material can be molded in this new iron, but the usual forms are circular in section, and the molds are therefore simple and inexpensive.

This new molded magnetic material is 92% iron by weight. But the remaining 8%, which is insulating material, so completely changes the electrical and magnetic behavior that it is really incorrect to still call it iron. At present we are referring to it as "Polydoroff iron" or as "Polyiron" which has the advantage of suggesting the minute subdivision of the iron. Eventually we shall have to have an entirely new name.

Permeability, in general, is the ratio between a magnetizing force and the flux which it produces in the material under consideration. But when alternating currents are involved, even at commercial frequencies, a more precise and complicated definition must be used. The presence of direct as well as alternating current still further complicates the matter. There is an extensive literature on this subject alone. As we approach the frequencies used in radio, all the usual definitions and methods of measurement cease to have any rational meaning. We are left, therefore, with no alternative except to state the permeability of the new material in terms of its effect upon the inductance of an air-core radio frequency coil into which it is inserted. On this basis, the permeability of Polyiron is about 8, which is adequate for the use we are describing, but I must caution that this figure is not to be compared with the direct current permeability of commercial sheet steels.

Hysteresis loss in magnetic materials at commercial frequencies, is proportional to the area of the hysteresis loop, and increases with frequency. But as we approach the frequencies used in radio, the area of the loop becomes disappearingly small, and the loss from this cause becomes negligible. Whatever effect the introduction of an iron core in a radio-frequency coil may have upon its effective resistance, is due, therefore, to the eddy-current loss. This loss may be reduced by shortening the paths which the induced currents can take, and by decreasing the resistance of these paths. This result is secured by lamination, which was carried to its practical limit in the one mil steel of the Alexanderson high frequency alternator. Beyond this, we may resort to powdered material, with the particles insulated, and this has been carried to the limit in Polyiron.

The extent to which the attempt to insulate the particles has been successful is indicated by the measured resistivity of the material. Here is perhaps the most unique property of Polyiron. It measures 50 ohms per centimeter cube, and, as you will see from the tabulation in Fig. 3, lies intermediate between insulators and conductors. No known material, whether ferric or not, lies within several orders of magnitude of this value. Polyiron has over five million times the resistivity of ordinary pure iron.

The losses in this new material are extremely low, but they increase with frequency. The core loss, in ergs per cycle, increases at a rate somewhat below the second power of the frequency, as shown in the upper curve of Fig. 4. The effective radio-frequency resistance of the core, however, increases almost as the fourth power of the frequency. How, then, can we make the high frequency resistance of the complete tuned circuit *decrease* with frequency, as it must if the performance is to remain constant? To answer this, I have only to remind you that the core is *withdrawn* to increase the frequency, so that as the frequency is increased, there is less and less of the iron present in the field.

The tuned circuit consists of a coil, wound on the usual bakelite form, a Polyiron core arranged so that it can slide into the coil, and a fixed condenser, usually of mica, with an adjustable blade, to secure initial resonance, with the core all the way out, at 1,500 kc. The condenser is mounted on a suitable ceramic base, and the coil and condenser on its base are mounted inside a cylindrical shield of aluminum or copper. The condenser is connected across the coil. There is no electrical connection to the core, but it is usually insulated from the grounded frame of the net, to prevent capacity effects. As shown in Fig. 5, the overall dimensions of the complete tuned circuit, with the core all the way out, are only *2* inches diameter by 3¾ inches long, a total volume of less than 12 cubic inches.

Note that there will be no leads to variable condensers at some distance. Also note that there is no primary on this coil, that it is not a transformer. There are only three leads from such a tuned circuit, one to a grid or plate, one to a B or C voltage supply, and one ground or to a coupling condenser. The circuit is therefore simple, and the shielding simple and inexpensive. The circuits may be placed as close together as desired, so long as the cans do not touch.

The internal member of the core is an easy fit inside the coil form. The inside diameter of the outside member of the core is made sufficiently large so that there is no possibility of its touching the winding. The total movement of the core is 1¼ inches. The winding is preferably of Litzendraht. In the usual condenser-tuned circuit this wire

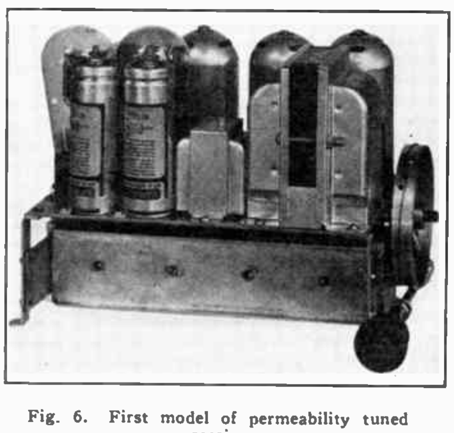


Fig. 6. First model of permeability tuned receiver.

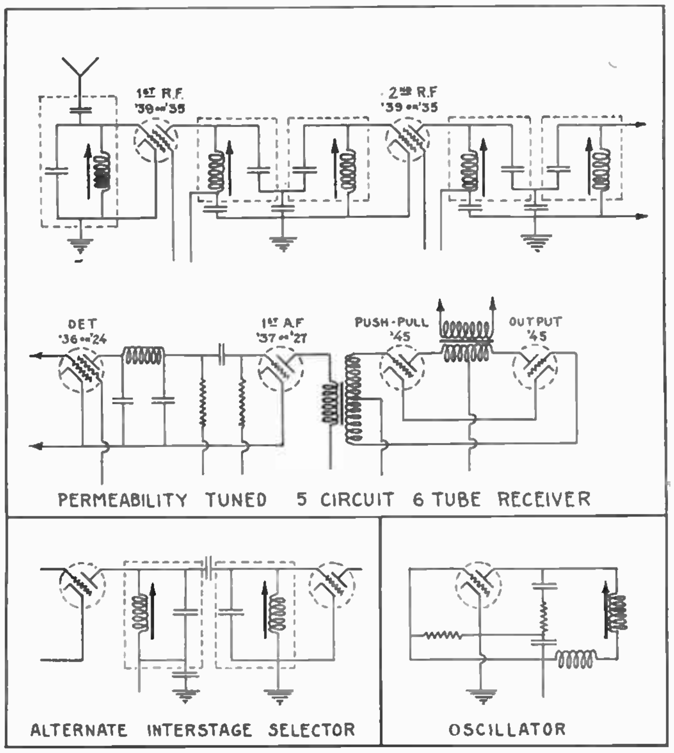


Fig. 7. Condenser coupling of plate and grid circuits.

does not have sufficient advantage to justify its use, but in the very much smaller inductances used in the permeability-tuned system, the stranded conductor gives a worthwhile decrease in the resistance at 1,500 kc., the frequency for which the coil is designed. The preferred wire has 10 strands of No. 41, which is a size standard with the wire manufacturers.

In Fig. 6 is shown the first permeability-tuned receiver employing the new core material. It had three radio stages, and four tuned circuits, with detector, output tube and rectifier, six tubes in all. The tuned circuits were assembled as a unit, and mounted under the chassis pan in such a way that the coil terminals came directly under the socket terminals making the leads extremely short. You will notice, at the bottom, the bridle which carries the four cores and the screws by which the positions of the cores were adjusted. This bridle slid back and forth on guide plates, one at either side, and was driven by a linkage at each end of a shaft running across the back of the unit. The sensitivity of this receiver was better than 1 microvolt, and it would successfully reject a signal 10 times as strong as the desired signal on the adjacent channels.

Practical Application

The development since this first receiver was produced has been chiefly in two directions: first, to produce a more effective and less expensive mechanism and, second, to determine the form of circuit best adapted to take full advantage of the unique properties of the new system and the high amplifying capabilities of the later screen grid tubes. As a result of this work, the latest chasses are quite different, both mechanically and electrically, and they are correspondingly better in performance, lower in cost, and more completely adapted to quantity production in a modern factory. Because of the inherent savings of space which result from the method, no attempt has been made to crowd the new designs into the smallest possible compass. There is, therefore, ample room for easy wiring and assembly, and yet the complete chassis is smaller and lighter than any of the current condenser tuned chasses of equivalent performance.

The circuit development has led to the adoption of a condenser coupled arrangement with both plate and grid circuits tuned, as is shown in Fig. 7. The antenna circuit, which directly feeds the grid of the first tube is also tuned so that we have five tuned circuits, but only two radio-frequency amplifier tubes. The antenna circuit is made to follow the other tuned circuits exactly by initial adjustment of the series antenna condenser and gives a gain on the first grid of from 18 to 22. The value of this preliminary tuning, before any amplification takes place, reducing the value of interfering signals and inductive disturbances before they reach the first grid cannot be over-estimated. That this produces a marked improvement in performance is apparent the moment the receiver is tuned to the first signal.

In all the tuned circuits the inductance value, measured without the core, is 65 microhenrys, and the capacitance is 160 mmfd., which is approximately three times the minimum capacitance, effective at 1,500 kc., in condenser tuned systems. The coupling condensers are .02 mfd. Other constants of the radio amplifier and the complete audio amplifier are normal.

The symbol used here to indicate variable permeability has simplicity if nothing else to recommend it, and it has been found to be not easily confused with other features usual in radio diagrams.

At the lower left is shown an alternate arrangement for the tuned circuits between the tubes which more nearly corresponds to the forms that have been used with condenser tuning, but, perhaps for that very reason, is not quite so constant in performance over the range. There is also shown, at the bottom right, the circuit for an oscillator, which will have very nearly constant output.

The five tuned circuits are assembled into a mechanical unit illustrated in Fig. 8 actually smaller than the usual

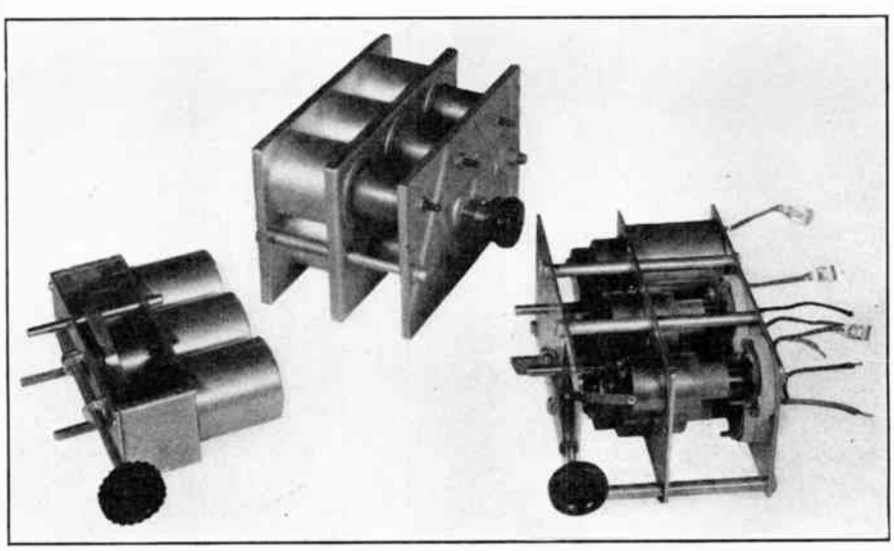


Fig. 8. Assembly of tuning units.

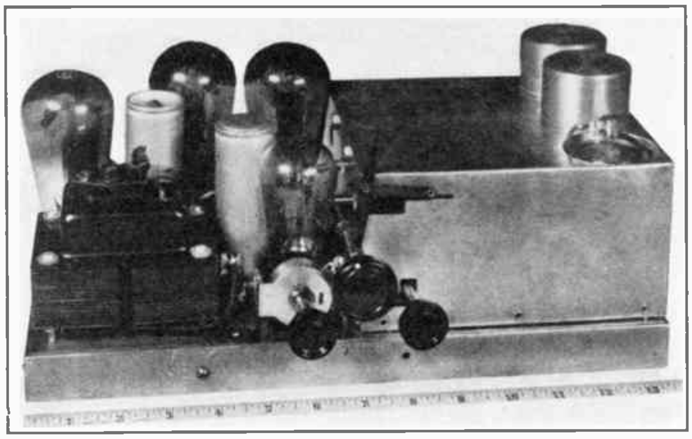


Fig. 9. Completed chassis.

five-gang condenser. The cores are mounted on a rigid bridle, actuated by a short rack and a cooperating pinion on the knob shaft. Any reasonable motion reduction can thus be easily secured, and this without complicating the very simple indicator, which can be adapted to either "full-vision" or the more usual type of dial, and is automatically "straight-line-frequency."

In the view at the lower right, some of the shield cans have been removed to show the coils and cores, and the insulating bases that support the mica condensers. The three top wires, with clips, connect to the grids of the two radio tubes and the detector, the black wire to the antenna terminal, and the four remaining wires to the two plates, and to the B supply. The coils are mounted directly on the back plate, not on the porcelain, in such a way that they may be adjusted to give the initial correct position with respect to the cores which are rigidly mounted on the bridle.

Since both the inductance and the capacitance are capable of adjustment, the inductance by the relative position of the core and coil, and the capacitance by the small adjustable leaf on the fixed condenser, the receiver is aligned after it has been completely assembled. There is no step equivalent to the necessity, in condenser-tuned systems, of aligning the gang unit before it is assembled on the set. The only source of variation is the moulded cores, and these are made in the same mould, under the same temperature and pressure, from a weighed quantity of material from a large and thoroughly mixed batch. Careful checks have shown that the degree of reproducibility is very high, and that the maximum error in a five gang unit will be less than one-half of one per cent. There is the further advantage that the maximum error occurs at 550 kc. where the stations have the greatest per cent separation. The method of alignment produces exact agreement at two points in the range. With the cores all the way out, the circuits are definitely tuned to a 1500 kc. signal, by adjustment of the condensers. The cores are then advanced to a mid position, and exact resonance to a 1000 kc. signal is secured by adjustment of the position of the coils with respect to the cores.

The overall alignment is thus actually better than can be secured by the prior calibration of variable condensers and coils in the usual system, and nothing short of actual tinkering will change it after it has once been established. The effect of changes in temperature is nil, and there are no parts sufficiently delicate to be displaced due to jars received in shipment. Slight differences between the inductance values of the coils are of no consequence, provided the coils are geometrically alike, and this is secured by using moulded forms.

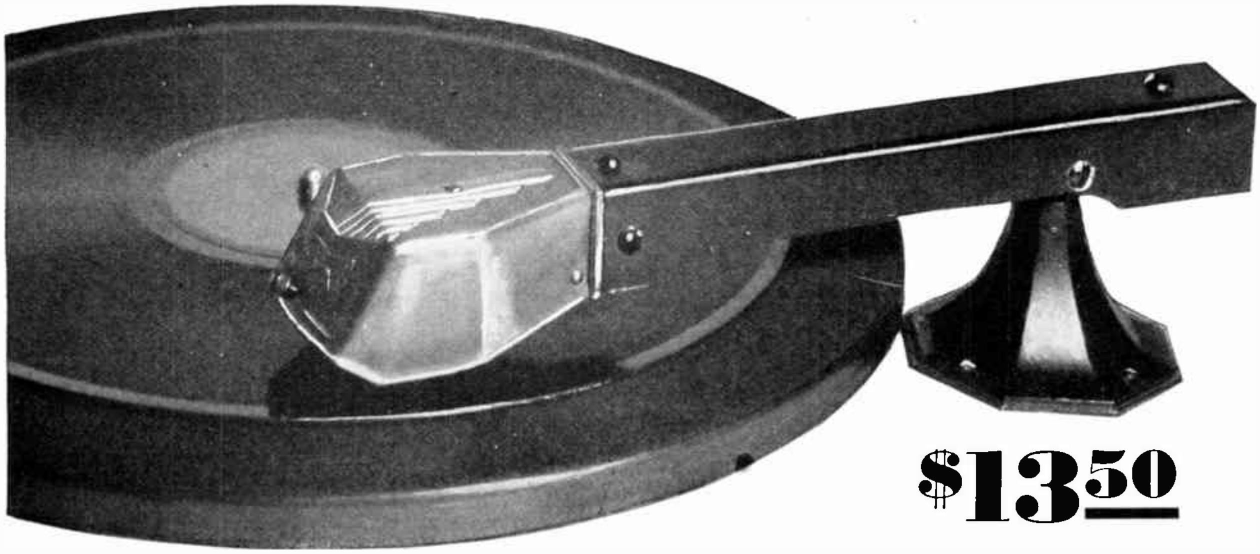
Another form of unit, shown at the center, Fig. 8, is directly adjusted by a screw passing through the bridle. This type may be more adaptable in some applications. There is also shown, at the left, a three core unit intended for possible use as a pretuner in superheterodynes.

In the completed chassis shown in Fig. 9, the units have been so arranged as to bring the three controls out at the center, so that adaptation to any cabinet design would be easy. Other arrangements, to suit particular cabinet designs can of course be made. Because there is no variable condenser gang, and because each tuned circuit is complete in itself, the wiring under the chassis pan is very much simplified. The receiver shown is only an "engineering model" and still requires the attention of the factory or production engineers to eliminate those little difficulties of assembly and wiring which make such a large difference in the speed of production and in the cost. Being almost completely hand made, it does not present the finished appearance of a factory product.

It is a matter of some difficulty to give anything amounting to an accurate cost comparison. The cores themselves will cost no more than the variable condensers which they replace. Beyond this there are a number of direct and indirect savings. The coils, for example, have a very much smaller secondary winding, and no primary. Nor have they any compensating windings. They are smaller in diameter, and so are the shield cans. Thus the space now occupied by the variable condenser gang is completely saved, and the space required for the coils greatly reduced. The high frequency wiring is materially simplified and shortened. Since the tuning and coupling condensers are mounted inside the shield cans, which are magnetically closed by the cores, the shielding is also greatly simplified. Compared to the superheterodynes, the oscillator and its tuned circuit and coupling means are saved. Even if the cores had to be sold at a slight advance over the cost of the variable condenser sections, there would still be a considerable saving.

One factor deserves to be emphasized. Receivers built in accordance with the new method will be strikingly new and different, both in appearance and in performance. The dealer first, and the public later, will be conscious of this difference. And they will conclude that a worthwhile new contribution has been made to the art of radio reception. This is the factor which more than any other recommends permeability tuning to the sales managers and the executive heads of the industry.

To the inventor, Mr. Polydoroff, and to Mr. Victor S. Johnson, who supported him, goes the credit for having successfully completed an important and courageous research addressed to the problem of radio reception.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Notes on the design of radio receivers†

By Lincoln Walsh

THE design of radio receivers is today a problem of obtaining satisfactory performance within limits set by considerations of cost and size. Satisfactory performance is largely a question of the resistance of the tuned circuits, both radio and intermediate frequency. Sensitivity and selectivity are improved as circuit resistances are decreased. Fidelity is seriously impaired as the resistance is decreased, beyond certain limits, unless band-pass circuits are employed.

The resistance of tuned circuits is commonly expressed in several ways:

The series resistance in ohms, R.

The power factor, pf; or its reciprocal, Q.

The band width at half amplitude, B, expressed in kilocycles at a given carrier frequency.

These expressions are related as follows:

$$\frac{R}{2\pi f L} = pf = \frac{1}{Q} \qquad (1)$$

$$\frac{1}{pf} = Q = \frac{2\pi f L}{R} \qquad (2)$$

$$B = \frac{\sqrt{3}\,R}{2\pi L} = \sqrt{3} \times f \times pf = \frac{\sqrt{3} \times f}{Q} \qquad (3)$$

The expression for B is derived as follows:

The series impedance

$$z = R + j\,2\pi f L + \frac{1}{j\,2\pi f C} \qquad (4)$$

at resonance

$$j\,2\pi f L + \frac{1}{j\,2\pi f C} = 0 \qquad (5)$$

and

$$z = R \qquad (6)$$

when the amplitude has been reduced to half by shifting the frequency of the applied voltage Δf

$$z = 2R = R + j\,2\pi\,(f \pm \Delta f)\,L + \frac{1}{j\,2\,(f \pm \Delta f)\,C} \qquad (7)$$

An approximation that has negligible error in all practical cases gives

$$z = 2R = R \pm 2\,j\,2\pi\,\Delta f\,L \qquad (8)$$

$$4R^2 = R^2 + 16\,\pi^2\,(\Delta f)^2\,L^2 \qquad (9)$$

$$\frac{3R^2}{16} = \pi^2\,(\Delta f)^2\,L^2 \qquad (10)$$

$$\Delta f = \frac{\sqrt{3}\,R}{4\pi L} \qquad (11)$$

As Δf is the frequency change in one direction to reduce to half amplitude, the band width B is twice Δf.

$$B = 2\Delta f = \frac{\sqrt{3}\,R}{2\pi L} \qquad (12)$$

or

$$B = \sqrt{3}\,f\,\frac{R}{2\pi f L} = \sqrt{3} \times f \times pf = \frac{\sqrt{3} \times f}{Q} \qquad (13)$$

The parallel tuned impedance of a tuned circuit, expressed in ohms, is

$$Rt = \frac{(2\pi f)^2 L^2}{R} = \frac{2\pi f L}{pf} \qquad (14)$$

$$= \frac{1}{(2\pi f)^2 C^2 R} = \frac{1}{2\pi f C\,pf} \qquad (15)$$

expressed as a conductance in mhos

$$g = \frac{1}{Rt} = \frac{R}{(2\pi f)^2 L^2} = \frac{pf}{2\pi f L} \qquad (16)$$

$$= (2\pi f)^2 C^2 R = 2\pi f\,c\,pf$$

Factors in Circuit Resistance

The resistance of a tuned circuit consists of the copper resistance of the coil, and the dielectric loss, made up of the losses in the condenser, in the coil form, in the tube and in the leads. In general, losses are also reflected into the tuned circuit from the primary circuit from which it receives its energy.

