Radio Digest

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(Another RADIO Publication)

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JANUARY AND FEBRUARY, 1938

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RADIO DIGEST

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We present:

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Bell Laboratories
Record, Dec., 1937

Forecasting Sunspots and Radio Communications Conditions

BY A. L. DURKEE

(Drawings courtesy of "Bell Laboratories Record")

THAT there is a close relationship between the best frequencies for long-distance radio communication over short-wave circuits and the average number of spots on the sun has been recognized for some time. The frequencies which give the best transmission are considerably higher during periods of great sunspot activity than at times when sunspots are few. This has been attributed to increased ionization in the higher layers of the atmosphere when sunspots are numerous, with the result that the shorter radio waves are more effectively returned to the earth. In years of high solar activity severe disturbances of the earth's magnetic field occur frequently. These disturbances, known as magnetic storms, are nearly always accompanied by disturbances of short-wave transmission.

Solar activity is now approaching another peak in its well-known eleven-year cycle of change, and in view of its influence on radio communication, its probable magnitude is of particular interest at the present time. Attempts have been made to predict the magnitudes of the peaks on the assumption that there are systematic, long-period variations superimposed on the eleven-year cycle, but the determination of these long-period effects is quite uncertain with the limited amount of data now available. Dependable sunspot observations go back less than two hundred years, which in terms of eleven-year cycles represents a comparatively short range of experience.

Astronomers express sunspot activity in terms of an index which is determined by the grouping as well as the actual number of sunspots present, and is called the relative sunspot number. The values of this number for each year since 1750 are shown in figure 1. A new method of analyzing these data proposed by the author indicates the possibility of making short-range forecasts of the probable magnitude of succeeding peaks of the curve on the basis of the activity at the preceding minima. This analysis shows that the magnitude of each peak apparently is related to the

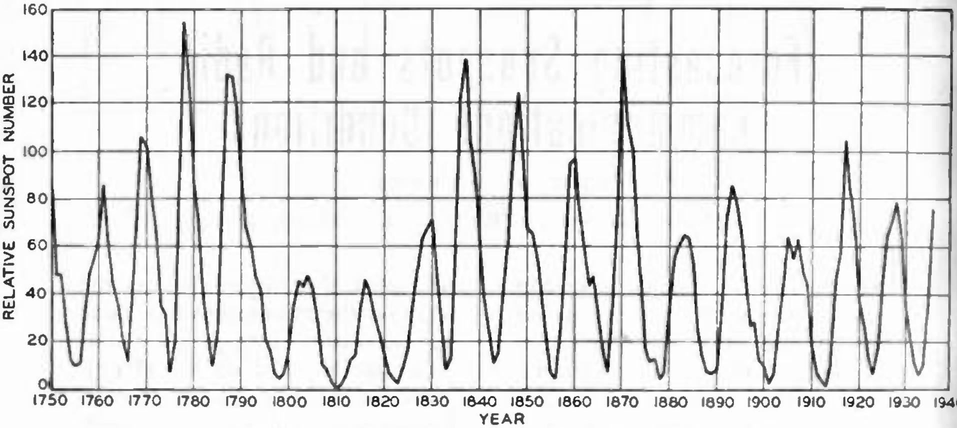

Figure 1—Variations in sunspot activity since 1750.

average sunspot number at the preceding minimum and the rate at which the sunspot numbers begin to increase immediately after the minimum. High minima and high rates of increase tend to be followed by high maxima.

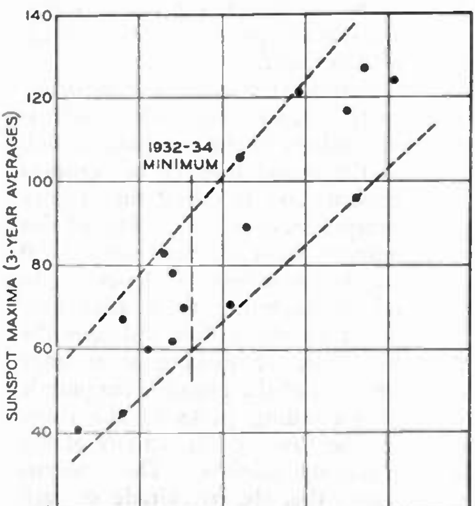

Figure 2—Relation between sunspot maxima and preceding minima.