The resistance of a coil at radio frequency is many times its resistance to direct current. In a coil designed to cover the broadcast range, the power factor due to copper resistance only, at 1,500 kc. will be close to 0.8 per cent over a wide range of coil dimensions and size of wire. At 600 kc. the power factor due to copper resistance will vary from 2 per cent for some of the smaller coils now in use, to about 0.4 per cent for the larger coils employed in the earlier receivers.

In coils using solid copper wire, the diameter of the wire may be varied from about one-third the distance between turns, up to the point where the wires are almost touching without greatly affecting the power factor. Using larger wire reduces the power factor slightly at low frequencies, and increases it slightly at high frequencies.

The effect of shields is to decrease the inductance of the coil and to decrease the resistance to a slightly less degree, so that the power factor is only slightly increased. The reduction of resistance seems to be due to a reduction of skin effect. When the coil is not shielded the current crowds to the inner surface of the wire. In the shield

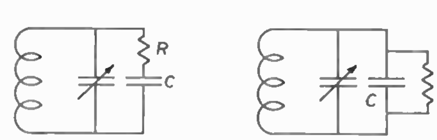

Fig. 1.

$R = \frac{pf}{2\pi fc}$ $\qquad g = 2\pi Cpf$

†Delivered before the Radio Club of America, May 11, 1932.

the current crowds to both inner and outer surfaces, and the consequent reduction in resistance more than compensates for the energy loss due to currents flowing in the shield, the net result being a drop in the coil resistance almost as great as the drop in inductance.

Coil Diameter

To obtain the coil of lowest power factor in an aluminum shield of given diameter, the coil diameter should be about 0.6 times the shield diameter; in a copper shield about 0.65. Cost considerations will dictate a coil slightly smaller than these sizes, as the power factor does not increase rapidly with decrease of diameter, but the material and labor costs drop in proportion to diameter.

If the coil diameter is 0.707 times the shield diameter the loss is slightly increased, but the coil has the unique property of having its inductance substantially independent of small variations in the diameter of the coil form. This is due to the reluctance of the magnetic path being equal inside and outside the winding, so that any change in diameter increases the reluctance of the inner path by the same amount that it decreases the reluctance of the outer path, or vice versa. The inductance then depends on the diameter of the shield, the length of winding and the number of turns.

The dielectric loss, when expressed as a conductance across the circuit varies in proportion to frequency. It may be represented by a condenser of fixed capacity and constant power-factor comprising part of the tuning capacity of the circuit, as shown in Fig. 1.

In a circuit having fixed inductance, and tuned by a variable capacity, the dielectric loss when expressed as a series resistance or as band width varies as the third power of frequency. Expressed as power factor it varies as the second power of frequency.

Among the main contributors to dielectric loss are the insulators and compensators of variable condensers, and the insulation of the leads connecting the grid, coil high terminal and variable condenser stator. Care should be taken in the placing and insulation of these leads, or their loss may exceed all the other losses of the circuit.

The power factor due to dielectric loss may vary from values too small to measure to about 1.5 per cent, at 1,400 kc.

The r-f. system of the average broadcast receiver has a power factor due to all causes of about 1.4 per cent at 600 kc. and 1.7 per cent at 1,400 kc., corresponding to band widths for individual stages of 15 kc. and 42 kc. The intermediate frequency stages of superheterodynes have band widths of 6-10 kc., corresponding in a 175 kc. amplifier, to a power factor of 2-3 per cent.

The loss reflected from the primary consists of the reflected plate impedance of the tube, and the loss due to current circulating in the primary coil itself. The loss due to circulating current is determined by measuring the power factor of the secondary with the primary removed, and then measuring the power factor with the primary in position and connected to its normal circuit, with the preceding tube plate connected to the primary, but the cathode cold or the tube biased beyond cutoff. The difference of these two power factors gives the loss in the primary.

The power factor due to reflected plate impedance is a measure of efficiency of coupling between the plate of the amplifier and the tuned circuit. For maximum transfer of energy into the secondary circuit, the impedance of the primary should equal the plate impedance of the tube. The primary impedance is

$$z_1 = R_p \times \frac{pf}{pf_o} - 1 \qquad (17)$$

where R_p is the plate impedance of the tube.

pf is the power factor of the circuit in normal operation with the tube operating at R_p normal.

pf_o is the power factor of the circuit normal except that R_p is substantially infinite (cathode cold, or tube biased almost to cutoff).

The expression for primary impedance is derived as follows:

Neglecting $L_{1L}\ \tau^2$, the total resistance across the tuned circuit is Z_2

$$\frac{1}{Z_2} = \frac{1}{Z_{2-o}} + \frac{1}{R_p\tau^2} \qquad (18)$$

$$\frac{pf}{2\pi f L} = \frac{pf_o}{2\pi f L} + \frac{1}{R_p\tau^2} \qquad (19)$$

$$\frac{pf - pf_o}{2\pi f L} = \frac{1}{R_p\tau^2} \qquad (20)$$

$$\frac{pf - pf_o}{pf_o} = \frac{2\pi f L}{R_p\ \tau^2\ pf_o} \qquad (21)$$

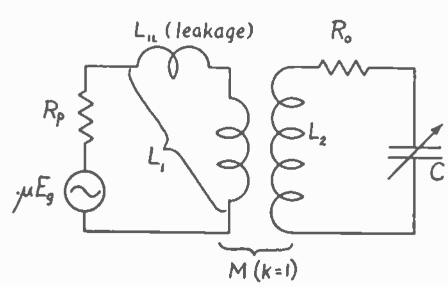

Fig. 2. Actual circuit. Effective turns ratio or voltage turns ratio $\tau = \frac{L_2}{M}$

$\frac{2\pi f L}{pf_o}$ is the secondary tuned impedance and $\frac{2\pi f L}{pf_o\ \tau^2}$ is the primary tuned impedance.

Then the preceding equation reduces to

$$\frac{pf}{pf_o} - 1 = \frac{z_1}{R_p} \qquad (22)$$

This method must be modified when the primary leakage inductance is not negligible relative to R_p.

The method as described in general is correct for all circuits except those employing a primary circuit tuned to a frequency below the low end of the frequency range.

The relation between primary impedance, voltage ratio, gain, and power factor is shown in Fig. 4.

It will be seen that if the primary impedance is made somewhat below optimum, the power factor, and therefore the selectivity are considerably improved, with a very slight reduction of gain.

Computation of Gain

Knowing the inductance L, power factor pf_o, and voltage ratio or effective turns ratio τ of a tuned amplifier stage, the gain can be computed as follows:

Tuned secondary impedance

$$z_2 = \frac{2\pi f L}{pf_o} \qquad (23)$$

Tuned primary impedance

$$z_1 = \frac{2\pi f L}{pf_o \times \tau^2} \qquad (24)$$

The voltage developed across the primary is

$$\mu E_g \times \frac{z_1}{z_1 + R_p} \qquad (25)$$

The voltage developed across the secondary

$$E_s = \tau\ \mu\ E_g \frac{z_1}{z_1 + R_p} \qquad (26)$$

Amplification

$$\frac{E_s}{E_g} = \tau\ \mu \frac{\frac{2\pi f L}{pf_o\ \tau^2}}{\frac{2\pi f L}{pf_o\ \tau^2} + R_p} \qquad (27)$$

The optimum effective turn ratio or voltage ratio is

$$\tau = \sqrt{\frac{z_2}{R_p}} = \sqrt{\frac{2\pi f L}{pf_o \times R_p}} \qquad (28)$$

The optimum gain is

$$\frac{\tau_{opt} \times \mu}{2} = \frac{\mu}{2}\sqrt{\frac{2\pi f L}{pf_o \times R_p}} \qquad (29)$$

The above expressions are primarily for use with 3-element tubes in which the plate impedance is low. When the plate impedance is greater than the tuned secondary impedance, it is in general not possible to secure optimum coupling and gain.

When the plate impedance is very much greater than the primary impedance (27) reduces to

$$\frac{E_s}{E_g} = \frac{\mu}{R_p}\frac{2\pi f L}{pf_o\,\tau} = g_m \frac{2\pi f L}{pf_o\,\tau} \qquad (30)$$

When the plate is directly coupled to the tuned circuit this further reduces to

$$\frac{E_s}{E_g} = g_m \frac{2\pi f L}{pf_o} \qquad (31)$$

Most superheterodynes employ in their intermediate-frequency stages a pair of coupled circuits, the first of which is directly coupled to the plate of the amplifier tube, with the coupling between them critical or over. The tuned primary impedance is half the impedance of one circuit alone. The tuned impedance of such a circuit is generally a considerable fraction of the impedance of the screen grid amplifier tube.

The primary impedance is then

$$\frac{2\pi f L}{2\,pf} \qquad (32)$$

The voltage amplification is

$$\frac{E_s}{E_g} = \mu \frac{\dfrac{2\pi f L}{2\,pf_o}}{\dfrac{2\pi f L}{2\,pf} + R_p} \qquad (33)$$

the voltage being substantially the same across both primary and secondary.

Methods of Measuring Resistance

The more common methods of measuring resistance at high frequencies may be grouped under the following headings:

High frequency bridge.
Resistance variation.
Capacity variation.
Frequency variation.

The ordinary a-c. bridge has been used to measure the series resistance of tuned circuits. It has been used also to measure the primary impedance of tuned transformers at resonance, when this value was of the order of 1,000 to 10,000 ohms. This method has been found fairly accurate, but it is so difficult to operate a bridge of this character that is very rarely used.

The resistance variation method is perhaps the most widely used method of measuring resistance. A voltage is induced in the tuned circuit, and a vacuum tube voltmeter connected across

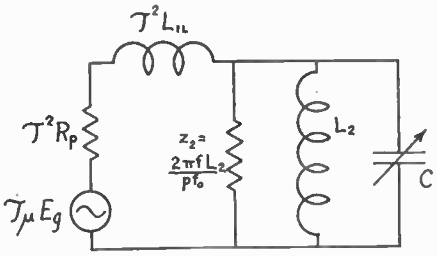

Fig. 3. Equivalent circuit.

the circuit or an ammeter connected in series with the coil and condenser, and the circuit tuned to the applied voltage. The reading of the meter is noted. Resistance is introduced in series with the inductance and capacity, and its value adjusted until the meter reading indicates half current or voltage. When the meter reading is proportional to voltage squared, the reading should be adjusted to quarter the original deflection. The value of resistance introduced is then equal to the resistance of the circuit.

Precaution must be taken that the induced voltage does not change when the resistance is introduced.

This method is open to the serious objection that the results are accurate only when the resistance is in series with all the tuning capacity. In the average broadcast circuit at 1,400 kc. more than half of the capacity of the circuit is distributed, or reflected from the primary, and less than half is in the condenser, and the results obtained are correspondingly in error.

In the capacity variation method, a small calibrated variable condenser is connected in parallel with the tuning condenser; the circuit is tuned to resonance with an applied voltage as indicated on a vacuum tube voltmeter. The meter reading is noted and the auxiliary condenser setting increased until the voltmeter reading has dropped to quarter scale, indicating one-half voltage. This is repeated, decreasing the condenser setting.

Call the difference of the two settings $2\Delta C$. Then

$$\frac{2\pi f}{\sqrt{3}}\Delta C = \frac{pf}{2\pi f L} = \frac{R}{(2\pi f L)^2} \qquad (34)$$

or

$$\frac{\Delta C}{\sqrt{3}\,C} = pf = \frac{R}{2\pi f L} = \frac{1}{Q}$$

This method is quite satisfactory and accurate. It does call for the inductance or capacity being known. The auxiliary condenser may add sufficient dielectric loss to the circuit to seriously affect the results at high frequencies.

When the voltmeter reading is dropped to half instead of quarter on a square law meter, the same expression results, but the $\sqrt{3}$ (1.732) drops out of the expression.

Then

$$2\pi f\,\Delta C = \frac{pf}{2\pi f L} = \frac{R}{(2\pi f L)^2} = \frac{1}{Q\,2\pi f L} = pf\,2\pi f C = \frac{2\pi f C}{Q} \qquad (35)$$

$$\frac{\Delta C}{C} = pf = \frac{1}{Q} \qquad (36)$$

Frequency Variation Method

In the frequency variation method the circuit is tuned to resonance with a voltage from the signal generator, as indicated by a vacuum tube voltmeter. The frequency of the generator is increased until the voltmeter falls to half it original value, and the frequency noted. The frequency is then decreased until the voltmeter falls to the same half value. The difference of frequency for the high and low settings represents the band width at half amplitude. From this figure the power factor may be directly determined

$$pf = \frac{B}{f \times \sqrt{3}} = \frac{B}{f \times 1.732} \qquad (37)$$

The main requirement of the frequency variation method is that the signal generator shall be accurately calibrated for small changes in frequency. It is desirable to have the scale divisions in fifths of a kilocycle in the broadcast range to permit band width measurements to tenths of a kilocycle. This does not mean that the frequency calibration of the generator must be within one-fifth kilocycle, but that for small variations of frequency, the vernier shall read to fifths.

In practice, measurements have been found to be reproducible to plus or minus 1 per cent. The accuracy of calibration of the vernier is well within 2 per cent.

The vacuum tube voltmeter used in this work is of the conventional plate rectification type, uses any type of tube, and imposes zero load on the tuned circuit. The type of tube used is the type with which the circuit is intended to operate, so that the measurements are taken with the circuit normal in every respect. When a screen grid tube having four or more elements is used, the control-grid is the input element of the voltmeter, the plate and screen are connected together and act as the plate. The suppressor grid is connected to plate or to cathode.

In measuring the antenna circuit of a complete receiver the signal generator is connected through the dummy antenna to the antenna lead of the receiver, and the grid lead of the first tube is connected to the grid of the voltmeter tube. The band width measurement is then made without making any changes in the receiver. For measurement of interstage circuits, the generator is connected to the grid of the amplifier tube, the grid lead to the succeeding tube connected to the voltmeter tube, and the band width measured.

It is not necessary to feed the energy into the circuit through the amplifier tube or the primary circuit. The energy may be fed through a coupling coil connected to the generator and very loosely coupled to the coil under test. The generator frequency may be changed slightly by connecting the coupling coil across its terminals, but this does not introduce any appreciable error into the band width measurement.

The frequency variation method has the advantage that no change is necessary in the circuit to be measured; it is not necessary to open the circuit to insert a resistance, or to add a calibrated vernier condenser in parallel with the circuit. The inductance does not have to be known to determine power factor or band width. Over the resistance variation method it has the advantage that the results do not depend on a resistance standard, which may not be accurate at the frequency of the test. These points become increasingly important at the higher frequencies. The method does call for a special form of signal generator having a calibrated frequency vernier.

Band Pass Circuits

The frequency variation method cannot be applied directly to measure the resistance of tuned circuits in band-pass coupled circuit systems. In this case it is necessary to uncouple the coils before measuring them. Energy may be fed to the first coil of the coupled system through its primary, and to the other coil or coils by loosely coupling them to a coupling coil connected to the generator.

A useful method of measuring band-pass circuits is to measure the band width of the pair of coils at quarter amplitude. If the coils are very loosely coupled this band width will be the same as the average of the band widths of each of the two coils at half amplitude. As the coupling is increased, the band width at quarter amplitude increases in proportion to the increase in coefficient of coupling. The gain of the circuit also increases, reaching within 5 per cent of the maximum attainable when the band width has increased about 50 per cent over the minimum band width.

Measurement of Resistance Units at High Frequency

The frequency or capacity variation method can be used to measure the value of any resistance unit at any frequency by noting the change in power factor when the resistor is connected in series or parallel with a tuned circuit. The choice of series or parallel connection and the value of inductance and capacity should, if possible, be such that the power factor of the circuit with the resistance connected is not over 5 per cent. The error due to the approximation in expression (8) used to determine the simple expression for power factor, multiplies the result by 1.004 at 5 per cent power factor, and increases as the second power of power factor.

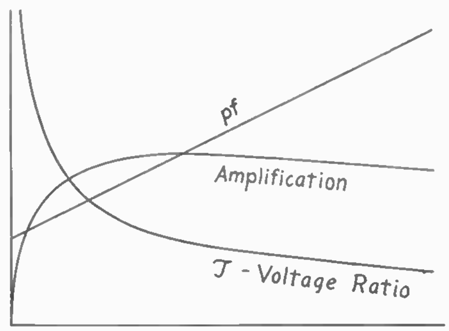

Fig. 4.

When the resistance R is in series

$$R = 2\pi f L \times (\text{change in power factor}) \quad (38)$$

When in parallel

$$R = \frac{2\pi f L}{(\text{change in power factor})} \quad (39)$$

The Decibel as a Method of Rating Receivers for Sensitivity

We have found the use of the decibel as a measure of the sensitivity of receivers, of the gain of amplifier stages, and of the sensitivity of detectors, to be a distinct advantage. The system which has been under consideration by the I. R. E. Technical Committee on Radio Receivers expresses voltages in decibels below 1 volt. Sensitivity is then the signal input expressed as decibels below 1 volt, modulated 30 per cent, required to give normal output of 50 milliwatts. The decibel rating has the advantage that the rating of a receiver increases with its sensitivity, and that the number representing the rating does not vary over a great range for variations in sensitivity which perhaps are barely noticeable to the user. The difference in usefulness between a 5 microvolt set and a 1 microvolt set is not such as to justify a difference of 5:1 in their rating. On the decibel rating these sets are rated respectively 106 and 120, which ratings represent better the usefulness of the receivers to the user who is looking for sensitivity.

The fact that the rating increases with sensitivity eliminates the confusion which the microvolt rating caused all except engineers.

Much work is being done on field strength measurement in decibels so that these measurements can be more easily correlated with receiver sensitivity in decibels than with sensitivity in microvolts.

In laboratory work the decibel system is a great convenience. By having the output of the generator and the scale of the vacuum tube voltmeter calibrated in decibels, all need for computations to determine the gain of a stage or the sensitivity of a receiver is eliminated. When the tube of the vacuum tube voltmeter is changed the only change in calibration is to use a calibration figure which is added to the scale reading in decibels. All tubes can be made to follow the decibel scale, which is made square law, by adjusting the grid voltage. Most tubes should be adjusted to a plate current with no a-c. voltage applied, of approximately .5 ma. The exact value should be determined by trial, applying voltages differing by 5 or 6 db. and noting whether the meter reading changes by exactly that amount. This simple calibration eliminates the need of making a new scale or a new calibration curve when the voltmeter tube is changed.

The sensitivity of a projected receiver can be computed very quickly as follows:

Detector sensitivity (defined same as receiver sensitivity)	2 db.
I-F. amplifier gain	44
Translator gain	30
R-F. amplifier gain	30
Antenna stage gain	14
Receiver sensitivity	120 db.

In a well designed receiver, the sensitivity will be found to agree very closely with the computed sensitivity.

The decibel as originally defined is a measure of power gain or loss.

$$\text{Gain or loss in db.} = 20 \log_{10} \frac{E_2}{E_1} \quad (40)$$

when E_1 and E_2 are measured across equal impedances. As used in radio receiver work, the decibel is a measure of voltage gain or loss, and the impedances are neglected. This is because vacuum tubes in general are voltage rather than power operated devices, and their input resistance very high. This neglect of impedance should be borne in mind when comparisons are made with decibel measurements where impedance is taken into account.

REFERENCE

L. A. Hazeltine, "Discussion on The Shielded Neutrodyne Receiver," Proc. I.R.E., Vol. 14, No. 3, June 1926.

Book Review

RADIO-FREQUENCY MEASUREMENTS, by Hugh A. Brown. Published by McGraw-Hill Book Co., Inc., New York City, 1931. *Price,* $4.00. (386 *pp. Illustrated. Cloth.*)

This recent volume compiled by a professor of electrical engineering of the University of Illinois is a combination laboratory manual and textbook. It is prepared particularly for the engineer and advanced student and is "intended to present both the well-known methods of making certain measurements and some of the important advances recently made in the solution of radio-frequency measurement problems."

The selection of the group of measurements included is worthy of mention. It is rather difficult for a technical writer to prepare a suitable text on this subject without going beyond the normal range of topics and to maintain his work within reasonable proportions. Hence we appreciate the care and thoroughness Professor Brown has employed in the compilation of this volume. Within the recent years a book of this type that would be suitable as a ready-reference for popular measurements of radio-frequency practices has been generally demanded and thus we feel that this particular work fulfills its purpose admirably.

The general composition of the text consists of nearly seventy-five measuring circuits and individual manipulations employed in solving problems of radio-frequency standards. There also appears some measurements that are of audio-frequency or continuous-current nature. The treatment of this subject is unique among works of this type. The first part considers the elucidation of the underlying theory of the material, which is followed by a compendious discussion of the procedure of measurement and finally there is given a general argument of merits and limitations of the method involved.

The measurements appearing are of a varied group and are accompanied by circuit schematics and illustrated with cuts of some of the laboratory setups. Free use is made of engineering mathematics which is to be found throughout the text and employed as a means of exact expression of certain technical idiosyncrasies. Among those considered are measurements of the elements comprising a simple tuned circuit, frequency and wave form, antenna, thermionic-tube, coefficients, electromotive force, current, power, and transmitters, receiver, and piezo electricity. It is also replete with an appendix wherein there appears (among several other subjects) an interesting discussion relative to circuit drivers and piezo-electric quartz crystals.

Not only is this book an ideal laboratory guide for the senior student; for to the advanced reader it will also prove of especial value because of the recent collection of standard information contained herein and interestingly perpetuated in this succinct manner as to render it a service.—*Reviewed by Louis F. B. Carini.*

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Antenna transmission line systems for radio reception[†]

By C. E. Brigham*

IN designing radio receivers radio engineers are careful and anxious to meet the desired characteristics in receiver design. Selectivity, sensitivity and fidelity are three of the most important qualifications which have presented serious problems to every engineer. With the changing of broadcasting conditions, new demands and improvements were necessary in the selectivity, sensitivity and fidelity requirements. Increased sensitivity, whether in tuned-radio-frequency or superheterodyne designs, has presented new problems such as cross-modulation, instability, whistles in superheterodyne reception due to low image ratio response, intermediate-frequency harmonics and reradiation. Increased sensitivity has also resulted in greater noise pickup from man-made interferences, especially in congested metropolitan areas. These are all interference problems to the radio engineer, most of which have been successfully eliminated, with the exception of noise.

With the desire for better fidelity it became necessary to improve the selectivity requirement of a radio receiver in preventing r-f. or i-f. sideband cutting of the higher modulated audio frequencies, by employing band-passed intermediate- and radio-frequency tuned circuits. With the improvements in the reproduction of higher audio frequencies in the speaker greater fidelity of reproduction is realized. In certain important areas, however, the faithful reproduction of high audio frequencies have resulted in serious complaints of noisy reception.

The granting of high power from 20 to 50 kw. by the Federal Radio Commission to a chosen few of the broadcasting stations has hastened the advancement of automatic volume control, or avc, in radio receivers. The automatic volume control development has been quite remarkable and it is common to experience receivers today holding a constant output on a station of 1000 microvolts field intensity and a station of 500,000 microvolts field strength without changing the position of the volume control. To hold a constant output at these extremely wide variations of input it has become necessary to allow the sensitivity of the receiver to vary automatically over wide limits, such that when no signals are impressed across the antenna and ground the sensitivity of the receiver is naturally high, resulting in serious noise pickup between stations while tuning.

From the foregoing it is seen that in the past few years improvements in the three essential performance features of a radio receiver have led to a type of interference which has only recently been taken into serious consideration by radio engineers. This type of interference is known as "inductive interference" or noise induction from man-made devices. The problems of interference and its elimination have always confronted the radio engineer. Interference from insufficient selectivity, cross-modulation, whistles in superheterodyne reception, have all been satisfactorily eliminated by the development of new circuits, tubes, and by better engineering. Quiet operation and uninterrupted by interference is the ideal requisite of radio performance today. It is

†*Presented before the Radio Club of America, December 14, 1932.*

**Chief Engineer, Kolster Radio, Inc.*

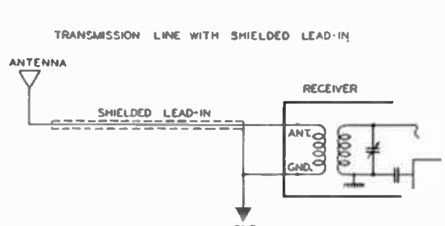


Fig. 1.

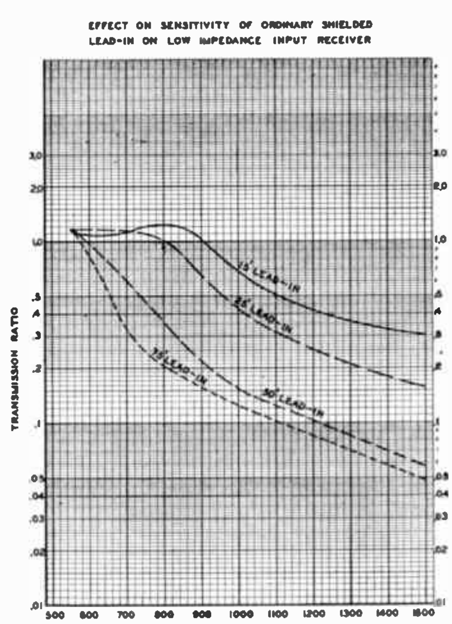


Fig. 2.

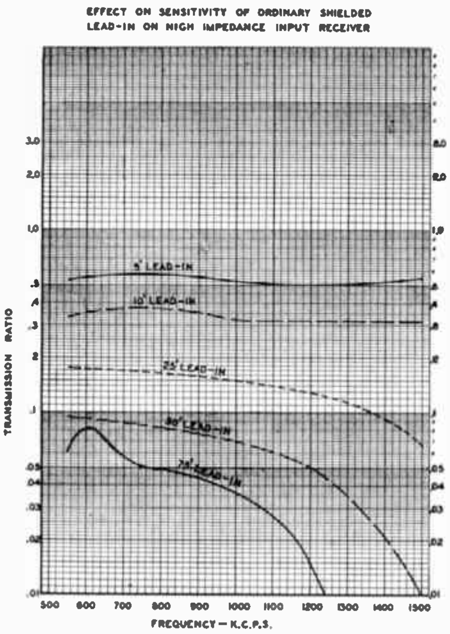


Fig. 3.

evident that today the noise level is being reached in the radio receiving system. The study of inductive interference or noise interference and how it may be eliminated or reduced considerably is the subject of this paper.

Inductive interference in radio receivers is caused by inductive coupling to the receiver system from the noise making devices. Noises in the home are produced from such devices as sparking motors or generators, electric refrigerators, oil burners, electric heating appliances, vacuum cleaners, the shutting on and off of electric lights, violet ray machines and the like. Outside the home some of the most severe sources of noise interference result from high tension power lines, trolley lines, electric elevators, dial telephones, etc.

Noise interference may be introduced into the radio receiver system by four ways:

1. The receiver chassis.
2. The power supply system.
3. The antenna.
4. The antenna lead-in.

Of these four, noise interference is the greatest on the antenna lead-in.

Experimentation and experience have shown that little noise interference is being introduced in the present-day receiver chassis, due to its comparatively complete shielding, except from such powerful noise interference devices as the violet ray machine and doctor's or dentist's equipment. It has been found that household noise interfering devices do not radiate at distances much greater than twenty feet, which makes it possible to locate the receiver proper at some point remote from the noise making device. In receivers designed prior to this year, where careful shielding of the radio-frequency and the intermediate-frequency circuits were not employed, noise pickup on the receiver chassis became an important factor. In the receiver chassis of the superheterodyne type it has been found that the radio-frequency grid circuits are much more subject to noise pickup than the intermediate-frequency grid circuits and on the audio system there is very little pickup.

For best results and perfect assurance against noise pickup on the chassis itself complete shielding of the receiver should be employed, including all grid leads, top of grid tube caps and the antenna and ground leads to the input of the receiver. A test for determining the effect of the completeness of shielding of the receiver chassis parts is to turn the volume control to the maximum position and with the antenna and ground leads free, but not exposed, tune for the local broadcasting stations. If the shielding is effective no broadcasting stations will be heard, or only the very powerful local stations will be heard faintly.

Proper Filtering

Noise from the power supply system is possible if the power supply circuit in the receiver is not properly filtered. A copper shield between the primary and secondary windings, properly grounded to the receiver chassis frame, is found to be an effective filter against both line noises and radio-frequency pickup. A condenser from one side of the a-c. line to ground is another but less effective method of line filter.

The antenna is the second worse offender in picking up noise interference. Next to the antenna lead-in, its position and the way it is installed are of the utmost importance. Unfortunately the public, including radio engineers, have been extremely lax in the installation of antenna systems and much education will be required before full realization is effected in the proper installation of the antenna for quiet operation and freedom from noise interference. It is extremely important that the antenna be erected outside the source of interference. The location of the antenna is the only limitation in the successful elimination of noise interference. Since the purpose of the antenna is to collect the radio-frequency energy sent out by the broadcasting station and the amount of this energy is determined by the antenna length, its height above nearby obstacles and its distance from the broadcasting station, a long, high outdoor antenna is most essential. An antenna on the roof of any building and especially of a large apartment, hotel, or office building is exposed to a great variety of electrical disturbances. These disturbances are made up of "natural static" and man-made static." Little can be done to suppress natural or atmospheric static, but an efficient antenna system can do much in the elimination of man-made static. The antenna should be at least thirty feet above surrounding obstacles. It is important that the location and direction of the antenna be considered in reducing noise. The antenna should be at right angles to exposed electric light, power or telephone lines and should not cross above or below these lines.

Since the antenna lead-in is necessarily subject to close proximity to the electrical disturbances by having to run near a side of buildings, pass exposed power and telephone lines, and inside of rooms to the input of the radio receiver, it is natural that this lead-in picks up most of the "man-made static" from the electrical disturbances. The

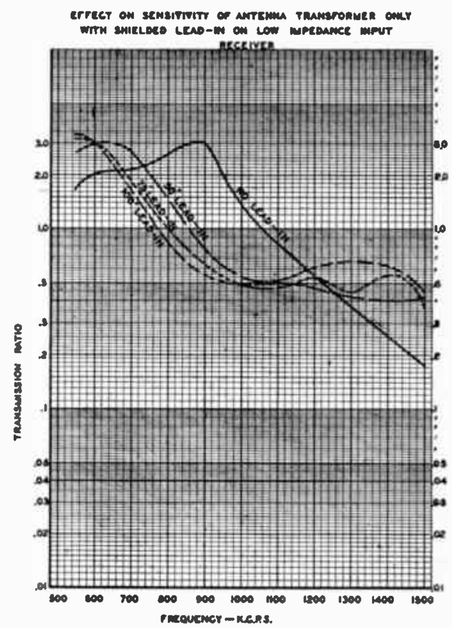


Fig. 5.

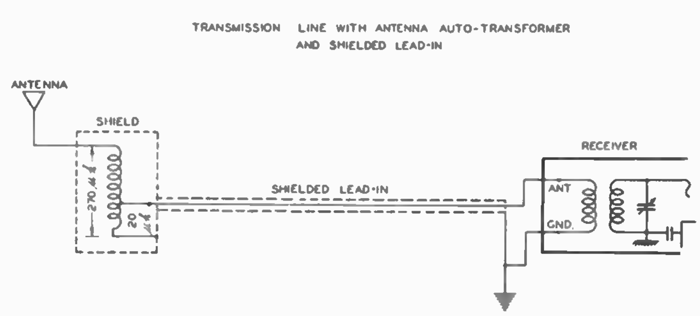


Fig. 4.

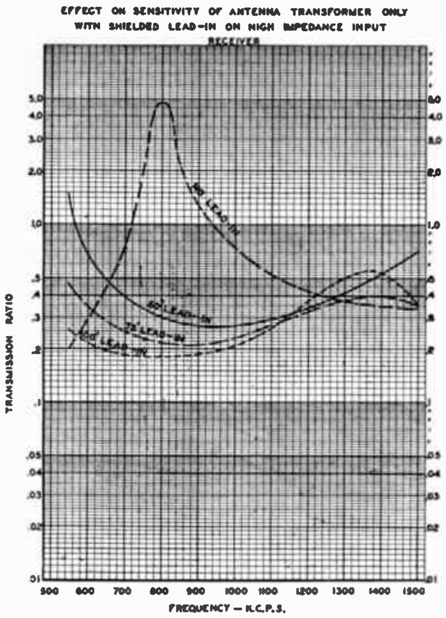


Fig. 6.

problem of shielding this lead-in, without attenuation or losses to the received signal over the wide broadcast frequency range is a very interesting one. This problem today is two-fold since there are two types of input circuits used in receiver designs; the low impedance input and the high impedance input. By low impedance input system is meant an antenna circuit coupled to the first tuned radio-frequency circuit by means of a low impedance inductance of 10 to 50 microhenrys which is naturally periodic above 1500 kc. By high impedance is meant an antenna coupled to the first tuned circuit by means of a high impedance inductance of approximately 3 millihenrys which is naturally periodic below the broadcast range of 550 kc.

Shielded Lead-In

In the past it has been customary to employ an ordinary shielded lead-in for the elimination of noise on the antenna lead-in, where the lead-in consisted of a single rubber and cotton covered conductor inside a copper braid. This is the simplest type of transmission line system as shown in Fig. 1. The effect of the ordinary shielded lead-in on the sensitivity of the radio receiver of the low impedance type is shown in Fig. 2. The curves are plotted with abscissa covering the broadcast frequency range and the ordinate showing the transmission ratio. By transmission ratio is meant the ratio of the microvolt sensitivity as measured across the antenna and ground of the receiver chassis to the microvolt sensitivity as measured across antenna and ground at the beginning of the transmission line system. It is noticed that serious attenuation becomes effective above 700 kc., increasing with the length of the shielded lead-in, due to the by-passing capacity effect of the lead-in. Attenuation is even much more serious on a high impedance input receiver with the ordinary shielded lead-in wire as shown in Fig. 3. Even five feet of shielded lead-in wire on a high impedance input receiver affects the attenuation in the order of six decibels. Such simple systems usually recommend antenna lengths from 200-400 feet long to make up for the losses in the shielded lead-in. Although effective as far as minimizing noise interference on the antenna lead-in, antenna lengths for the ordinary shielded lead-in became impractical for the complete elimination of noise, especially with the high impedance input receivers.

It is known in transmission line theory that low impedance transmission lines are not subject to inductive interference and also considerable less attenuation exists under the proper conditions.

In an attempt to employ a low impedance transmission line for the antenna lead-in between the antenna proper and the receiver chassis an arrangement has been used as shown in Fig. 4. With this arrangement an auto-transformer is used at the antenna end in conjunction with an ordinary shielded lead-in. When such a system is used on a low impedance input receiver its effect on sensitivity is shown in Fig. 5. It is immediately noticed the improvement this system has over the ordinary shielded lead-in system. Even with 100 feet of ordinary shielded lead-in wire between the auto-transformer antenna unit and the receiver chassis the maximum attenuation is only six decibels. However, when such a system is employed on a high impedance input receiver the attenuation for various lengths of shielded lead-in is shown in Fig. 6. These curves show maximum attenuation of over twelve decibels over a considerable portion of the broadcast frequency range. The improvement of the auto-transformer arrangement with the shielded lead-in wire over the ordinary shielded lead-in system is shown for the low impedance input receiver in Fig. 7. The attenuation above 900 kc. on the low impedance input receiver with the antenna auto-transformer is caused by detracking of the first r-f. tuned circuit by reaction of the transmission line. Retrimming of the first tuned circuit at 1400 kc. results in less attenuation.

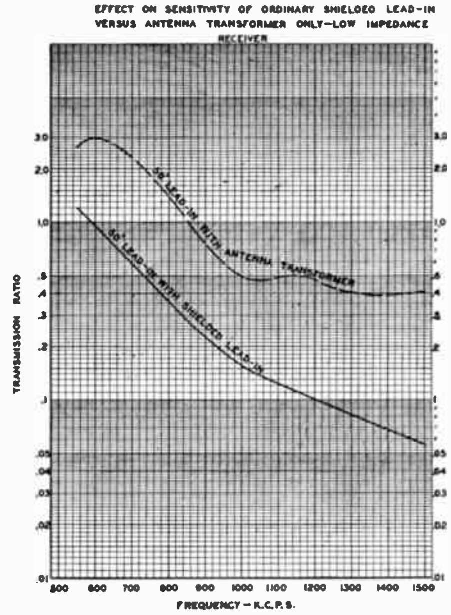


Fig. 7.

From the foregoing curves shown in the figures any transmission line system on a high impedance input receiver has disclosed bad attenuation over a considerable portion of the broadcast spectrum. This high loss of signal over such transmission line systems has been due to by-passing of the signal energy from the capacity of the conductor to ground shield and the mis-matching of impedances between the low impedance of the auto-transformer and the high impedance input.

Antenna—Input Balance

One arrangement in properly matching or balancing impedances between the antenna and input of the receiver is by employing auto-transformers at both the antenna and receiver as shown in Fig. 8. With this arrangement its effect on sensitivity of a high impedance input receiver is shown in Fig. 9. Compared with the attenuation curves in Fig. 6, which show the condition for the auto-transformer at the antenna end only, the improvement in the proper impedance matching is clearly demonstrated. It is noticed in Fig. 9 that even

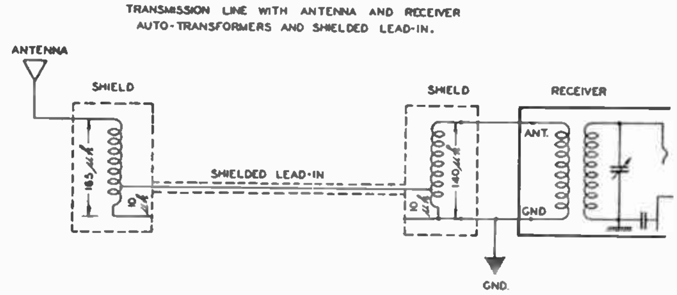


Fig. 8.

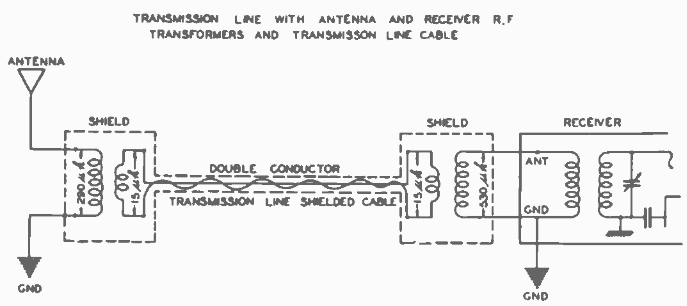


Fig. 10.

with 400 feet of shielded lead-in wire between the antenna and receiver auto-transformers no attenuation is noticed up to 1200 kc., and only a maximum of six decibels loss between 1200-1500 kc. The effect on sensitivity of the antenna and receiver auto-transformer transmission line system on a low impedance input receiver is similar to that obtained with the antenna auto-transformer alone with the shielded lead-in wire.

Another effective method in obtaining the proper impedance matching between the antenna and receiver input over a low impedance transmission line system is by the use of simple antenna and receiver r-f. transformers as shown in Fig. 10. In this arrangement the two transformers are connected by means of a twin conductor shielded cable. Such a system gives attenuation curves on a high impedance input receiver similar to the curves shown in Fig. 9.