To show this relationship each maximum sunspot number was plotted again the square root of the product of the preceding minimum sunspot number and the rate of change of activity at that minimum (figure 2). This particular function was selected by trial, and three-year averages of the relative sunspot numbers were used in determining the maxima and minima. The results show a correlation which is indicated by the points all falling within the band between the two straight lines. The abscissa corresponding to the minimum of 1932-1934 is 16.2; hence it appears from figure 2 that the three-year average sunspot number for the coming peak may fall somewhere in the region between 60 and 90.

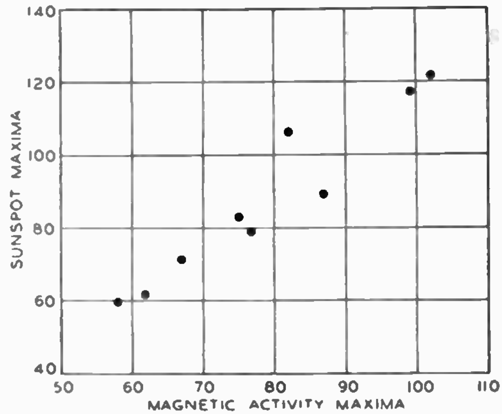

Figure 3—Relation between sunspot maxima and magnetic activity maxima.

The years of highest sunspot numbers are not always those of greatest terrestrial magnetic disturbance, although both effects follow an approximate eleven-year cycle. There is a tendency, more pronounced in some cycles than in others, for magnetic activity to lag behind sunspot activity and the effect has been particularly noticeable in the last three cycles. This is illustrated in figure 4, where the three sunspot and magnetic-activity cycles since 1900 have been superimposed and smoothed by averaging. These results show that the peaks of magnetic activity came later than the sunspot peaks, and

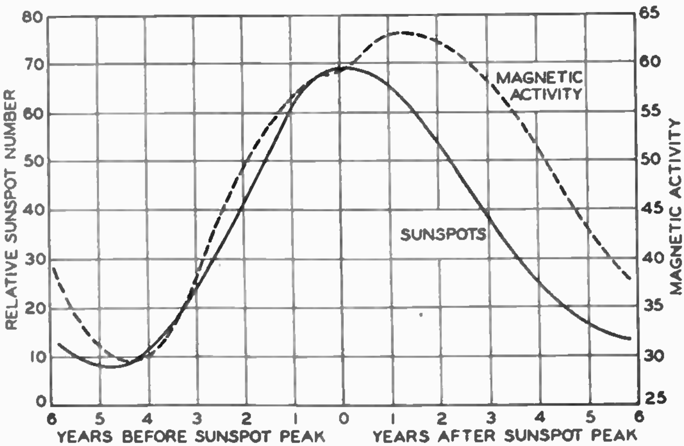

Figure 4—Average sunspot and magnetic activity cycles.

that a given sunspot number was associated with substantially higher magnetic activity in years following than in years preceding the sunspot peak.

Magnetic activity is represented by numbers which are proportional to the average change from day to day of the mean horizontal intensity of the earth's magnetic field.

Data on which to base forecasts of magnetic activity are more limited than those for sunspots, although consistent observations on day-to-day variations in the earth's magnetic field go back about one hundred years. In figure 3, three-year averages taken at the peaks over this period are plotted against the corresponding, although not always coincident, average sunspot peaks. The points fall roughly along a straight line, which naturally would indicate that these factors are correlative.

These results, together with the results shown in figure 4, suggest that a moderate peak of sunspot activity in any cycle probably will be accompanied by an equally moderate peak of magnetic activity and that the year of greatest magnetic disturbance will occur possibly a year or two after the year of highest sunspot number.

•

Did You Know . . .

. . . that as commonplace an occurrence as the blackening of an electric light bulb led to the discovery of the basic operating principle of radio tubes?

. . . that regular broadcast stations licensed by our F. C. C. radiate power which totals three and a quarter million watts—over four thousand horsepower?

. . . that one-way military communication by way of carrier pigeons travels at the rate of half to three-quarters of a mile a minute?

. . . that except for one of those strokes of the hand of Fate, your quartz crystal might have been a spoonful of sand?

. . . that one prehistoric version of the triode ran on illuminating gas; another had cathode, grid, and plate immersed in acid?

. . . that thermometers were used as indicating devices in early wave-meters? (We'll take a neon bulb for ours.)

¶ From *Television*, Vol. 2

Television Problems . . .