Link Circuit Balanced to Ground

In locations where the electrical disturbance is particularly violent, such as with violet ray machines, it is possible for the inductive interference to get in upon the transmission line. To take care of such a possibility the transmission line, particularly the link circuit, should be carefully balanced to ground. Such an ideal system is shown in Fig. 11. Due to the capacity effect of the windings a copper shield is used between the primary and secondary windings to prevent any noise transfer which is not balanced to ground. Although the copper shields do not affect the inductance value of the windings, the mutual inductance is decreased on account of the physical space required for the shields. A tuned antenna system as shown in Fig. 11 allows a uniform attenuation over the broadcast frequency band. With a 500 foot transmission line an average of only six decibels of attenuation is obtained over the broadcast spectrum.

Shielded transmission line systems with proper impedance matching and carefully designed to give little or no attenuation over the complete broadcast frequency range, serve as ideal systems for the elimination of man-made static. The type of transmission line system used, whether of the antenna and receiver auto-transformer type; the simple antenna and receiver r-f. transformers; or the more complicated and elaborate tuned antenna and receiver balanced system, is at present one of preference. It may suffice to say that such systems give remarkable results in the elimination of man-made static where heretofore noise interference was so great as to drown out the radio reception. Successful installations in congested theatre districts, newspaper rooms, office buildings, etc., have proven the value of such transmission line systems for radio reception.

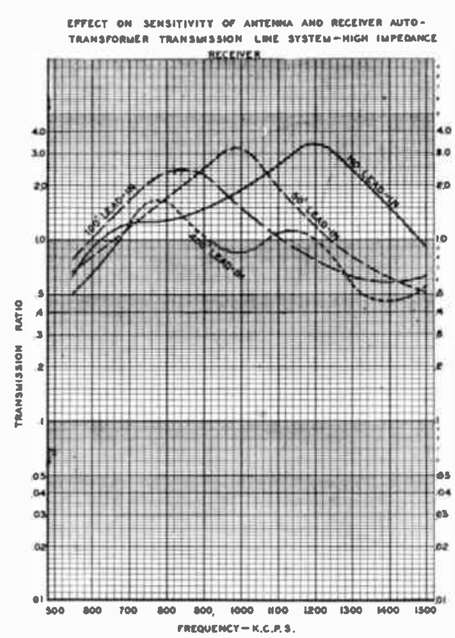


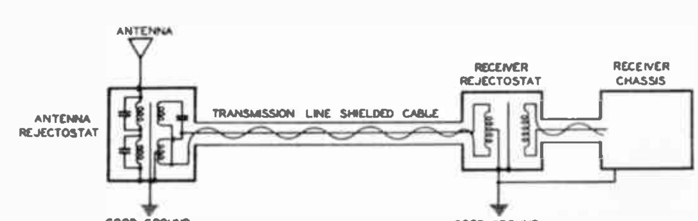
Fig. 9.

These transmission line systems, properly balanced and employing correct impedance matching, do not require an excessive aerial length. A flat top at least 75 to 100 feet long and at least 30 feet above the roof of any building or obstacles, is more than sufficient. It is vital and important that the antenna be erected outside the field of the electrical interference. If the lead-in to the antenna unit is long, it should never be shielded as loss in signal will result. If it is found that the noise interference is getting on this lead-in some means must then be provided for locating the antenna unit nearer the antenna proper.

A perfect installation may be ruined by the reradiation of noise from other antenna structures, power and telephone lines in close proximity to the antenna proper of the transmission line system. It has been found that violent noise interference such as from violet ray and X-ray machines, is picked up by neighboring antenna wires, telephone and power lines, which in turn radiate interference to the antenna of the transmission line system.

Grounding of the transmission line system is of next importance. Improper or insufficient grounding may mean failure in the performance of the transmission line system in eliminating noise. This ground wire should be as short as possible. Any piece of pipe is not necessarily a good ground, neither are soil pipes found on the tops of large buildings and apartment houses. Metallic water drains (many times dry) and steel structures are also not good grounds. A water pipe is the best type of ground which can be obtained. Grounding at both the receiver and antenna ends has often been found to be extremely important in eliminating noise interference, especially in metropolitan areas. In very extreme cases where the noise interference is particularly violent, and where the shielded transmission lead-in cable is several hundred feet long, it may be found necessary to ground the sheath of the transmission line cable at several points. When more than 100 feet of transmission cable are used, it is good practice to ground the cable every 100 feet. Although the grounding is very important, no definite procedure and recommendation in grounding can be given on account of inconsistent results obtained due to length of ground leads, resistance of grounds and types of grounds. The type of grounding employed on one installation may or may not be correct for another installation in a different location. When having difficulty with noise interference it is

Fig. 11.



highly recommended that experimentation be made with different grounding systems until the source of noise interference is eliminated.

In conclusion, the importance in reducing man-made static is shown by the great number of transmission line kits which have recently been brought on the radio market.

The logical place to eliminate man-made static is at the source of interference, but this is such a costly and difficult procedure, especially in these times, that radio manufacturers have been forced to solve this problem independently.

However, manufacturers of electrical appliances and power companies have coordinated with the radio manufacturers for the past few years in combatting noise interference in radio reception. The Joint Coordination Committee on Radio Reception of the National Electric Light Association, the National Electric Manufacturers' Association, and the Radio Manufacturers' Association are meeting four times a year on this one subject of noise elimination.

Until such time as these noises are reduced at the source the antenna transmission line system is one answer to the reduction of man-made static, and more enjoyable radio entertainment with freedom of interference.

▲ ▲ ▲

Book Review

THE RADIO CONSTRUCTION LIBRARY. 1932 EDITION. By James A. Moyer and John F. Wostrel. Published by McGraw-Hill Book Co., Inc., New York City. Price $7.50. (1,087 pp.; 605 Illustrations; Cloth.)

The Radio Construction Library is composed of three well known books on practical radio that have in the past years become popular with students and service men as study and reference guides for the understanding of radio fundamentals.

The revised printing maintains the same treatment employed in the preceding editions with some added material including the more important developments in electronics and television which have resulted during the past few years. Although written to have a general appeal among persons engaged in the radio industry, the Library appears to be of most practical value to student experimenters and radiotricians. Engineering mathematics have been omitted in the explanation of radio principles; however, the clarity of operating procedures of various equipment is well treated, and although somewhat concise and superficial at points, is consistent with the purpose of the works.

All of the three volumes are generously illustrated with drawings and schematics as an aid in elucidating the text. There occurs in the first two volumes a noticeable repetition of subject material which it appears could have been restricted to one book alone. Each text may be considered as an independent work, the study being arranged in order of progressive sequence with each of the three different topics of study constituting the Library.

Volume 1 on *Practical Radio* is a text of the underlying fundamentals applied to radio communication in general. As the initial volume of the group, this book is more or less elemental in treatment, considering the "skeleton framework" of receiving and transmitting apparatus.

The second volume is entitled *Practical Radio Construction and Repairing*, and herein the authors delve into the more important idiosyncrasies of radio receiving apparatus. Information is given about the components constituting various receiving circuits and the common methods of procedure followed in "trouble shooting." The last chapter is devoted to television, wherein a simple receiver is explained with regards to its construction and operation.

Radio Receiving Tubes comprises the subject of treatment for the third book of the series in which volume an interesting study of the operation of thermionic-electronic vacuum tubes is outlined. The introductory chapter, reviewing the development of the vacuum tube, presents an especially appropriate opening for the ensuing chapters which are particularly well prepared to render this entire reading decidedly instructive and easily conceivable. The last chapter, considering the various industrial applications of vacuum tubes, is an effort to present to the reader a conspectus of the universal applicability of the modern Aladdin lamp and the accomplishments it has brought to mankind. Doubtlessly more applications have been omitted than included; however, when we consider the innumerable roles to which the vacuum tube has been applied it becomes readily apparent that such a treatment, in order to be thorough, would easily constitute another volume. Hence we feel that the authors' treatment is in consistence with the purpose of their book. Thus, this chapter might be considered as a collateral appendix to the text in general.——*Reviewed by Louis F. B. Carini.*

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Vol. 10 MARCH, 1933 No. 3

Recent developments in cathode ray tubes and associated apparatus†

By Allen B. DuMont

THE past year has seen a growing interest on the part of engineers in the use of cathode ray tubes for all types of analytical measurements and also for numerous industrial applications. In order to make the cathode ray tube generally more useful it was felt that the life could be considerably improved as well as the uniformity of the tubes. Furthermore any increase in the brilliancy of the spot obtained would facilitate their use in a number of applications. The use of these tubes commercially calls for a tube which is rugged mechanically and which can be operated from equipment which is reasonably foolproof as to adjustment. In this paper it is proposed to discuss the essential characteristics of the cathode ray tubes as well as the essential equipment necessary to operate them.

Tube Characteristics

The requirements of tubes used for oscillograph and allied work may be summarized as follows:

1. They should reproduce with fidelity the observed wave.
2. The threshold effect should be at a minimum.
3. They should give a brilliant spot on the fluorescent screen.
4. The spot should be regular in shape over the entire screen.
5. It should be possible to focus the spot to any desired size.
6. Maximum sensitivity is desirable.
7. There should be a minimum current across the deflection plates.
8. The trace should not blur at high frequencies.

Although special uses may call for more attention to one or more of the preceding requirements if these are met a satisfactory tube for general use will be obtained. Before going into detail on these various points it might be well to mention that experience has shown that a number of screen sizes were necessary. Fig. 1 shows cathode ray tubes having 2, 3, 5, 7, and 9 inch screens. In order to simplify classification of these various tubes it was decided to designate each tube by a two-number combination the first number representing the diameter of the fluorescent screen and the second numeral the number of deflection plates in the tube. Hence a tube with a 3-inch screen and four deflection plates is known as a type 34 tube and one with a 9-inch screen and no deflection plates is given the type number 90.

Fidelity of Observed Wave

In order to obtain fidelity in the observed wave the deflection plates of each pair should be parallel to each other and the same size. Each pair of deflection plates should be at right angles to one another. The leads supporting the deflection plates should be so positioned that they do not exert any appreciable deflection on the beam. The distance between each pair of deflection plates should be calculated so that the sensitivity is the same along the X and Y axis. This can be obtained by the use of the following formula:

$$h = \frac{ElL}{2E_a d}$$

where

h = Deflection in cm.

E = Volts difference between the deflection plates.

E_a = Accelerating electrode volts.

l = Length of deflection plates in cm.

d = Distance between deflection plates in cm.

L = Length from center of deflection plates to screen in cm.

Hence by having a slightly greater separation between the lower deflection plates than the upper plates the same sensitivity can be obtained along both axes. It is also important that the

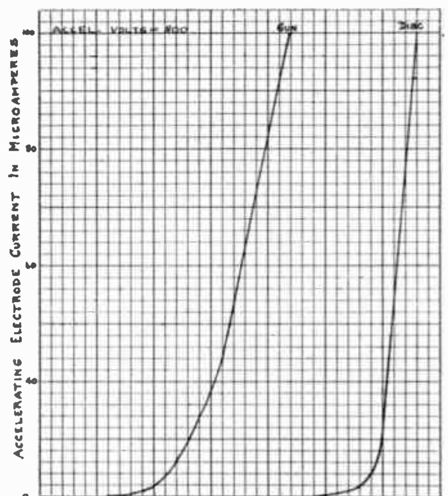


Fig. 3. Focusing electrode bias.

†*Presented before the Radio Club of America, January 18, 1933.*

screen be smooth and have the same radius of curvature as that of a sphere having its center at the top of the accelerating electrode. In designing the mount which would accomplish the desired results a number of tests showed that by using a suitable mounting jig and assemblying all the elements from a common press greater accuracy could be obtained than by taking the connections out separately from the side of the envelope. In the first case after the mount was assembled it could be sealed in without disturbing the elements while in the second case too much responsibility is put upon the glass blower to line up the various elements. Fig. 2 shows tubes with a three and a nine inch screen using this design.

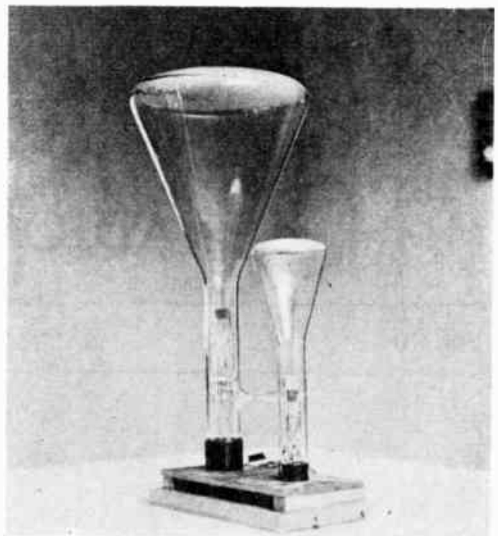


Fig. 2.

Brilliance of Spot

The brilliance of the spot is determined by a number of factors. Among these are the chemical composition and particle size of the fluorescent screen used. Willemite and calcium tungstate are the two most commonly used salts. The former gives a green color which is probably the best for visual work while the calcium tungstate gives a blue color which is better for photographic work. By using a screen composed of a mixture of these two salts a very satisfactory screen can be obtained which is good for both visual and photographic work. At low accelerating electrode potentials the screen gives a light green color which changes to a white as the accelerating electrode voltage is increased. With the developments in films the importance of the special screen for photographic work is considerably reduced and we have found that by using verichrome film better results can be obtained using a combination screen, than when using calcium tungstate and the older type films which were quite sensitive in the ultra-violet region but not so sensitive to the longer wavelengths. Generally speaking, the larger the particle size of the salt the more brilliant the spot but, of course, a balance has to be worked out between brilliance and the permissible coarseness or texture of the screen. Some other salts tried with some success are calcium fluoride, phosphorescent calcium sulphate and phosphorescent calcium tungstate. In connection with a particular application calling for the development of a time delay salt we have been able to work out a screen which gives a white spot of from two to three times the brilliancy of any of the screens mentioned. This particular screen is satisfactory for any of the present uses and in addition will retain the trace for as long as one minute and a half after all voltages have been removed when used in a darkened hood or room. However, the spot is so intense that the phosphorescence does not bother the tube when used for any oscillograph application. The phosphorescence itself is bright enough to be readily seen. Another important factor effecting briliancy is the design of the accelerating electrode. One of the simplest and most effective accelerating electrodes is a disc with a hole in the center placed between the focusing electrode and the bottom set of deflection plates at right angles to the direction of the beam. If the hole is sufficiently large practically the entire beam passes through it and a sharp, well defined spot of excellent brilliancy can be obtained. An accelerating electrode consisting of a cap with a small diameter gun attached to it has proven useful when an extremely fine trace is desired. This construction, however, does not allow all the electrons in the beam to pass through it, a number being masked off by the cap. The first construction mentioned normally has a current to the accelerating electrode of approximately 30 microamperes, while the last mentioned construction has a current of about 50 microamperes to give the

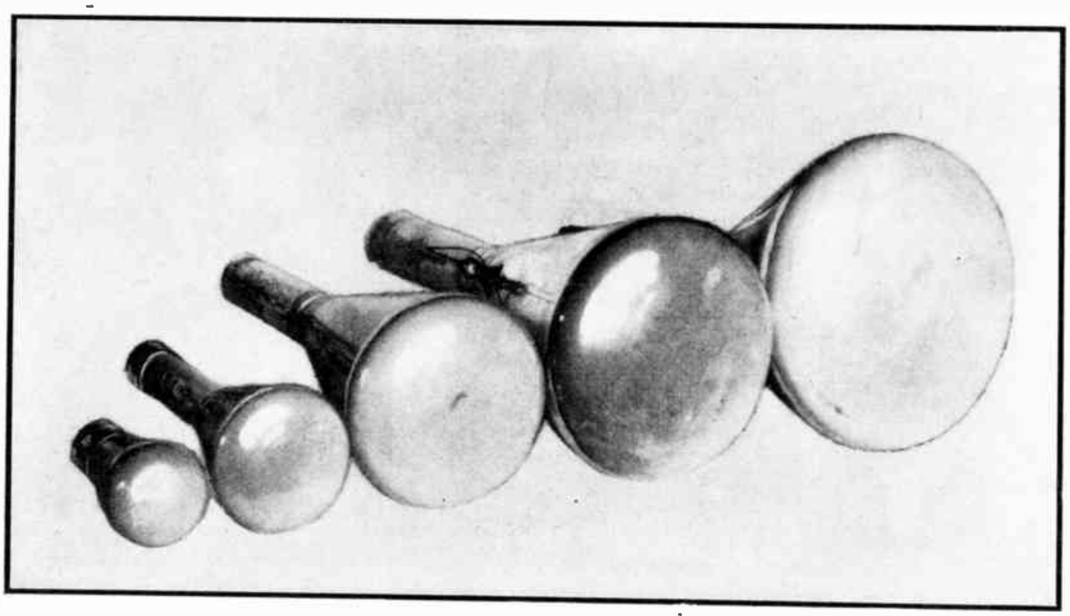


Fig. 1.

same brilliancy. The characteristic curve of accelerating electrode current versus focusing electrode bias for the two constructions mentioned is shown in Fig. 3. These curves were taken on a type 34 tube with an accelerating voltage of 800. The amount of air or gas in a cathode ray tube also has much to do with the intensity of the spot. Tubes with a considerable amount of gas give a poorly defined spot and low brilliance. The factors discussed assume that the accelerating electrode voltage was the same in all cases. As this is increased the intensity increases approximately proportionally to the square of the accelerating voltage, since the fluorescent action depends upon the velocity of impact of the electrons onto the fluorescent screen.

Focus

The design of the filament, the shape of the focusing electrode and the pressure inside the envelope are the main points to be considered in connection with focusing the beam of electrons to a point. The spot obtained is the same shape as that of the coated or active part of the filament. The three elements of the cathode ray tube, namely, the filament, focusing electrode and accelerating electrode concerned with the generation, focusing and acceleration of the electrons combine to act in a manner quite similar to that of a pin-hole camera. Hence it is possible to obtain a round spot, a square spot or a spot of any shape depending upon the design of the filament. With reference to the filament the ideal condition is to use a point source of electrons although it is possible to use a large area filament or cathode and concentrate or mask off a portion of the beam to obtain a fine spot. For oscillograph work the focusing electrode is usually in the form of a cylinder surrounding the filament. Fig. 4 shows how the beam may be concentrated by increasing the bias on this electrode. Fig. 5 is a curve on a type 34 tube which shows the bias necessary to obtain a sharp spot at various accelerating electrode voltages. The function of gas in the tube is twofold. It provides a path for the charge to leak off the fluorescent screen and it also causes the beam to converge as it approaches the screen. Fig. 6 shows this effect. Fig. 7 shows the beam spread out by the application of an a-c. voltage to the lower set of deflection plates. While on the subject of focusing it might be worthwhile to mention a few things which can affect the sharpness of the spot in ordinary operation.

1. Filament current too high causes halo around spot.
2. Insufficient bias to focusing electrode causes halo around spot.
3. Filament current too low causes large weak spot.
4. Too high a bias on focusing electrode causes large weak spot.
5. A-C. ripple in accelerating electrode voltage supply causes radial line instead of spot as beam is moved from normal center position.
6. Unshielded stray fields cause distortion of spot.

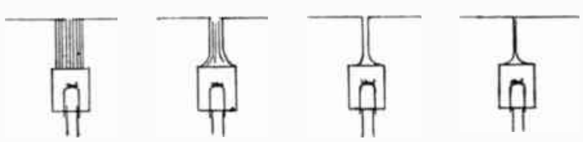


Fig. 4.

Effect of Gas

Although a certain amount of gas is useful as previously explained, if the pressure exceeds a few microns certain undesirable characteristics come into play. Too high a gas pressure increases the current across the deflection plates. It also limits the frequency at which the tube can be operated. In practice it has been found possible by careful regulation of gas pressure to extend the upper limit of frequency to well over 4 megacycles without having the trace become blurred due to the lateral speed of the beam moving faster than does the ionized gas. Another effect of too high gas pressure is the increase to objectionable proportions of the so-called "threshold effect." That is, the deflection produced by small voltages applied to the deflection plates is not at as great a rate as when higher voltages are applied. Fig. 8 shows the current across the deflection plates versus the deflecting potential, and Fig. 9 shows the curve of beam deflection versus the deflecting potentials. These were taken on a type 34 tube operating with 800 volts on the accelerating electrode.

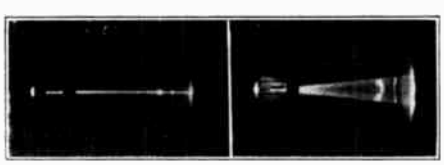


Fig. 6. Function of gas.