A Description for Laymen

BY ARTHUR VAN DYCK
Manager, RCA License Laboratory

RADIO has attained its present position of important widespread use so rapidly that it has not been possible for people generally to gain clear understanding of it to the degree they do understand many other technical devices. When radio's new service of television arrives, there will be even more intimate contact and impact between radio and the home. Many people realize this and an interest in "how television works" is frequently expressed to radio engineers. This article is an attempted answer to those questions.

In both telephony and telegraphy we transmit intelligence by modulating the flow of high-frequency current in an antenna to represent what we want to transmit, whether that should be the words of a message, letter by letter, with a dot-dash code, or whether it should be a sound occurring in front of a microphone. Now suppose that the form of intelligence to be transmitted is a picture, a drawing, a visual scene of any kind. We must arrange to modulate the same antenna high frequency current in some way which can represent the picture to be transmitted. And right here we come up against the enormous difference between sight and sound. In sound, we have to transmit only one thing, one bit of intelligence, one sound at a time, with others in sequence. A symphony concert, or a Jack Benny program, consists merely of one sound at a time. True, each sound may be a complex one, with various tones composing it, but it is only one sound, and can be represented by one current. An instant later, another sound can be represented by another current, and our signals radio transmitter can follow the progression of single instantaneous

Condensed from lecture given before the Brooklyn Institute of Arts and Sciences (February 1937). Complete text appears in Volume 2 of TELEVISION, *published by RCA Institutes Technical Press.*

sounds faithfully. But a picture, even one instantaneous flash, is not a single thing of any sort, and cannot be described or represented by *one* electric current or one anything else. It is composed of many little elements, one for each area of that size which the eye can distinguish. For example, if we look at a scene whose dimensions are ten feet square from a distance where the eye can distinguish objects one inch in diameter, there are about fifteen thousand small, one inch areas which must be described individually to convey the whole picture. If the scene to be transmitted is a stationary one, and we are permitted to take any amount of time to describe the scene, we could do so successfully by an ordinary telegraph system and a simple code. We might divide our scene up into imaginary squares, one hundred each way, and number them in sequence beginning with the upper left corner, going across the top row, then beginning the second row at the left, and so on until the lower right small square would be number ten thousand. We will then arrange an understanding with our correspondent that we will telegraph him a message containing ten thousand numbers and that the numbers will be the digits one, two, or three. One will mean white, two will mean gray, and three will mean black. Our telegram may then read 111322123333112311 et cetera for ten thousand digits. If our correspondent then takes a sheet of paper ruled with one hundred squares each way, and fills in the squares by the information we have sent him, he will have the complete picture—when he finishes.

Obviously this procedure is an exceedingly slow one, impossibly so if we desire to transmit pictures of moving objects. But it is satisfactory, with only moderate change, for the transmission of still pictures, or the art known as facsimile transmission. If for example, instead of transmitting numbers by telegraph code, we arrange the transmitter to send out an impulse once each second, let us say—one impulse for each of the little squares in sequence, and the strength of each impulse to correspond to the degree of light in the square it represents, we can send out a description of the picture in ten thousand seconds, or two and one-half hours. At the receiving end we will arrange a printing device to record each impulse in the same order and location which they had at the transmitter, and with an ink intensity corresponding to the current intensity of each impulse. Our chief problem will be that of synchronization between transmitter and receiver, that is, the receiver must make its mark in square number one when the transmitter is describing number one, and so on coincidentally throughout the picture. This is the facsimile system, as used on wire and radio, and now in commercial service in various applications. In these services, the performance has been speeded up by several impulses each second, so that only ten minutes or so are required to transmit a picture, rather than two and a half hours mentioned in the simplified illustration.

We can notice, from this requirement of transmitting a simple still picture bit by bit until the whole scene has been covered, that the problem is very different from sound radio where only one thing, one sound, has to be transmitted. The facsimile art, that of transmitting single still pictures, has been developed extensively and well, so that very excellent pictures can be transmitted. Note, however, that a time of several minutes is required to accomplish the transmission of *one* picture.

Now, television, the transmission of moving scenes, really requires transmission of many pictures each second, enough so that, just as in motion pictures, the eye will be deceived by the succession of still pictures, into believing it sees a continuous scene.

The motion picture of today shows twenty-four different lantern slides each second, and that is what we have to accomplish in television, namely, transmit at least two dozen different pictures each second. In other words, we have to send out information about each little element of each picture, repeating the process many times each second. Remembering that the facsimile system takes ten minutes to send one picture, if we need say thirty pictures per second for television, we shall have to speed up the process of facsimile by eighteen thousand times to accomplish television.

There, in a nutshell, we have the primary cause of practically all the television engineering problems. It may be described as a requirement for transmitting an enormous amount of information very accurately in a very short space of time. Let us proceed to examine how it may be accomplished.

OF COURSE we have only light to start with. Any object or scene is visible because of the light waves which reflect from it to the eye. We desire to catch these light beams in a device which will convert them into electric currents which we can use, in turn, to modulate or control the radio currents being fed into the transmitting antenna from a generator. Several ways are known by which to convert the light images to electricity. Two or three different ways were used in early television systems, but the modern system utilizes a device of outstanding superiority, and it is necessary to consider that one only. This device is called the "Iconoscope," from the Greek meaning "image observer". The "Iconoscope" in television corresponds to the microphone in sound transmission. Where the latter converts sound waves to electricity, the former converts light waves to electricity. The "Iconoscope" has two main parts. One is a plate upon which is focussed by ordinary optical means, the scene to be televised. This part corresponds exactly to the plate or film in a photographic camera. Its surface is covered, not with photographic emulsion, but with light-responsive, or photo-electric, cells. These cells are microscopic in size, but each is separate from the others, and each generates electric voltage when light strikes it, with the voltage being proportional to the strength of the light.

Therefore when a picture is focussed on this plate, with various parts of the picture at various degrees of brightness, those tiny cells having no light upon them generate no voltage, those with strong light generate strong voltage, and those with intermediate light generate intermediate values of voltage. It remains to collect these various voltages off of the plate in order to use them. To do this we might have a tiny wire brushing against the plate and sweeping with uniform strokes all over it, thus contacting the whole area bit by bit. But since we must sweep the plate so fast, and so many times per second, it is impossible to devise any mechanical system light enough to be so moved. So the "Iconoscope" utilizes a brush which has no material weight, namely a beam of electrons. The second main element of the "Iconoscope" is an arrangement for generating this small beam and directing it so that it falls upon the plate in one tiny spot. Other electric arrangements cause this spot to move all over the plate, in regular fashion, line by line. The present standard television system is designed to have 441 of these lines to cover the whole picture from top to bottom. The first systems had only 24 lines. It is clear that the picture will be more accurately reproduced, more capable of showing small details, the greater the number of lines. Also of course, the more lines there are the more information about the picture must be transmitted in the same length of time, and this is more difficult. It has been a most important problem to determine the best number of lines to use, and in general to find the best compromise between the opposing factors of picture quality and apparatus difficulty. The value of 441 has been chosen after very careful study and experiment covering several years' time, and will be the standard value in this country.

The little electron "searchlight" beam, sweeping across the plate with its 441 regular brush strokes, acts just as a wire brush would, and collects electricity from the cells on the plate as it passes over them. It is interesting and important to notice at this point that the scene being televised is focussed on the plate continuously, and therefore the cells receiving light are storing up electric charges continually. The electron beam sweeping across the plate contacts with only one little spot of the plate at a time, which incidentally is smaller than a pinhead. After the beam has completed its travel all over the plate, that is after it has traversed all the 441 lines, it comes again to the same spot on the plate. Each time it comes to a spot, it collects the electricity which has been storing up there while the beam was travelling over the rest of the plate collecting from all the other spots.

So the electron beam is a collector, travelling over the plate in a regular pattern of lines, picking up electricity wherever there is any present, as there will be in places where light is present.

Now this electron beam originates in a simple part of the "Iconoscope"* which is called the electron gun or cathode. The cathode is covered with certain chemical compounds which give off electrons when heated, and the cathode may be heated readily by current, just as is a lamp filament. Therefore the cathode is a part of the electron beam and if we connect the cathode and the plate to external apparatus, we can obtain the electricity which the beam collects from the plate having the light image upon it.

The electric currents which are obtained from the image plate by the electron beam are of course very small. But they can be fed into vacuum tube amplifiers and be amplified to useful proportions. When this is done, we will have currents carrying intelligence representing the light pictures, and these we will use to control the transmitter antenna current.