Fig. 7. Beam spread cut by application of voltage to lower plates.

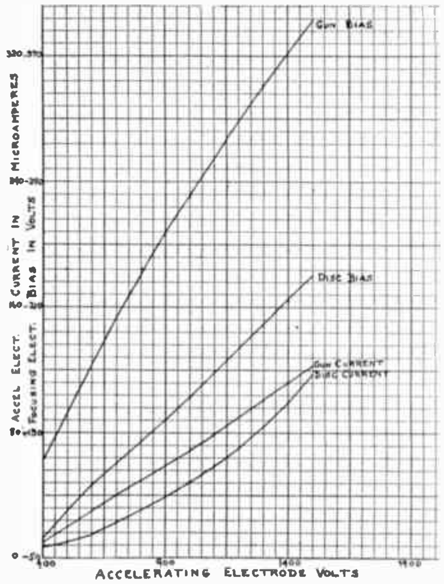


Fig. 5. Curve of type 34 tube, showing bias necessary to obtain a sharp spot at various accelerating electrode voltages.

General

The life of cathode ray tubes has been somewhat of a problem although a large number of tests to determine just what factors determine life have shown that it is entirely practical to design and build these tubes so that consistent and satisfactory life can be obtained when they are operated in suitable equipment. The two major problems have been deterioration of the filament coating by bombardment, and a gradual change in pressure in the tube either caused by the clean-up action of the high voltage or by the liberation of gas from the elements of the tube. The first problem can be eliminated by correct design of the electrodes to reduce positive ion bombardment to a minimum and at the same time use a coating which mechanically withstands this bombardment. The second problem has also been solved by the application of proven vacuum tube exhaust technique.

Because of the wide and dissimilar applications of the cathode ray tube it was soon apparent that no one tube would answer all requirements. To date four different screen sizes have been standardized, namely tubes with 2, 3, 5 and 9 inch screens. The 2 inch screen type is useful for moving film recording where only one set of deflection plates is used, and a number of these can also be used in certain applications to do similar work to the multi-string oscillograph. The three inch screen size type 34, is an economical tube suitable for factory measurements, industrial applications and general laboratory work. The intensity at a given accelerating voltage is somewhat better than the 5 or 9 inch types and because of this, with a given intensity of spot the sensitivity, is approximately the same as with the larger screen types. The larger screen types of necessity must have a longer L value and the slowing up of the beam in the additional distance from the accelerating electrode to the screen accounts for this.

The 5 inch type is mainly used for laboratory determinations where a larger trace is necessary. Certain applications where the tube is used for time interval determinations also require a larger trace. The 9 inch tube has its main use for demonstration purposes although several applications require its exceptionally large screen.

All of the types mentioned can be operated interchangeably from a standard power supply and the prongs of the base fit into a standard six prong socket. The filaments of all tubes consume 1.3 amperes at .6 volt, and heat up in three seconds.

Associated Equipment

In order to realize the full possibilities of the cathode ray tube when used for oscillograph work, it is necessary to provide a power supply which will supply all the required voltages and which is easily adjustable to accommodate the tube to the optimum conditions under test. Although for many applications this is all that is required, a sweep circuit to provide a linear time axis is extremely useful for the accurate study of waveforms and other periodic phenomena. Fig. 10 shows a complete power supply and sweep circuit unit. The power supply being contained in the case nearest the shielded cathode ray tube holder, the sweep circuit contained in the other case.

In Fig. 11 is shown the diagram for the power supply unit. Provision is made for adjusting and checking the filament current. The voltage to the focusing electrode is continuously variable to control the size of the spot, and the voltage to the accelerating electrode is also continuously variable to control the brilliance of the spot. However, when using voltages on the accelerating electrode, over 1,500, this arrangement is not very practical, and separate rectifiers supply the voltages to the focusing and accelerating electrodes.

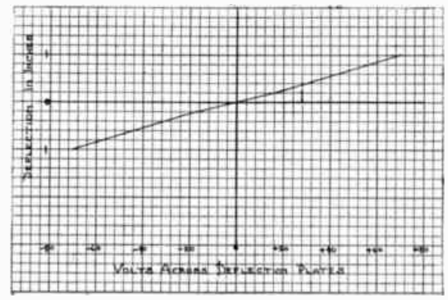


Fig. 9. Beam deflection versus deflection potentials.

The sweep circuit as shown in Fig. 12 provides a linear time axis which may be made to sweep from one to 5,000 cycles per second. The power supply contained in this unit furnishes all the necessary voltages for the sweep circuit except the bias voltage of the mercury vapor discharge tube which is obtained from a standard 4½ volt C battery. The linear sweep frequency is obtained by charging a condenser through a constant-current device. The actual device used is a screen-grid tube operated with the plate voltage well above the screen voltage so that the plate volts versus plate current curve is practically flat over the working region. This arrangement secures not only ease of control (varying grid bias) but also comparative freedom from line voltage variation. The "quick return" discharge is obtained by means of a mercury vapor discharge tube. The use of this tube permits controllable amplitude and ideal synchronization. The unit has the following controls:

1. Position control. A potentiometer arrangement enables the figure to be centered on the screen and moved to any desired position.

2. Amplitude control. The mercury vapor discharge tube flashes at an anode voltage determined by the bias on the grid of this tube. This control varies the grid bias.

3. Frequency control. A fine, and a rough frequency control are provided. The rough control selects one of five condensers for the plate circuit of the screen-grid tube. The fine adjustment is obtained by varying the bias of the screen-grid tube.

4. Synchronization control. A suitable portion of the voltage of the wave under investigation is fed to the grid of the mercury vapor discharge tube by means of a variable resistance, causing the tube to trip in step with the frequency of the wave under investigation. When this voltage is strictly recurrent a locked or stationary picture is obtained. This control can also be used for tripping a single traverse to record transient phenomena.

It is possible to combine these two units and obtain both the voltage for the cathode ray tube and sweep circuit from one common power supply. However, in this case it is not practical to use as high voltages on the cathode ray tube as with the separate units. Fig. 13 shows one of these combination units. Its main value lies in its portability and it is very satisfactory for all types of visual observations, the limited accelerating voltage, however, somewhat restricts its use for high speed photographic recording.

Classification of Applications of the Cathode Ray Tube

The applications of the cathode ray tube may be roughly grouped into three classifications.

1. Applications requiring a time base.
2. Applications not requiring a time base.
3. Applications requiring some independent base other than time.

The applications requiring a time base comprise the general study of waveform. Across one pair of plates is placed a time base potential. This is such as to cause the spot to move forward and backward over a straight line in a known manner. Across the

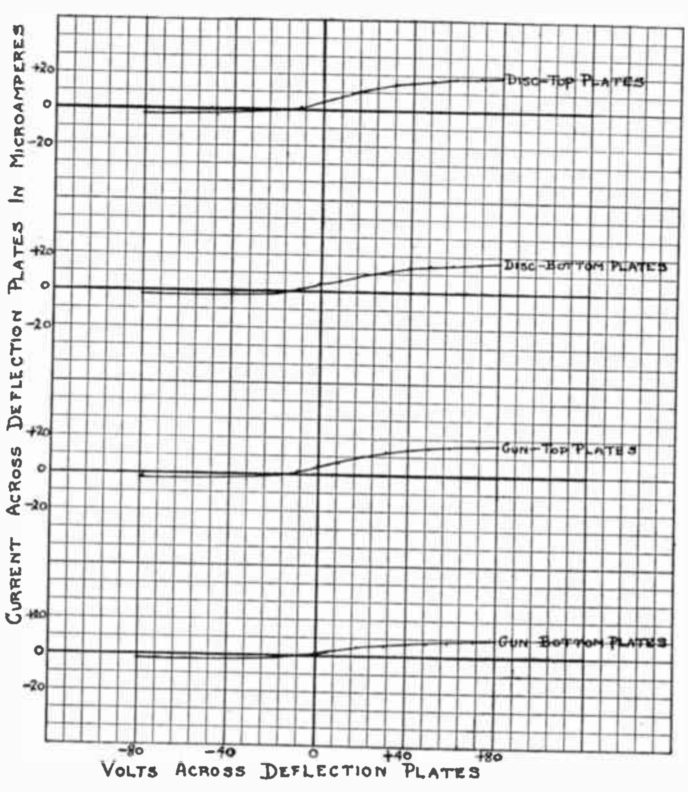


Fig. 8. Current across deflection plates versus deflecting potential.

other pair of plates the voltage under investigation is applied. For some purposes a convenient time base is provided by the 60-cycle mains, but more generally the time base makes its excursion at a uniform speed and then restores rapidly. The apparatus described provides this type of a time base.

When the time base is linear the picture or figure that appears is the wave shape of the voltage examined. With a non-linear time base the wave shape is distorted, but if only the middle portion of a sinusoidal time base is used, this distortion is not particularly bad. The method of investigation of wave shape against a time base applies equally to transient as well as periodic phenomena.

Some periodic phenomena which may be studied are:

Waveform studies on alternators, transformers, ripple on d-c. supplies (generators and rectifiers).

Waveform studies of tube oscillators and amplifiers.

Measurement of percentage modulation.

The transient phenomena possible to study include:

Making and breaking of circuits, current and voltage waveforms.

Study of electric sparks.

Static or local interference.

Physiological phenomena such as heart beats or nerve response.

Measurement of explosive and acoustical pressures.

A hybrid case lying between the two groups is the study of the waveform of speech and music and also the case where the voltage takes the form of modulated r-f. In the latter case if the time base is set for observing the lower frequencies the r-f. waveform will be so congested as to give the appearance of a solid figure. The fine structure of this, however, can be seen by speeding up the time base.

Use of Time Delay Screen

With the new time delay screen it is also possible to readily measure time intervals without the use of a moving film camera. A suitable timing pulse is put across one pair of plates and the focusing voltage biased so no spot is seen. The device or wave to be measured is then connected so that at each impulse the focus bias is decreased so that the spot shows and remains on the screen for about one minute. Hence, the distance between the spots can be measured and the time between pulses determined. In some cases it is desired to measure the time at which certain waves reach given devices and the shape of the wave identified. In this case the voltage of the wave is placed across the other set of deflection plates and the

Fig. 11. Diagram of power supply.

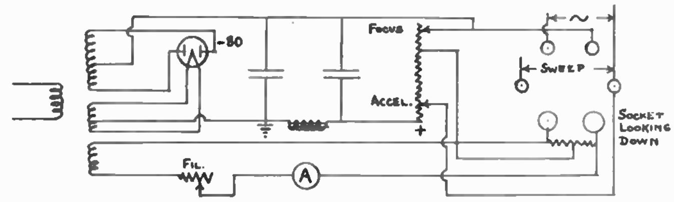
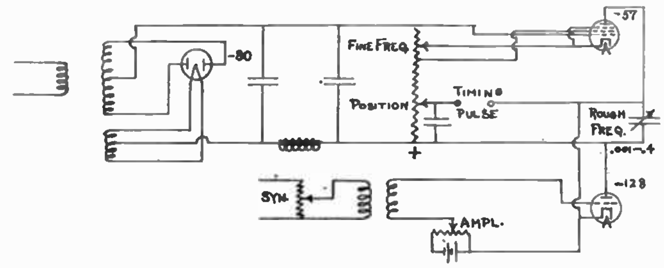


Fig. 12. Diagram of sweep circuit.



time interval is determined in the same manner as previously.

Another use of the time delay screen is for comparison of given figures. It is possible to put one figure on the screen and then another one over it or in any desired position. With ordinary fluorescent screens it is impossible to see the wave shape of phenomena occuring at rates below approximately one-sixteenth of a second. The time delay screen allows heart beats to be visualized as well as starting curves of motors, etc. In the study of high-speed transient phenomena the present practice is to photograph the transient, as the eye is not able to retain an impression long enough to arrive at conclusions. The time delay screen permits these to be readily observed.

Applications Not Requiring a Time Base

The applications not requiring a time base include the investigation of current and/or voltage relationships in electrical circuits, wherein both pairs of plates derive their deflecting voltages from the circuit itself. Some examples are:

Observation of tube characteristics either static, dynamic or oscillating.

Comparison of input and output of amplifiers and transformers.

Studies of phase relationship.

Properties of dielectric and magnetic materials.

Radio direction finding.

Frequency comparisons.

Studies of modulation and detection including maintenance and fault-finding on radio transmitters.

Monitoring on radio broadcasting, talking motion picture and phonograph recording.

Voltmeter with extraordinary h-f. range.

Fig. 10. Power supply and sweep circuit unit.

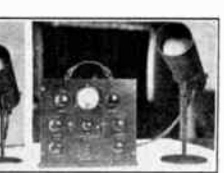


Fig. 13. Combination, portable set.

Applications Requiring Some Independent Time Base

Certain applications arise in which a base deflection is required which is not provided by the circuit under investigation and is not a simple time base. Such cases arise whenever it is necessary to graph an electrical quantity against a variable, other than time, and which is not directly obtainable from the circuit itself. The most important variable is frequency. For example, it might be required to make the oscillograph show the frequency response curve of, say, a band-pass filter. We would need first an oscillator of variable frequency and constant output, or at any rate we would need to know the output as a function of the frequency. The output from the filter would be applied to one pair of plates. To the other pair we would have to apply a voltage representing frequency to some known scale; a matter which could be arranged either mechanically or electrically.

Photographic Recording

The methods commonly used to record waves or figures drawn by the cathode ray tube may be classified into two general classes. The first method is to use an ordinary camera, focus it on the screen of the tube and expose the film. The time of exposure depends upon the brilliance of the trace, the size of the figure and the rate of movement of the spot. This method is satisfactory for stationary figures or for recurring phenomena. Fig. 14-A is a photograph taken showing an a-c. wave across one set of deflection plates. Fig. 14-B shows the trace caused by an a-c. voltage on each set of plates, the voltages being out of phase. Fig. 14-C is the same but with a greater phase difference between the two voltages. These were taken with a standard

Graflex camera using Verichrome film. An exposure of one half second was used with the accelerating electrode voltage only 500 volts. Fig. 15-A shows an a-c. wave as traced using the linear sweep circuit and the synchronization adjustment. Fig. 15-B shows the same wave through a cheap transformer. These were also time exposures of the same length of time. By increasing the voltage to the accelerating electrode it is possible to photograph in considerably less time. For instance, with 2,000 volts on this electrode successful photographs were taken in one thirtieth of a second with an F11 opening of 16 cycles of a 1,000 wave covering an area on the screen approximately 2½ square inches.

The second method for photographic recording is mainly used for non-recurring phenomena. The wave is applied across one set of deflection plates and the spot is focused onto a moving film which supplies the time axis.

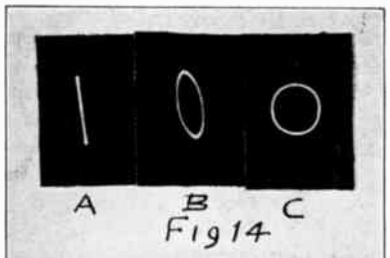


Fig. 14.
A. A-C. wave across one set of deflecting plates.
B. Trace of a-c. voltage on each set of plates.
C. Same as 14B, but with greater phase difference between the two voltages.

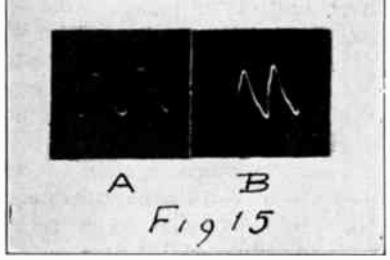
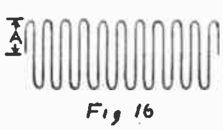
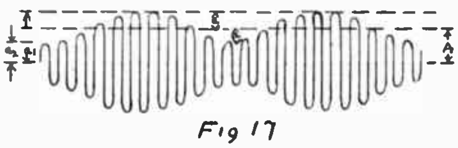
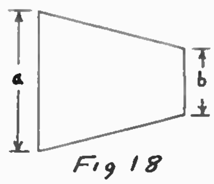


Fig. 15.
A. A-C. wave using linear sweep circuit and synchronization adjustment.
B. Same as 15A, but through a cheap transformer.







Figs. 16, 17 and 18.

Some Present and Future Applications Checking Percentage Modulation

The cathode ray tube lends itself very nicely to modulation studies and the determination of the percentage modulation of a transmitter. This determination may either be made with or without a sweep circuit. In the first case a constant amplitude and frequency signal is used to modulate the transmitter. The sweep circuit is then adjusted so that the modulated r-f. wave applied across one set of plates is stationary, and synchronized on the screen of the tube. Percentage modulation is the ratio, expressed in per cent, of the amplitude of a sinusoidal modulating signal wave to the amplitude of the carrier wave. This is illustrated in the following figures. Fig. 16 shows the unmodulated radio-frequency carrier wave, having an amplitude of A. Fig. 17 shows the same carrier wave, modulated at audio-frequency which results in a maximum amplitude of a_1 and a minimum amplitude of a_2. The percentage modulation is then

$$\frac{a_1 - a_2}{2A} \times 100.$$

This is equivalent to considering the envelope as an alternating current having an amplitude of (a) superposed on the carrier of amplitude A, as shown in Fig. 17. The per cent modulation is then

$$\frac{a}{A} \times 100.$$

The modulation becomes 100 per cent when the amplitude a_2 becomes zero, that is when the amplitude of the audio-frequency wave (a) becomes equal to that of the carrier A.

The second method which does not use a sweep circuit has one disadvantage in that any phase shifting makes determinations rather difficult. In this method the modulating voltage (a-f.) is put on one pair of plates, and the modulated r-f. across the other pair; then, provided no phase shift occurs, the resulting figure should be a solid trapezium; at least the sloping sides of this figure should be linear so long as the modulation is linear. Fig. 18 shows the shape of the figure. Where

$$\text{Percentage modulation} = \frac{a - b}{a + b} \times 100.$$

With undistorted, complete modulation, the resulting figure is an isosceles triangle. Any distortion of the modulating wave which occurs between the grid of the modulator tube and the antenna output will be indicated by the converging boundary lines of the pattern.

With the standard cathode ray tube it is somewhat difficult to check accurately the percentage modulation during regular programs unless photographs are taken. However, with the time delay screen patterns may be studied by using a quick acting switch to sample the trace.

Cathautograph

The cathautograph is an interesting and useful application of the cathode ray tube for the transmission of intelligence either in printed or written form. The electron beam is controlled by a suitable transmitting apparatus which causes the spot to move in any desired direction for any desired dis-

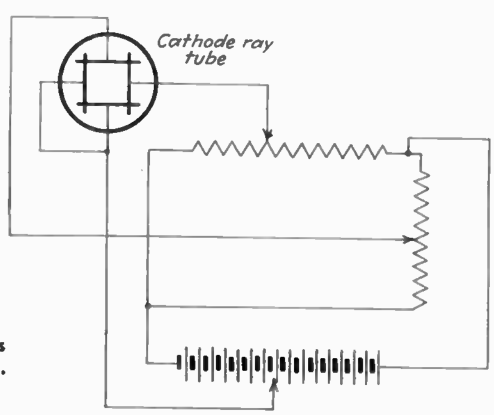


Fig. 19. Connections of the cathautograph.

tance on the screen. If a standard cathode ray screen were used the operation of the transmitting apparatus would cause the spot to move around but it would be impossible to tell what was being written. However, with the special screen previously mentioned which, instead of having a decay period of a fractional part of a second, has a decay period of around a minute, a line can be drawn the same as with a pencil. At present some ten words can be seen on the fluorescent screen of the cathode ray tube at one time. As the eleventh word is being written the first word has faded out.

The transmitting system consists of a pencil or stylus which is connected with two resistances so that as the pencil is moved a voltage is picked off the resistances which is proportional to the movement of the pencil. The receiver consists of a standard cathode ray tube with two pairs of deflection plates having the time delay screen. Fig. 19 shows the connections used and Fig. 20 is a sample of the writing as it appeared on the screen of a 3-inch tube. A suitable shielded stand or holder supports the tube. The voltage picked off one resistance is applied across one pair of plates and the voltage picked off the other resistance is applied across the second pair of deflection plates.

Provision has been made so that when the pencil of the transmitter is brought into writing position the receiver at the distant station is set into operation, which requires less than two seconds. A buzzer signal is also operated at the distant station. Provision has been made so that when the pencil is lifted from the paper the spot is turned off eliminating traces between the words. The complete apparatus is shown in Fig. 21.