NOW LET us examine this scanning process again with an overall viewpoint. The scene to be televised is focussed upon the "Iconoscope" plate. The plate is continuously being explored by an electron beam, about the size of a pin, which sweeps across it in regular lines, taking 441 lines to cover the picture from top to bottom. The time required to sweep the whole picture is made such that the process can be repeated thirty times per second. In other words, every spot of the picture is visited by the collecting beam, thirty times per second. And there are about a quarter of a million spots on the picture to be thus visited! Undoubtedly the busiest thing in the world is this electron beam as it scans the picture, flying back and forth at a speed of several miles per second, and collecting the current, so to speak, at each tiny spot of its path.

In short, we have a system which is operating to pick up scenes a spot at a time, but covering spots so quickly, and the whole scene over and over so many times a second, that if we arrange a reproducing system to act in reverse fashion to that described, and to deliver light images corresponding to the spot currents, our very slow human senses will not follow the details of the process, and will perceive only the average total result, which is the complete picture.

We have now "scanned" the process of television transmission, perhaps almost as rapidly as the "Iconoscope" scans a picture, and of course we have lightly passed over many engineering problems. It will be of interest to list at least some of them.

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FIRST THE "Iconoscope" must have sufficient sensitivity, that is, it must be able to generate electric currents from small light intensities falling upon it. The latest forms have developed sensitivity to equal that of the photographic camera and film, so that any scene which can be photographed by snapshot, can be televised.

Also, the "Iconoscope" must be free from color-blindness. Present "Iconoscopes" are sensitive to all colors, and in fact to the invisible parts of the light spectrum as well as the visible. As a result, interesting applications are possible for purposes other than television, and utilizing ultra-violet and infra-red rays.

We have referred repeatedly to movements of the electron beam over the image plate. Of course its travel sideways and up and down is not inherent, or voluntary, and must be caused and controlled. To do this, coils are located outside the tube, and magnetic fields from these coils move the beam as desired because the beam responds to magnetic forces. The nature of the currents in the coils and the physical location of the coils determine how the beam will move. The proper kinds of currents are provided from oscillating vacuum tubes and so-called deflection circuits. These currents, which are at the transmitter, will also be used to control a similar beam at the receiver, as we shall see later.

The electric currents mentioned so frequently are alternating currents, flowing back and forth millions of times per second. Many of the most difficult problems of television result from the fact that such rapid reversals, or such high frequency currents, have to be used. Ordinarily we think of electricity as being instantaneous. Actually it is not, but has a finite speed of about 186,000 miles per second. So that when we not only call upon a current to travel even a few feet, but to turn around and reverse itself, and repeat this millions of times per second, we begin to encounter limitations even in the speed of electricity. This situation is so real that a copper rod four or five feet long, which is a practically perfect conductor for current at low frequencies, under some conditions acts like an insulator when the current is at frequencies of millions per second. Since we have to make and connect up our television apparatus with wires hundreds of feet long, it is obvious that expedients and special conditions must be provided to enable the currents to behave as we want them to.

These tremendously high frequencies are forced upon us because we are trying to crowd so much information into each interval of time, much more than we need to with sound broadcasting, or telegraphy, or even facsimile.

The unusually high frequencies give rise to new problems in the really wireless part of the system, that is the medium between the transmitting and receiving stations. Everyone is familiar with the conditions existing in sound broadcasting and knows that the quality of service received depends upon the power of the transmitter, the distance between transmitter and receiver, and the degree of static or other interfering noise present in the receiving neighborhood. With the higher frequencies used for television, the same factors are present, but in different ways and degrees. The television frequencies are so high that the waves approach in behavior that of light waves. It will be remembered, of course, that there is no difference in character between light waves, heat waves, ultra violet rays, X-rays, radio waves, except that of frequency. All are disturbances in space of the same character, and differ only in frequency. We are accustomed to ordinary radio waves going around the curvature of the earth, over and behind mountains, through buildings and so on. But radio waves at television frequencies, behaving more like light, act somewhat as does a powerful searchlight. They do not follow the earth's curvature very well or go behind a mountain, or through a building. Therefore they are more limited by obstacles on the earth's surface, and conversely, the transmission will be more effective the higher the antennas are located. Similarly, better reception is had by locating the receiving antenna as high as possible, and when television does come to the home, it will be found advantageous in most cases to put a good antenna on the roof, rather than a wire on the base board in the living room.

The propagation characteristics of the medium and the interferences existent, chiefly determine the distances over which reception may be effected. The tests now being carried on indicate that with an antenna as high as the Empire State building, satisfactory reception can be had to distances somewhere between twenty-five and fifty miles. In general, it may be observed that the service area of a television station is limited, in comparison with the areas of sound broadcasting stations as we now have them.

This condition results in a television engineering problem of the greatest magnitude, and one with profound economic influence on the television problem as a whole. The service area of a station is small because the frequencies required for television are extremely high. Just as it is difficult to make these high frequencies travel far through space, so is it difficult to make them travel far over wires. Consequently the television studio must be located close to the television transmitter and antenna. This means that we cannot utilize the simple effective method used in sound broadcasting of conducting a single studio performance in one city, and radiating its program from scores of radio stations scattered over the country, all connected to the studio by wire telephone circuits. At present, a television program is confined to the area around the originating studio, and its audience can be only that within that area. Obviously the expense of providing programs to the nation is vastly greater.

While on the subject of program expense, there is another aspect which is sometimes overlooked in the comparison of television and sound broadcasting. In the latter, sound is all-important, and nothing else has to be considered. In television, not only is sound required, but the added visual problem corresponds to that of making a sound motion picture. Scenery, special lighting, and costumes are required, actors must be letter perfect in their parts—and retakes are not possible. This means that the more economical types of program will be those where artificial aids are minimized—for example, the football game, or news events generally.

[*Television receivers will be discussed by the author in the next issue (March, 1938) of* RADIO DIGEST.]

Television in Los Angeles

FOR A period of several years, the Don Lee Broadcasting System has been transmitting television programs, newsreels and shorts, over its u.h.f. television transmitter, W6XAO. However, these programs were not, except on rare occasions, tied in with the regular sound broadcasts over KHJ. The frequently asked question, "When can we see the person that is broadcasting?" will be answered early in 1938 by this same broadcasting system.

In 1938 a number of the regular Mutual-Don Lee shows will be transmitted over television as well as over the usual network. These will be released over the sight-sound television station W6XAO in Los Angeles, simultaneously with their dispatch over the Mutual-Don Lee network.

"The new apparatus will embrace inventions and principles evolved during our seven years of television research," stated Harry R. Lubcke, director of television for the Don Lee Broadcasting System. "In addition, the equipment takes on a new form in which the camera-control units are completely mobile. This allows entry to any of our studios or pickup of outdoor scenes, according to our choice."

The complete channel comprises a pickup camera with new optical system and mounting, amplifiers, scanning sources, new synchronizing circuits, image and waveform monitors, current control panel, and power supplies. A mosaic-type direct pickup tube of a large eastern manufacturer is employed in the camera.

W6XAO is now daily on the air, as it has been since its inauguration on Dec. 23, 1931. Current newsreels and other subjects are broadcast nightly, except Sunday and holidays, at 6:30 p.m., and also on Monday at 9:00 a.m., Wednesday at 11:00 a.m., and Saturday at 2:00 p.m.

¶ From RADIO,
April, 1937

Why . . . RESEARCH

Charles F. Kettering, president and general manager of General Motors Research Corporation, answers this question.

Mr. Kettering, while most widely known as a motor vehicle engineer, also is famous for his electrical inventions. He long has employed cathode ray instruments and other electrical tools in solving motor vehicle problems. Many may not realize how closely the general spring and shock absorber problem in a motor car resembles a tuned resonant circuit problem with resistance, reactance, and broad frequency response as important considerations. Mr. Kettering was one of the first to experiment with artificial fever equipment utilizing high frequency, vacuum tube generators.—Editor.

A RESEARCH department is established by a company for one of three reasons. They may feel that a research laboratory is a good thing because they can use it in their advertising copy. Or they may feel that it is something to gamble on; if they spend a little money down that alley, the boys might stumble on something and they might make a little money on it. The third, and more serious thing, is to find out where they are going.

One way of illustrating the relationship of research to industry is this: On the first day of January, somebody gives you a calendar. It has 365 pages in it, and lines upon which you can write things which probably won't come out the way you wrote them. As you tear off these pages the calendar becomes thinner and thinner. I think it is the duty of research in industry to put a new page on the back of that calendar just as fast as you tear one off the front. It must see that that calendar remains the same thickness regardless of the particular date or the year. Research must assure the management that they will not wake up some day and find they have nothing to do.