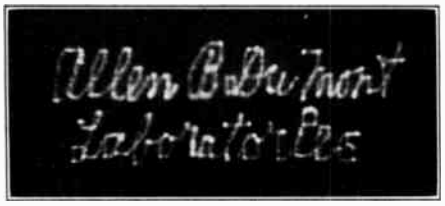


Fig. 20. Specimen of cathautograph writing.

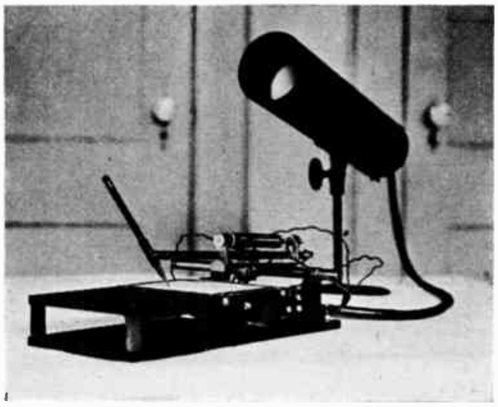


Fig. 21. Cathautograph. Complete apparatus.

The cathautograph may be operated over radio circuits by modulating two separate tones on a single carrier. At the receiver each tone is rectified and used to operate a set of deflection plates.

Some of the applications which suggest themselves are communications between airplanes and ground stations, communication between small vessels at sea (not carrying a licensed operator) and land stations, office intercommunication, and communication between distant offices, communication between police department and radio equipped cars, noiseless instructions to broadcast artists, Chinese or Japanese communication circuits and also for advertising displays.

Depth Measurements

By rotating the beam in a circle at a known rate and sending out an impulse at a predetermined time the echo can be made to appear as either a spot or a radial line along the circumference of the circle. A suitable scale will indicate the depth. Using cathode ray tubes for this purpose it is economical to place repeaters at any desired point in the ship. Due to the fact that there is no inertia to the system it is also possible to use these tubes to detect extremely small differences in time such as might be useful in a radio altimeter, etc.

Radio Compass

For a long time the use of the cathode ray tube for this purpose has been experimented with. One suggested method was to use two large fixed loops at right angles to each other and feed the voltage from each loop to a set of deflection plates. Hence, if the common deflection plate lead was periodically interrupted a line would be drawn on the screen of the tube pointing directly toward the sending station. So far, because of the extreme sensitivity of the cathode ray tube which is required, no great success has been obtained. However, if the signal from the loops is amplified and then fed into the tube, the problem is simplified, providing the apparatus is so designed that each amplifier gives exactly the same overall gain. Recent developments along this line appear to be practical and there is a good possibility that the tube may become a valuable aid in this field. The advantage over the present radio compass would be that it could be left on continuously and would constantly indicate the location of the sending station. Furthermore the device would indicate a group of stations when they were within range, each being distinguished by its respective time interval.

Book Review

"RADIO SERVICING COURSE." By Alfred A. Ghirardi and Bertram M. Freed. Published by the Radio Technical Publishing Co., New York City, 1932. *Price* $1.50. (192 *pp.*—121 *illustrations—cloth*).

THIS text has been prepared primarily to provide the reader with a general explanation of the fundamentals of routine practice employed in radio servicing. It is co-authored by the author of the *Radio Physics Course* and embodies many of the instructive features employed in that volume; for which reason the text may be easily digested by the novice.

The entire problem has been presented in a logical manner; the authors first considering the basic principles of this profession and progressing by order of related sequence to an explanation of the purpose and application of servicing equipment. The contents are arranged so that this book may serve as a text for individual or group study. With the terminative study of each chapter, the student may test his assimilation of each section by answering review questions chosen to cover the most important problems of his study.

Each chapter considers practical topics for discussion, each type of equipment under study being presented with a concise explanation of its principle of operation, application, and value to the radiotrician in his work. The treatment is semi-technical and no use is made of mathematics, save in the explanation of simple formulae. Circuit diagrams have been rendered useful by including the electrical constants of each component constituting the unit. This provides the reader with full details on the construction of numerous aides such as analyzers, oscillators, tube checkers, etc. A liberal use of photographic illustrations also assists in the elucidation of the accompanying text.

The *"Course"* consists of nine chapters; the first of which is introductory, serving as a preface in presenting the following study. Chapter two reviews the principle of operation and expounds the construction of useful electrical measuring instruments employed in circuit testing. In the third chapter a further discussion of simple testing aids and procedures are outlined with a view of their practical use in actual service work. The use of the set analyzer is explained in the succeeding chapter wherein a brief description is also given of popular commercial set testers. Constructional data is included for the making of several practical analyzers for the benefit of those interested in building their own equipment.

"Trouble shooting the receiver" is the title of the fifth chapter outlining the preliminary procedures of radio servicing with practical interpretation of common troubles; their general symptoms, analyzation and elimination. The value of the test oscillator in aligning and neutralizing receivers is next dealt with. Following in order, the subject of interference and noise elimination is discussed as well as the purpose for and use of the tube checker. The last chapter is devoted to varied useful data of value to the prospective radiotrician.

The *"Course"* will prove to be a valuable guide for those contemplating entering the radio service profession.—*Reviewed by Louis F. B. Carini.*

FORUM

THE development of any art, such as radio communication, may be divided into three periods. During the early years, the workers in the new art are busy discovering what the problems are and in getting them clearly stated. Then comes the period during which several solutions for each of the problems are brought forward. The final period is devoted to finding out which of the many solutions is best.

The radio art is 35 years old, and broadcasting is over 12 years old. A great many problems have been solved in a great many ways, and some of the early solutions have already been discarded. But there are, even today, a good many questions which have not been answered. There are many choices still to be made, many solutions to be examined and approved or discarded, and there is the question as to whether even the best solution of any one of the problems, is adequate.

The Radio Club of America includes in its membership many of the oldest and ablest workers in the radio field. Many of these men have worked through all the years of development and research that have brought the radio mechanism to its present state. They bring to its problems a point of view born of experience.

But among the younger members there is the vision of new problems to be solved, and the determination to find better answers for the old problems. They view each new task in the light of the latest technical advances in mathematical analysis and laboratory investigation.

The Forum is a place where these men meet for discussion and an adequate exchange of ideas and opinion. Each month, a question, not yet definitely settled, is proposed and analyzed, and although no record is kept, each participant leaves with one problem much clearer in his mind than it was before. There is no attempt to settle a question, and no vote is taken. The only rule is that each man must confine himself to the question being discussed.

Come to the meetings, listen to the paper, and then participate in the Forum. If there is a particular problem on which you would like to have the ideas and opinions of other radio men, send the question in.

R. H. LANGLEY, Chairman,
Forum Committee.

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Vol. 10 APRIL, 1933 No. 4

The emission valve modulator for superheterodyne receivers†

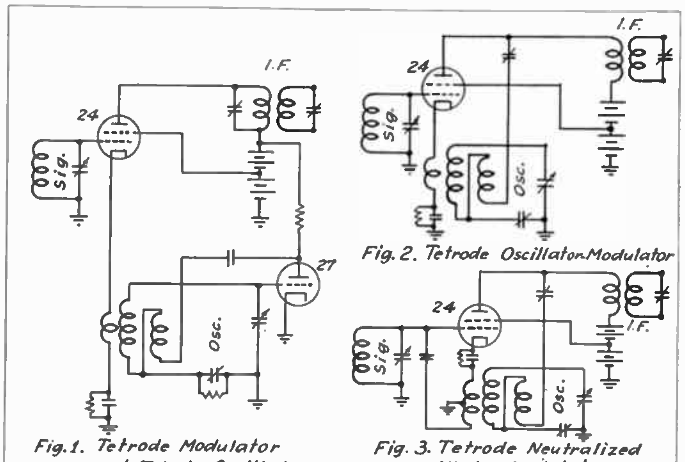
By Harold A. Wheeler*

WITHIN the past three years a great deal of attention has been paid to the special problems of the superheterodyne receiver, partly with a view to improving the performance and partly with a view to decreasing the number of tubes required. Many attempts were made to combine the oscillator and the modulator (or first detector) in one tube. There was no fundamental reason why this could not be done, but it was found to be difficult. Even when two separate tubes were used, the modulator conversion gain was much lower than the gain of an amplifier stage using the same type of tube. By conversion gain is meant the gain from the signal-frequency input to the intermediate-frequency output of the modulator stage, measured from grid to grid. The conversion gain was especially low when gradual-cutoff tubes came to be used as modulators to permit the use of a grid bias for controlling the conversion gain. These tubes were given a gradual cutoff of plate current with increasing grid bias, whereas a sharp cutoff is beneficial when high gain is desired in a modulator.

As a result of a large number of experiments, a number of circuits have been developed, which use only one tube to perform both functions of oscillator and modulator. Some of these circuits have been extensively used in commercial broadcast receivers. The problem was attacked from two points of view. First, circuits were devised which made the best use of tubes then commercially available, such as the type 24 tetrode, and the types 57 and 58 pentodes. Secondly, a special hexode tube has been developed which is giving even better performance as oscillator-modulator than the two tubes previously employed for the purpose. The new hexode is called an emission valve modulator, by way of describing the mechanism of modulation in this tube.

All of the circuits to be described are, in some respects, similar to the separate oscillator and modulator circuits shown in Fig. 1. At the time this work was started, a type 24 tetrode was commonly used as modulator and a type 27 triode as oscillator. The former is well adapted for the function of modulator, because it has a fairly sharp cutoff. The presence of the screen makes the tube capable of giving fairly high conversion gain. The triode is a satisfactory oscillator.

In the circuit of Fig. 1 the oscillator voltage is applied to the cathode of the modulator tube by a cathode coil coupled to the oscillator. This coil and the signal circuit are effectively in series between grid and cathode. It is generally desired to couple to the cathode coil as great an oscillator voltage as the grid-cathode bias of the modulator will permit without causing grid current. The optimum value of oscillator voltage is maintained uniformly over the range of signal frequencies by combined condenser and inductive feedback in the oscillator. A series condenser is used in the oscillator tuned circuit to assist in maintaining a constant frequency difference between signal and oscillator circuits, the latter having the



Figs. 1, 2 and 3.

Fig. 1. Tetrode Modulator and Triode Oscillator

Fig. 2. Tetrode Oscillator-Modulator

Fig. 3. Tetrode Neutralized Oscillator-Modulator

†Paper presented before the Radio Club of America, March 8, 1933.
*Bayside Laboratory, Hazeltine Corporation.

higher frequency. This same condenser is used as the main feedback coupling when the oscillator is tuned to lower frequencies, while the inductive feedback is mainly used at higher frequencies. These two are proportioned to apply a uniform oscillator voltage between the grid and cathode of the modulator.

Fig. 2 shows an oscillator-modulator circuit which has the same circuit elements as Fig. 1 except omitting the triode tube, two resistors and a condenser. In Fig. 2, the tetrode is used also as an oscillator, retaining the combined condenser and inductive feedback in the tetrode plate circuit, and using the cathode coil as a link in the feedback arrangement.

The circuit of Fig. 2 requires careful but not critical proportioning of the circuit constants to maintain the oscillations at a level just below that which would cause grid current. Having adjusted the inductive feedback in the plate circuit so that the grid-cathode oscillator voltage is uniform over the tuning range, a value of the cathode resistor is chosen which is sufficiently great to prevent grid current, but is much less than the value required to stop the oscillation. The oscillator circuit is then self-regulating without relying on grid current. When the oscillations start, the cathode current increases by rectification of the oscillation, which in turn increases the grid-cathode bias and regulates the amplitude of oscillation without grid current.

There are several difficulties which are sometimes encountered in the circuit of Fig. 2, for which appropriate corrective measures have been found.

The intermediate-frequency primary coil may cause some trouble because it is effectively across the oscillator feedback circuit. In general, a coil has one fundamental natural frequency, and also a number of overtone frequencies. The latter are each slightly higher than an even multiple of the fundamental. At these overtone frequencies of the primary coil, it is likely to reflect considerable resistance into the oscillator circuit. This is corrected by choosing this coil to have a fundamental frequency at least half the highest frequency in the oscillator tuning range.

There is a tendency for the circuit to oscillate at the natural frequency of the oscillator plate coil, instead of at the oscillator frequency. Where this occurs, a nominal resistance in the plate lead is a satisfactory corrective.

The by-pass condenser across the cathode resistor must be made smaller than usual to avoid periodic blocking of the oscillator at an audio frequency. The maximum safe value is easily determined by trial.

The grid-cathode capacitive coupling of two or three micromicrofarads causes appreciable interaction between signal and oscillator circuits at the higher frequencies. The effects are (1) degeneration in the oscillator circuit, (2) regeneration in the signal circuit, and (3) radiation of oscillator currents from the signal circuit. The best cure for all of these effects is neutralization of the grid-cathode capacitive coupling. Fig. 3 shows a circuit having such neutralization added to the oscillator-modulator circuit of Fig. 2.

When the types 57 and 58 pentodes became available, the connection of all three grids to separate terminals opened up new possibilities in the oscillator-modulator field. In the first place, the type 57 pentode gave improved results in the circuits designed for the type 24 tetrode, the added suppressor grid being connected to ground. Then a number of new circuits were developed, two of which are shown in Figs. 4 and 5. These two circuits differ mainly in that the oscillator circuit of Fig. 4 is connected to the outer electrodes of the pentode while that of Fig. 5 is connected to the inner electrodes. In both cases the plate is connected to the intermediate-frequency transformer, as in the foregoing circuits.

In the oscillator-modulator circuit of Fig. 4, the oscillator includes the suppressor grid and the plate of the type 57 pentode, the feedback arrangement being somewhat similar to that of Fig. 1. The suppressor has such a wide mesh that it must be given a considerable negative bias before it exercises sufficient control over the plate current, which is necessary for the production of oscillations. This bias is provided by the second cathode resistor in Fig. 4. For the same reason, the plate voltage is reduced by another resistor. The modulation is effected by the large oscillator voltage on the suppressor grid. The tube operates under unusual conditions, the screen voltage and current considerably exceeding the plate voltage and current.

The circuit of Fig. 4 has several distinct advantages over those of Figs. 2 and 3. One is the complete shielding of the signal circuit from the oscillator and intermediate-frequency circuits, preventing feedback of any kind and also preventing radiation of oscillator currents. Another is the complete avoidance of control-grid current, regardless of the oscillator voltage, requiring less care in oscillator design. The circuits of Figs. 2 and 3 still have some advantages, especially if the type 57 pentode is substituted for the type 24 tetrode. They are capable of higher conversion gain and usually require fewer circuit elements.

In the circuit of Fig. 5, the oscillator includes the control grid and the screen, while the signal is applied to the suppressor grid. This is an elementary form of the emission valve modulator which will be described in more detail with reference to Figs. 6, 7 and 8. The inner electrodes behave as in a triode oscillator, while the other electrode behaves as in a triode modulator. The latter has a very low amplification factor, because of the wide mesh of the suppressor, and therefore the conversion gain is very low. This circuit is very stable in operation, and is interesting as the forerunner of the new hexode circuit.

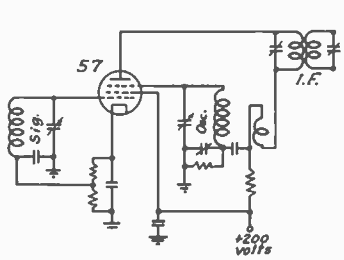


Fig. 4. Pentode Oscillator-Modulator with Outer Oscillator

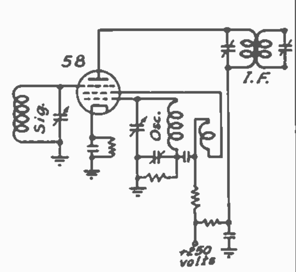


Fig. 5. Pentode Oscillator-Modulator with Inner Oscillator

Figs. 4 and 5.

All of the circuits using the available tubes were found lacking in one way or another. A circuit was desired which would perform with one tube the following functions:

1. Oscillation;
2. Modulation;
3. High amplification;
4. Grid-bias control of amplification.

Even the separate oscillator and modulator of Fig. 1 failed to meet all these requirements. When a sharp-cutoff modulator such as type 24 or 57 was used, grid-bias control was not satisfactory. When a variable-mu modulator such as type 35 or 58 was used, high conversion gain could not be secured. The arrangements of Figs. 2, 3 and 4 could not be subjected to grid-bias control without stopping the oscillator. That of Fig. 5 gave very low gain, but had the advantage that grid-bias control would not stop the oscillator.

Work was then carried forward on the development of a new tube to perform all four of the desired functions. The third and fourth requirements seemed at first to be incompatible, because high conversion gain requires a sharp-cutoff grid, while grid-bias control requires a gradual-cutoff grid. This problem was solved by locating two separate grids in the same electron stream, each having the structure best adapted to perform its function. The sharp-cutoff grid was used for the oscillator, giving a maximum modulating effect. The gradual-cutoff grid was used for the signal and the grid-bias control.

Figs. 6, 7, and 8.

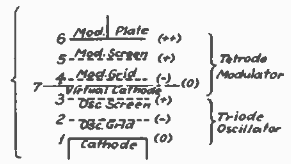


Fig. 6. Hexode Oscillator-Modulator Tube

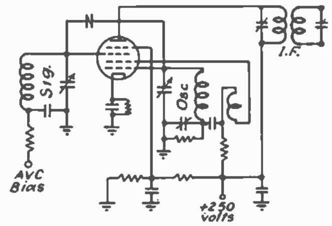


Fig. 7. Hexode Neutralized Oscillator-Modulator

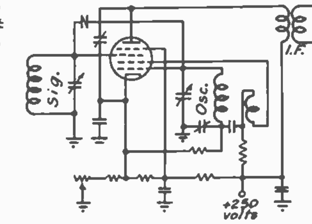


Fig. 8. Hexode Neutralized Oscillator-Modulator with I-F Regeneration

New Hexode Tube

Fig. 6 is a schematic diagram of the special tube which was selected as the best compromise between simplicity, low cost and low cathode current on the one hand, and a high degree of refinement on the other hand. It is a hexode having a structure generally similar to the 58 tube, but having a fourth grid and a redesign of all the grids. This was found to be the smallest number of grids which could be used and still meet the requirements. The cathode and the inner two grids are used as a triode oscillator. The outer two grids and the plate are used as the grid and plate electrodes of a tetrode modulator. The relative polarities of the electrodes are indicated on the diagram.

In operation, electrons emitted from the cathode 1 are attracted to the positive screen 3 through the meshes of the negative grid 2. As the electrons approach the screen 3, they are travelling at a high speed, so that most of them shoot through the screen 3 and approach the negative grid 4, where they are retarded and then attracted back to the screen 3. The cloud of retarded electrons between the screen 3 and the grid 4 is called a "virtual cathode," because electrons can readily be drawn away from this cloud in the same manner they were originally drawn away from the actual cathode. The relative position of the virtual cathode is indicated by the line 7 (which is not a part of the tube structure).

The modulator section of the tube includes the modulator control-grid 4, the modulator screen 5, and the plate 6, in addition to the virtual cathode 7 (formed by the oscillator section of the tube).

Part of the electrons arriving at the virtual cathode 7 are attracted toward the positive screen 5 and the more positive plate 6 through the meshes of the negative-grid 4. When the oscillator grid 2 is only slightly negative, or even somewhat positive, the virtual cathode 7 has a plentiful supply of electrons available for the modulator section of the tube. When the oscillator grid 2 swings considerably negative, the virtual cathode 7, and hence the modulator plate, are momentarily deprived of their electron supply. This is the "emission valve" mechanism by which modulation is effected in the new tube.

The modulator grid 4 (not the inside grid) is connected to the cap terminal of the tube, and is constructed to have a gradual-cutoff action so that a variable negative bias can be used to control the conversion gain over a wide range without distorting strong signals applied to this grid. It is important that this negative bias has practically no effect on the oscillator behavior, because the modulator grid is incapable of cutting off the major part of the oscillator screen current.

Hexode Circuits

Fig. 7 shows a representative circuit using the new tube. It is now unnecessary to provide any parts for coupling the oscillator to the modulator, since this is accomplished by the emission valve action. The capacitive coupling of two or three micro-microfarads between oscillator screen and modulator grid causes appreciable reaction between signal and oscillator tuned circuits at the higher frequencies. This coupling is readily neutralized by a small neutralizing condenser of about one micro-microfarad, denoted by the symbol "N," which also prevents radiation from the oscillator. In order to prevent feedback from the oscillator screen circuit to the signal circuit through the same capacitive coupling, it is desirable to make the self-reactance of the oscillator screen circuit very small at the higher frequencies. This is done by sufficiently reducing the insulating condenser in this circuit. It is interesting to note that the transconductance from modulator grid to oscillator screen is negative, and therefore a capacitive load in the oscillator screen circuit is regenerative in the signal circuit.

Fig. 8 shows the circuit of Fig. 7 with two modifications, either of which may be used individually. A cathode rheostat is shown for manual gain control, arranged for minimum disturbance of the relative voltages on cathode, screens and plate in the tube. Regeneration in the intermediate-frequency primary circuit is provided by connecting the primary condenser between plate and cathode. The cathode condenser is reduced to increase the amount of regeneration. This expedient is not critical and is under control of the grid-cathode bias.

High Gain

Using a good intermediate-frequency transformer tuned to 175 kilocycles, the conversion gain of Fig. 7 is 120 times. Using a good transformer tuned to 450 kilocycles, the conversion gain of Fig. 8 is 120 times with only 40 per cent regeneration.

One of the interesting possibilities opened up by the new hexode is the five-tube receiver with automatic volume control, having the following order of tubes:

1. Hexode oscillator-modulator;
2. Pentode intermediate amplifier;
3. Diode detector and triode audio amplifier;
4. Pentode audio amplifier;
5. Power rectifier.

In conclusion, it is desired to acknowledge the valuable assistance of other engineers of the Hazeltine Corporation, particularly D. E. Harnett, J. K. Johnson, V. E. Whitman and N. P. Case. It is also desired to express the gratitude owing to the executives and engineers of Hygrade Sylvania Corporation for their cooperation in constructing the many experimental tubes which were needed in the development of the new hexode.

FORUM

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R. H. LANGLEY, Chairman,
Forum Committee.

PAPERS TO BE PRESENTED BEFORE THE CLUB

April 12, 1933

A paper entitled "Radio, Electrons and Stars" is to be presented by O. H. Caldwell, editor of "Electronics."

Mr. Caldwell needs no introduction, and friends and members of the Radio Club of America are cordially invited to attend this interesting lecture.

May 10, 1933

"Ohmmeter and Capacity Meter Circuits for Radio Servicing" is a timely subject for presentation before the Radio Club of America by J. H. Miller, radio engineer of the Weston Electrical Instrument Corporation.

In this paper a new ohmmeter of rather unique design, and a capacity meter are discussed. The ohmmeter derives its power from a small self-contained battery, and the capacity meter derives its power from a normal, convenient outlet.

Friends and members of the Radio Club are earnestly requested to attend.

Probable future papers to be presented soon before the Radio Club of America, include:

"Intermediate - frequency filters for superheterodyne broadcast receivers;" "QAVC circuits for Broadcast Radio Receivers;" "International Radio Developments."

—C. E. BRIGHAM, Chairman,
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*For 1933 the Chairman of the Papers Committee is C. E. Brigham, 200 Mt. Pleasant Avenue, Newark, N. J.

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PROCEEDINGS
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Vol. 10 MAY-JUNE, 1933 Nos. 5-6

RADIO SERVICING INSTRUMENTS†

From the Engineering Viewpoint

By J. H. Miller*

▲

THE problem of adequate service on broadcast receivers is demanding increasing attention from the radio engineer. There are now in the hands of the public entirely too many receivers functioning well below par because of minor faults. Such sets do not result in new sales, but tend to convey the impression, in each individual case, that broadcasting as a whole is not advancing.

It is believed that equipment to enable the servicemen to resuscitate such sets easily, quickly and economically is a real requirement of the industry. If the old set can be brought to at least its normal condition, confidence can be restored and the way paved for modern equipment.

While the method of analysis of current and voltage in the tube socket is well known, it merely serves to point out the stage in trouble and give a general picture of what may be the specific difficulty. Modern radio sets, however, are becoming increasingly complex as to circuits and abnormal voltage or current readings may frequently be caused by a number of defects which can not be analyzed from such readings only.

In a single receiver we may have several times as many resistors as we have tubes; potentials, both direct current and radio frequency, are broken up into sections by resistance networks, and direct and intermediate and radio frequency currents are segregated by means of capacitors. The requirement for devices to more accurately measure these resistance and capacity units is, therefore, a growing one.

In the endeavor to reduce obsolescence in test equipment of various kinds, unit panels have been made available. Fig. 1 shows five such panels in a carrying case intended for the serviceman. This gives him sufficient equipment to run down even major troubles in most any instance.

The three lower units are an analyzer of conventional type, a self-modulated oscillator covering the broadcast and intermediate bands and a tube checking device.

Because of the rather bulky assembly of the several units, they have been made removable as individual testing devices and are enclosed in small steel boxes as shown in Fig. 2. This allows for the removal of any of these units where it may be particularly required and also allows for the transportation of only such test units as are needed in a particular call.

The Volt-Ohmmeter

The upper two units in Fig. 1 are the recently developed volt-ohmmeter at the left and capacity meter at the right. The volt-ohmmeter panel is shown in greater

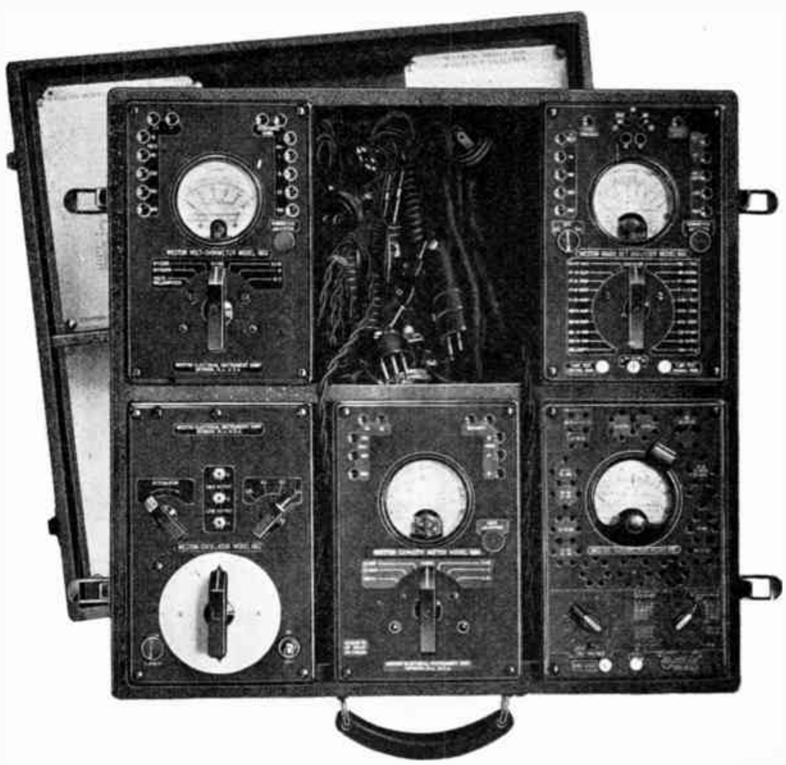

Fig. 1.

† *Presented before the Radio Club of America, May 10, 1933.*

* *In charge of Radio Engineering Division, Weston Electrical Instrument Corporation, Newark, N. J.*

detail in Fig. 3. The scale on the instrument is shown in Fig. 4. The switch positions are such that the scale reads directly in ohms on the next to the right hand switch position. In the right hand position the indications are divided by 5 and the first division to the right is 0.2 ohm.

Decimal multipliers are used for the higher values and the highest is R × 10,000; the last division at the left is marked 1,000 on the scale so that this becomes 10 megohms, directly readable with a truly portable device.

The details of the circuit have been worked out so that this rather wide range is obtainable through the use of a maximum of 15 volts of battery. A single No. 2 unit cell is used for all but the highest resistance. To this is added three of the smallest 3-cell "C" batteries for the highest range.

In order to obtain this wide range in values it has been necessary to use the very latest developments in instrument construction and a discussion of the ohmmeter theory will indicate the general angle of attack on the problem.

The series type ohmmeter, of which this is an example, may be analyzed directly by Ohm's Law. Consider first the current flowing through the instrument

$$I = \frac{E}{R}.$$

In this case E is the open circuit voltage of the battery being used and R the total resistance of the circuit including that of the instrument, the battery and connecting leads.

Taking the second case where an external resistance is connected in series, we have for the new value of current,

$$I' = \frac{E}{R + X},$$

where X is the external resistance which has been added to the circuit.

In order to get the reading on the instrument scale, let us consider the deflection in terms of full scale deflection; that is, let us arrange matters so that the result will be in per cent of full scale. We then have

$$\frac{I'}{I} = \frac{\dfrac{E}{R + X}}{\dfrac{E}{R}}.$$

The first member is per cent of full scale deflection and the second member may be reduced to

$$\frac{R}{R + X}.$$

This shows that the series type of ohmmeter is essentially a resistance comparator and if the resistance of the instrument circuit is known, the voltage of the battery and the current which flows may be completely dropped out of the picture. To be sure, there must be a sufficient amount of current to get a good readable indication on the instrument and in order that the scale may be of good length the potential and internal resistance must be so proportioned as to give sufficient current for full scale deflection with zero external resistance. But once these have been satisfied, they completely drop out of the picture and the readings in per cent of full scale are purely a matter of resistance proportion.

However, if we fix the resistance, the battery voltage will vary as the battery gets old and accordingly we must compensate the instrument sensitivity so that with a definite and fixed internal resistance full scale is always indicated. This may be done in any one of several ways.

Battery Compensation

A magnetic shunt is perhaps one of the most satisfactory methods of compensating for battery variation, but requires special construction in the instrument itself. A certain amount of scale distortion will also be present with different positions of the magnetic shunt simply because the flux distribution in the air-gap will change with the position of the shunt itself. While not of great importance in a small instrument it is definitely a factor, although the mechanical difficulties perhaps are of greater importance.

Another method of adjustment for battery voltage is to provide a variable shunt for the instrument movement itself. Since the resistance of the instrument movement is rarely more than 6 or 7 per cent of the total circuit resistance, shunting it down a matter of another 10 per cent will change the total circuit resistance by the order of considerably less than 1 per cent. The method is very simple to apply, simply requiring a small rheostat of suitable value. Practical ratios seem to indicate that the rheostat should have a maximum resistance of from ten to twenty times that of the instrument. In series with the rheostat is a fixed resistance to prevent the instrument from being completely short-circuited and this is usually from two and one-half to three times the resistance of the instrument movement.

This method, therefore, allows for the adjustment of the current sensitivity of the instrument to match the variation in the applied voltage and at the same time maintains the circuit resistance constant to within better than 1 per cent. If adjustments have been made at the center of the resistance variation, then the adjustment is good to considerably better than ½ of 1 per cent.

Making the analysis in this way, and considering the instrument as a resistance comparator, it will be seen that methods of adjustment using series resistance are inherently wrong in that they change the value R in the foregoing equations. It has been assumed by some that the change in effective battery voltage was not a change in open circuit potential, but rather a change in the internal battery resistance and that a series external resistance would compensate. This is not the case, however. The battery voltage drops even on absolute open circuit, as measured on a potentiometer, and the resistance increase is in general a very great deal smaller in terms of the circuit as a whole than the true drop in voltage.

Ranges

The resistance ranges supplied are largely the result of a study of the requirements. Ten (10) megohms seems to be the maximum which it would be necessary to measure; 5 megohm units are fairly common, but very few units of over 10 megohms in value are found in commercial receivers. In the design of a series type ohmmeter the left end

Fig. 2.

Fig. 3. Model 663.

Fig. 7. Model 664.

of the scale is always infinity on any range. The practical top of the scale, however, is considered arbitrarily after the first division and this is 2½ per cent of the scale length. We may then allocate 10 megohms at this point.

In a series type ohmmeter, where the pointer indicates full scale on zero external resistance, the center scale point is equal to the resistance of the instrument circuit including all necessary series resistance. If, therefore, we consider the maximum reading as 2½ per cent of full scale, center scale is 1/40 of this value or 250,000 ohms. If the instrument resistance on the highest range is to be 250,000 ohms, we must get an instrument of sufficient sensitivity so that it will give full scale deflection with this resistance as a part of its circuit on whatever battery used.

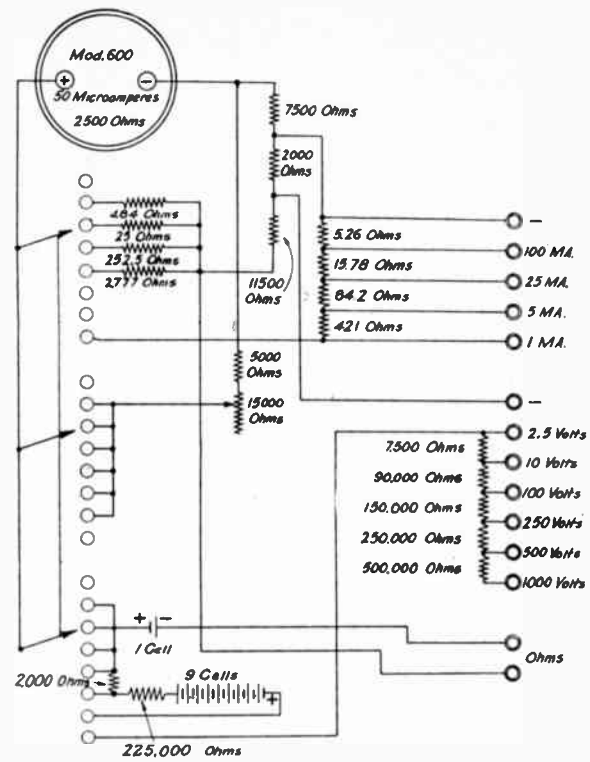

Fig. 5. Connections of volt-ohmmeter.

Microammeters

Recent developments in the design and construction of direct-current instruments have made available microammeters with ranges very considerably lower than have been heretofore available and in the present instance an instrument with a full scale sensitivity of 50 microamperes has been used. It is not very many years since 1 milliampere was considered as maximum full scale sensitivity on a small instrument and it will be seen that the present sensitivity of twenty times the older value is a very marked gain and has been made over the last decade. Magnets of special alloy steels of large cross section, coils wound from wire considerably finer than the human hair have both contributed to the increased sensitivity now available. Incidentally this sensitivity is by no means the maximum since in the present instance an instrument with a reasonably high torque was required; by reducing the torque as may be done for laboratory work, full scale currents of considerably less than 50 microamperes can be had.

With a sensitivity of 50 microamperes and a resistance of 250,000 ohms the battery voltage works out to be 12.5. It seemed in order to use a lower voltage for the lower resistance measurements and of course the lowest battery voltage is a nominal 1.5. A decimal ratio would, therefore, indicate 15 volts as the higher voltage. This fits very nicely and will allow for the 15-volt battery dropping in voltage a reasonable amount and will also allow for a slight increase in current due to that shunted by the rheostat for adjusting purposes.

For the next lower range in resistance the same current sensitivity is maintained with a single dry cell of 1.5 volts, the next lower range is obtained by shunting to 500 microamperes, the next by shunting to 5 milliamperes, then 50 milliamperes and for the lowest range the instrument is shunted to 250 milliamperes. This last value is considered as the maximum which can be taken from one of the larger unit cells and as a matter of fact the battery resistance is a very definite factor in this range and must be considered in setting up the network. It is probable that the accuracy over the full scale is somewhat reduced on this low range because of the change in battery resistance over its useful life. This range, however, is used only for the very low resistances which are read at the extreme right of the scale adjacent to the point where the initial adjustment is made and the error is, therefore, small. For readings of over a few ohms the next range is selected.

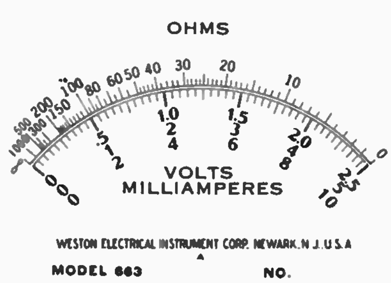

Fig. 4. Model 663 scale.

This completes the electrical design with the selection of the instrument, its current and voltage values and the type of adjustment. The wiring diagram is shown in Fig. 5 in schematic form and it will be noted that a 3-pole 8-position switch is used, one blade of which selects the shunts to change the current drain of the instrument. Another blade throws in the battery adjusting rheostat and a third blade throws in the extra battery and resistance on the high range.

The center blade would not have been necessary except for the fact that the instrument is also supplied with four current ranges and six voltage ranges to increase its utilitarian value and it is necessary to remove the adjusting rheostat where absolute values are to be taken. As a voltmeter the instrument is shunted to 1 milliampere full scale; as a milliammeter its drop is several hundred millivolts because of the rather high resistance coil, but this is usually quite satisfactory where plate currents are to be measured.

While originally developed for radio servicing, the wide range of usefulness of this assembly has made it one of the most popular instruments in the plant. Wherever a department must determine possible troubles in an assembly, this particular combination volt-ohmmeter seems to be the best single unit. While not possessing the accuracy of a bridge in the measurement of resistance, it will nevertheless segregate resistance errors and will even read leakage values where these exist to spoil the functioning of an assembly. It is believed, therefore, that with its multiplicity of ranges, this instrument will find an increasing range of usefulness.

The Capacity Meter

A capacity measuring device can be built along the same general lines as the ohmmeter, using alternating current of a definite frequency and a sensitive alternating current instrument. The equations are somewhat more complex because the reactance of the condenser must be considered as such and instead of the somewhat simple equation we get,

$$\% \text{ deflection} = \frac{R}{\sqrt{R^2 + X_c^2}}$$

Converting this into a form wherein the capacity is shown directly in microfarads we have,

$$\% \text{ deflection} = \frac{R}{\sqrt{R^2 + \frac{10^{12}}{4\pi^2 f^2 c^2}}}$$

This may be further simplified to bring it into the form,

$$\% \text{ deflection} = \frac{R \times 2\pi f c}{\sqrt{R^2 (4\pi^2 f^2 c^2) + 10^{12}}}$$

Again it will be noted that voltage and current are not in the picture, but that the per cent deflection is purely a function of the resistance of the circuit, the capacity in series and the frequency. But most lines are today carefully controlled and we must thank the makers of electric clocks that we now have a sufficiently constant frequency to make reliable capacity measurements simply and directly.

The instrument used is adjusted to 250 microamperes full scale and is of the rectifier type. Adjustments for variation in line voltage are made by a variable shunt across the instrument movement itself where the resistance is relatively low and this in turn keeps the change of total circuit resistance to a small value.

The instrument is first connected in series with suitable resistance to bring it to 4 volts full scale; it is then shunted as required for the higher ranges. For measuring electrolytic condensers up to 200 microfarads, the instrument is adjusted to 100 milliamperes and functions at 4 volts tapped from a small transformer. This low value of voltage does not seem to do any damage to electrolytic condensers and no polarizing voltage is apparently needed. The scale is shown in Fig. 6 and will be seen to be remarkably uniform over a good portion of its length. The high range to 200 microfarads is obtained by switching as shown in Fig. 7 to a position marked × 10; the direct position adjusts the instrument to 10 milliamperes full scale. The position marked ÷ 10 calibrates the instrument to 1 milliampere still maintaining the 4 volts. The position marked ÷ 100 removes the shunts so that the instrument functions at ¼ milliampere sensitivity and the 10-volt transformer tap is brought into play. The position ÷ 1,000 is the highest sensitivity of ¼ milliampere and 100 volts. This is used only for small fixed condensers and no difficulty has been had with breakdown. With this range it will be noted that the center point on the scale is 0.004 mf. The first main division is 0.001 mf. or 1,000 micromicrofarads. This is divided into 10 parts so that the first small division is 100 micromicrofarads. An ordinary 23-plate tuning condenser gives a nice indication. It is somewhat surprising to many engineers to see a sufficient amount of 60-cycle energy pass across the air-gap of an ordinary tuning condenser to give a readable indication on a commercially obtainable instrument.

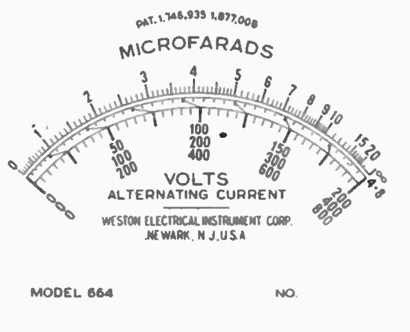

Fig. 6. Model 664 scale.

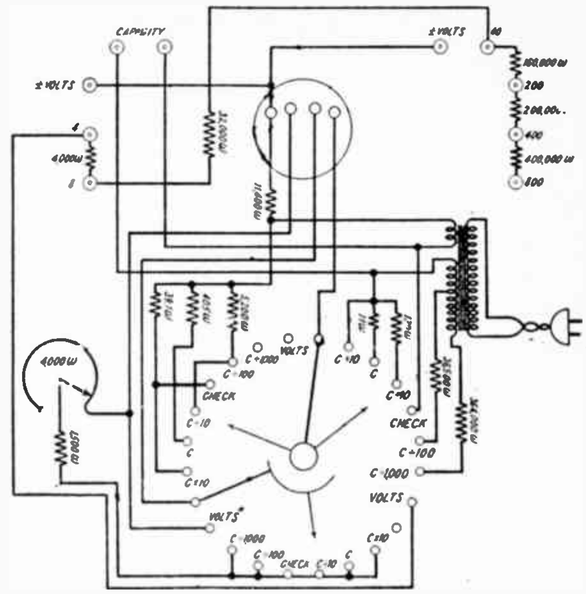

Fig. 8. Connections of capacity meter.

The diagram, Fig. 8, is somewhat similar to the ohmmeter in that a multiple blade switch is used which picks up the shunts, the series resistance and transformer taps and throws in the adjusting shunt. A position is arranged for a series of voltage readings to extend the usefulness of the instrument.

While the rectifier type of instrument somewhat limits the accuracy of a device of this sort, its very wide range of usefulness from air dielectric tuning condensers up to larger electrolytics makes it a most desirable unit for checking capacities. It is being used not only in the radio laboratory, but in many plants manufacturing other equipment where condensers constitute a part of the apparatus.

The radio serviceman, as represented by the requirements of all trouble shooting organizations, is really responsible for these two instruments. The development of combinations of this sort is largely a matter of replying to field pressure for equipment which is needed for a specific purpose. Now that the instruments are available, the instrument manufacturer finds that they have an appeal considerably beyond the field of servicing receivers. They are being used by assemblers of electrical equipment and even the telephone and telegraph companies are finding the versatility of these combinations makes them valuable in all sorts of work, particularly with long lines.

We might, therefore, credit the radio field as a whole with being responsible for another small contribution to the field of measurements and measuring equipment.

BOOK REVIEW

▲

RADIO ENGINEERING HANDBOOK. Edited by Keith Henney. Published by McGraw-Hill Co., Inc., New York City. 1933. *Price,* $5.00 (583 *pages*—482 *illustrations—flexible*).

As the allied industries have their handbook of engineering principles, practices, and standards we may now thank Keith Henney for a handbook prepared expressly for radio engineers. Henney's work in radio literature is of the highest order and his editorial efforts in this new conception make the text one of the most authoritative collections of engineering data ever compiled for the radio engineer in a single volume.

Essentially, the *"Handbook"* is a technical symposium prepared by a select staff of twenty-two specialists, each of whom are authorities on the particular subject they have submitted. Its primary purpose is to serve as a handbook for those engaged in engineering practices; however, much of the text can readily be assimilated by the average radio man. The use of mathematics in elucidating many of the compound problems is employed in abundance throughout the book. Although the first section is composed of arithmetical and allied electrical tables, there is a wealth of such information interposed throughout the entire book. The inclusion of schematics of new circuits and other hook-ups not common to everyday routine makes the text particularly useful as a reference guide.

The subject treatment may be regarded as divided into two parts: The first half of the book considers the theoretical study of the primary components constituting the tuned circuits as well as the fundamental applications and inherent properties of individual arrangements such as regards the vacuum tube in particular. The second half of the Handbook comprises a distinct study of a particular branch of the science, dealing with the more specialized ramifications of radio communication.

Section six on "Combined Circuits of L, C, and R" is worthy of mention since a similar treatment of the varied applications of this subject has not heretofore been completely incorporated in any radio text and was generally confined to special assignments in technical magazine articles. The following section seven on "Measuring Instruments" brings at hand a general and readily digested review of a wide variety of electrical instruments common to the engineer's laboratory. A sectional chapter is devoted to theoretical discussion of "Detection and Modulation" and their applications to engineering design.

C. W. Horn is well prepared to consider the broadcasting practices effectively in a very instructive, although too brief account of this art. R. C. Hitchcock in a section on "Rectifiers and Power Supply Systems" combines both theory and practice to render a practicable and useful treatment of a subject usually given inconsiderable thought in common discussions. In the posterior section on "Loud Speakers and Acoustics," the idiosyncrasies and performance inherent to electro-acoustic motors are further exposed.

R. H. Ranger discusses "Facsimile Transmission" and in his lucid contribution relates the methods of this system. Harry Diamond is the contributor of section twenty-one wherein the significant aids to aircraft radio communication and navigation are mentioned. In conclusion Dr. Irby briefly describes the principal methods employed in recording and reproducing sound motion pictures.

This comprehensive reference manual is perhaps the most valuable technical book that has come to the writer's attention in several years and it is unhesitantly recommended to every engineer and technician desiring an authoritative cyclopedia of modern radio tendencies in general.—*Reviewed by Louis F. B. Carini.*

▲ ▲ ▲

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Vol. 10 NOVEMBER, 1933 No. 11

CORRELATION OF THEORETICAL AND EXPERIMENTAL DATA ON CLASS C OPERATION OF RADIO FREQUENCY AMPLIFIERS†

By R. J. Davis and W. J. Cahill*

THE post-war decade witnessed the initial development of thermionic tubes of large power capacity for use in radio transmitters. The first years were necessarily spent in design improvements in the tubes themselves with principal emphasis upon large radio-frequency power output. The operating efficiency of the tube circuits, and the optimum cascading of the successive amplifier stages were usually treated as of secondary importance. The opening up of transmitter manufacture as a competitive industry, and the development of plate structures permitting considerably greater anode dissipation than the older types, has forced the question of tube and circuit efficiency into a position of primary importance in transmitter design, especially with reference to Class C operation with very high positive grid swings. While limitations due to the necessity of modulation fidelity prevent the full exploitation of these new developments in broadcast and telephonic transmission generally, code transmitters can be designed today having overall efficiencies from 20 to 25% greater than those in common use only a few years ago. It is with this type of circuit that the present paper is concerned.

Our work has not progressed to the point where complete data can be presented, but the preliminary computations will be described and illustrated with curves, a complete method of attack outlined, and a brief critique attempted of other work in the field.

It is essential that complete static characteristics of the tube considered be at hand. To get these data in the region of positive grid swing is difficult on account of the emission of secondary electrons from the grid at high positive potentials. It is believed that on account of the short period of time during which high grid current passes in a r-f. cycle under Class C operation, this effect is small for all tubes except the high power water-cooled types. In order to avoid secondary emission when taking data, the grid must be placed at the desired positive potential just long enough for an oscillograph element to record the swing of current. By utilizing several elements, the instantaneous values of plate voltage and current, as well as grid voltage and current may be read on the same film. A detailed technique for this procedure has been given by Kozanowski and Mouromtseff[1]. The desirability of simultaneous records is evidenced by the fact that all practicable plate and grid voltage supplies will show considerable regulation when called on to supply the increment of current involved in switching the grid from zero volts to a high positive value. It is also necessary to allow the grid to retain its positive potential long enough to permit all transients in the voltage supply circuits to die down. Kozanowski and Mouromtseff have covered these factors very well in their technique.

Assuming that a satisfactory set of characteristic curves are at hand, the next step is to compute data following the method of Prince and Vogdes[2] which results in an ensemble of optimum conditions illustrated in Fig. 1. The details of the computations for *one* point on *one* curve are given in the appendix. It should be emphasized that the efficiencies given here refer simply to the ratio of r-f. power available to the input to the tube, taking account of both grid and plate losses, but without consideration of the transfer of fundamental frequency energy into a given plate tank impedance. To solve this problem, we have recourse to a procedure similar to that described by Fay[3]. Unfortunately, the method of Fay is open to considerable error when applied to Class C operation over angles of 50-60°, because of the fluctuation of the cut-off voltage with the instantaneous plate voltage. The method may be followed, however, provided the assumed data include the *angle of operation* as well as the *maximum positive grid swing*. This means in turn that the maximum grid swing must be adjusted to the value corresponding to the point selected by varying the excitation received from the preceding tube. We may now determine the value of plate impedance which will give maximum power out-

†*Presented before the Radio Club of America, October 11, 1933.*
**Hygrade Sylvania Corp.*

put at the fundamental frequency by utilizing Equation (12) of Fay's article, viz:

$$R_o = \frac{r_p}{K} \quad \text{.......} (1)$$

K is defined by the equation $K = \dfrac{I \text{ fundamental max.}}{I_p \text{ max.}}$

K is a numerical factor uniquely determined by the angle of operation, r_p is the plate resistance of the tube at the point where I_p max. flows, and R_o is the equivalent resistance of the plate tank when tuned to resonance with the fundamental frequency. Referring to Fig. 2, we get a reasonable approximation to r_p by taking

$$r_p = \left(\frac{\Delta E_p}{\Delta I_p}\right)_{E_c = 300} = 6400^w \quad \text{.......} (2) \ \& \ (3)$$

$$R_o = \frac{6400}{.35} = 18000^w \quad \text{.......} (4)$$

Going back to our tube conditions, we find e_{pm}, the minimum plate voltage by Prince and Vogdes' criterion that $e_{g\,max.}$ shall not be greater than 80 per cent of e_{pm}. Hence we know e_{pm}. The max. plate swing $= E_b - e_{pm}$. $\dfrac{E_b - e_{pm}}{\sqrt{2}}$ gives the r.m.s. fundamental voltage impressed across the plate tank. The power output into the plate tank at fundamental frequency is given by the equation:

$$W_o = \frac{(E_b - e_{pm})^2}{2R_o} \quad \text{.......} (5)$$

This power will be delivered with the tube operating at maximum efficiency for its assumed output. The result comes out

$$W_o = \frac{(15000)^2}{(2 \times 18000)} = 63 \text{ watts} \quad \text{.......} (6)$$

This does not agree with the value calculated further on, because the value of r_p picked off the extrapolated i_p—e_g curves is subject to considerable error. More exact numerical check of the above analysis follows:

$$E_b - e_{pm} = 2000 - 500 = 1500 \text{ volts} \quad \text{.......} (7)$$

$$\frac{E_b - e_{pm}}{\sqrt{2}} = 1060 \text{ volts r. m. s.} \quad \text{.......} (8)$$

$$W_o = \frac{E_b - e_{pm}}{2} K I_p \quad \text{.......} (9)$$

(I_p max = .576 amp.)

$$W_o = (750)\ (.35)\ (.576) = 152 \text{ watts} \ \text{....} (9a)$$

The actual measured power in the antenna for two tubes in parallel was 306 watts. Losses in the tank and antenna tuning circuit were estimated at 15.0 watts per tube giving a total output per tube of 168 watts. The difference in the measured and calculated powers is 10%, and is probably due to an incorrect value of the constant K, as this is sensitive to changes in the assumed shape of the tip of the plate current curve. The value of K used here is the value given by Fay for a 3/2-power curve. If the shape of the plate current curve is taken as slightly flattened (probably a closer approximation on account of filament saturation), the value of K for 60 deg. operation comes out to be about .37. Substituting this in the above equation, we get

$$W_o = (750)\ (.37)\ (.576) = 160 \text{ watts} \ \text{....} (10)$$

This gives a closer check.

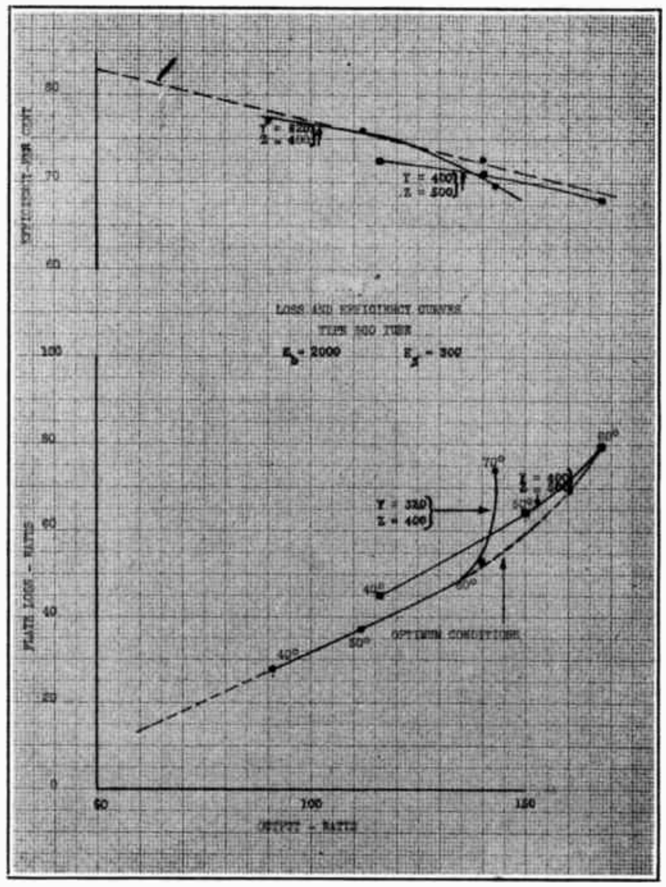

Fig. 1—Loss and Efficiency Curves.

In designing the plate circuit, the values of L and C are usually chosen with a primary view to stability. It is customary to assume a ratio of K.V.A./Watts in the amplifier tank circuit of about 20/1 to 30/1. This is in accordance with ideas developed in Prince and Vogdes' book which show that this ratio should be at least 12.6/1 for stable operation. The theoretical minimum is usually doubled to allow a factor of safety. A value of C is assumed, the circulating current through it at a given frequency determined with an r.m.s. voltage $\dfrac{E_b - e_{pm}}{\sqrt{2}}$ across it, and the value of R necessary to dissipate the power output with this circulating current through it found. L is determined from tuning considerations. The value of $\dfrac{L}{CR}$ is then computed and compared with the value of R_o obtained from the equation:

$$\frac{(KI_p)^2 R_o}{2} = 152 \quad \text{.......} (11)$$

$$K = \frac{I_1}{I_p} = \frac{\text{Peak Fund Current}}{\text{Peak Plate Current}}$$

$$R_o = \frac{152 \times 2}{(.35)^2\ (.576)^2} = 7500^w \quad \text{.......} (11a)$$

If the value of $\dfrac{L}{CR}$ differs markedly from this, a new value of C is selected, and the computation repeated until fair agreement is obtained.

The constants on the tank used in the experimental work are known, so that it is possible to check this

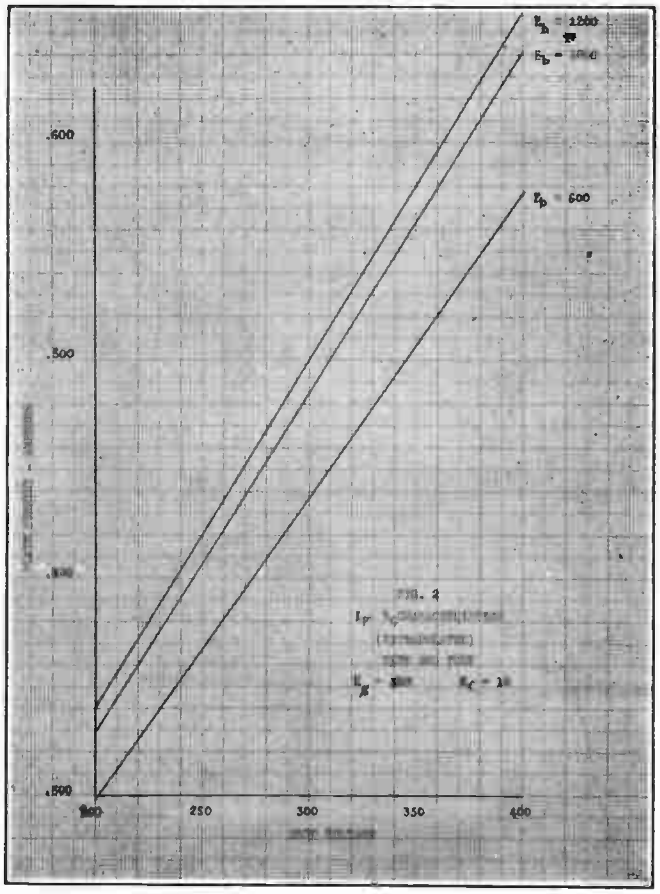

Fig. 2.

theory also. The measurement was made at a frequency of 2400 kilocycles/sec. The low frequency L of the tank by computation was 30 microhenrys. The C necessary to tune this to 2400 k.c. is 148 mmf. Of this, 92 mmf. was in the tank condenser, and 56 mmf. in the coil and circuit wiring as distributed capacity. With an r. m. s. voltage of $\frac{2000 - 500}{\sqrt{2}}$ or 1060 volts across the tank, the capacity current will be

$$I_c = \frac{1060}{X_c} = \frac{1060}{450} = 2.35 \text{ amp.} \quad (12)$$

In order to dissipate 168 watts, this current must traverse an equivalent resistance R given by the equation:

$$(2.35)^2 R = 168 \quad (13)$$
$$R = 30.2 \text{ ohms} \quad (13a)$$

This R includes the resistance of the tank coil itself together with the resistance reflected into the tank from the antenna circuit. The equivalent resistance of the tank R_o at fundamental frequency is then given by the equation

$$R_o = \frac{L}{CR} = \frac{30 \times 10^{-6}}{148 \times 10^{-12} \times 30.2} = 6700 \text{ ohms} \quad (14)$$

This is in fair agreement with the value (7500 ohms) deduced in equation (11a) above.

While the foregoing analysis may seem laborious, it can be attacked systematically, and the optimum values found very quickly. It should be noticed, furthermore, that the data so obtained are of use in designing circuits at any frequency and furnish a record of permanent value for the engineering files.

ADDENDUM

It should be noted that the power output of a tube computed by the method of Prince and Vogdes includes the *total* power available for transfer into a load, i.e. fundamental power and harmonic power. Fay's procedure leads to a value of *fundamental* power only. We should expect that the two values of computed power would differ, therefore by an amount equal to the *harmonic* power. For small angle Class C operation, this harmonic power is very small, so that close correlation between the available power outputs computed by the two methods should exist. The method of power measurement in the experimental work did not permit a sharp discrimination against the harmonic frequency power, so that part of the discrepancy between the measured and computed values may be explained as due to this fact.

REFERENCES

[1]Kozanowski and Mouromtseff: "Vacuum Tube Characteristics in the Positive Grid Region: Proc. I. R. E., August, 1933; p. 1082.

[2]Prince and Vogdes: "Vacuum Tubes as Oscillation Generators": G. E. Company, July, 1929.

[3]C. E. Fay: "Operation of Vacuum Tubes as Class B and Class C Amplifiers": Proc. I. R. E. March, 1932; p. 548.

APPENDIX

Tube: 860
60 deg. operation

D. C. plate volts X = 2000
Max. grid volts Y = 400
Min. plate volts = 500

		0°	10°	20°	30°	40°	50°	60°
A	1-cos θ	0	.0152	.0603	.1340	.2340	.3572	.5000
B	(X-Z) (1—cos θ)	0	22.8	90.5	201.0	351.0	536.0	750.0
C	e_p	500	522.8	590.5	701.0	851.0	1036.0	1250.0
D	$e_p/_u$	60	60	60	60	65	65	65
F	Y plus $e_p/_u$	460	460	460	460	460	460	460
G	1-cos θ	0	.015	.060	.134	.234	.357	.500
H	Max. grid swing (G)	—	—	7650	3440	1990	1300	930
J	A-C comp. of E_g	—	—	5420	2440	1410	920	660
K	Bias	—	—	—	3040	1590	900	530
L	1-cos θ	0	.015	.060	.134	.234	.357	.500
M	G (1-cos θ)	0	14	56	125	218	332	465
N	e_g	400	386	344	275	182	68	—65
P	i_p	.576	.560	.525	.440	.290	.124	0
Q	i_g	.082	.080	.070	.043	.028	.012	0
R	Plate loss	288	295	310	310	246	129	0
S	Grid Loss	32	32	21	11	5		

$I_p = .124$
$I_g = .015$
Grid Loss = 4 watts
R_g = 35,400"
R_g loss = 8 watts
Total grid loss = 12 watts

Plate loss = 80 watts
Input = 248
Output = 168
Efficiency = 67.6%