This calendar story is particularly apt in that it is the passage of time which makes research necessary. As long as the world keeps going around, there are something over 2,000,000 new people coming into the world every year. You can't tell what new ideas are going to come in with them, but you know there are going to be some. Many people are looking for a stopping place, some point where this continual change will end. The answer to that is that the only resting place on the great road of life is the seat in front of the undertaker's office.

I DON'T think research has kept up with its duties over the last fifteen years, and the biggest reason for this is that we have become too expert as bookkeepers. Everything is done with one eye on the balance sheet. It will cost so much money to complete this project, and we must have a return of such and such per cent on it.

We don't object to an accounting system. It's a very necessary thing, and I don't blame management for wanting to be consistent and handle everything on the same basis. But a research project just doesn't fit into this set-up. You have to have a different kind of accounting. I mentioned earlier that research was a form of insurance, and in the insurance business they use what is called "actuarial accounting". They don't worry so much about the individual items; they just want to be sure that the average of all the items comes out as they figured. So it is with research. We will take whatever amount of money the management will give us, and we will spend it just as carefully and thriftily as the manufacturing department would. But we won't guarantee that in a month, or six months, we will have produced some definite article which will make a certain amount of money for the corporation. All we can say is that in the long run something will come out of it which will more than repay the money spent. I think the record of any well-organized research laboratory will bear out that statement.

You can't look ahead and say just what you will want to be doing a few years from now. Out of all the past experiences it is impossible for us to project industrial developments very far into the future. Some people ask, "What will the next great industries be?" There is no answer to that because nobody knows. You can't recognize an industry when it is starting. Some grow quickly and steadily from the very beginning. Others are held back for years because some particular factor is not developed, and when that appears, the industry may reach tremendous proportions practically over night.

The radio industry is a very good example of this. The principles had been known for many years, and messages were transmitted before the turn of the century. As an industry, however, it was simply nonexistent. Then with the development of our present vacuum tubes, it was changed from an experiment and hobby of a comparatively few people to a full-grown giant industry.

It is interesting to note in this connection that in the technical study made by the radio amateurs who sat up all night trying to telegraph across the street we had developed the technicians who became the service men of this new business. The rapid advance of radio was due to a great extent to the ready availability of these trained men who had been amateurs. They were self-educated. Did they study radio because they wanted to go into the business? No, they didn't know it would ever be a business. It was something they wanted to do. It was an adventure. What did they expect to get out of it? They had no idea. It was something that looked like it needed to be done and they wanted to do it. Thus the stage was all set and when the final detail was added, there was no obstacle to keep from the public the apparatus and service they so quickly demanded.

This same attitude is true of many inventions. Most of the great inventions were not developed consciously. Some fellow wanted to do something and he didn't know why—just to satisfy curiosity, maybe. There are still people who are curious. The trouble is that the opinion seems to be growing that you have to put up a big building and buy a lot of apparatus before you can do any research work. That is fundamentally wrong. If you solicit technical help with your problems, the helper is quite likely to pull a slide-rule out of his pocket and say, "That won't work," before you start the experiment. Maybe he's right, but be sure his statement is based on factual evidence, not opinion.

MR. Kettering has often said, "Research is trying to find out what you are going to do when you cannot keep on doing what you are doing now." In other words, it's an insurance policy for the future. It is an attempt to tell what is ahead of the industry and what things we can do to determine, if possible, the trends which this industry may take.

Remember that you do not solve problems with a laboratory and its equipment. They are only tools, a method of arranging certain brain cells, machinery for getting through about one-eighth of an inch of the most dense material in the world. The problem is solved inside your head, but it is of no use to anybody until it has penetrated the skull.

We had an interesting case of this kind not long ago; I asked one of the boys to work on a little project for me, and I didn't hear anything about it for quite a while. I inquired, and pretty soon this engineer came to me and said, "I'll need some new equipment for this work. Here's the list. It amounts to 480 dollars."

I thought I'd try him out a little. "You're sure you need all this?"

"Yes," he said, "I've figured it all out."

You can't stop change any more than you can stop time.

"Suppose you had originated this thing yourself, and weren't connected with any laboratory. What would you have done?"

"I would have started working on it."

"But what would you have done for apparatus," I protested. "You wouldn't have the 480 dollars."

"I'd find some way of making a try at it."

"All right," I said, "You go back and make a try at it now."

He came back in two days, grinning. "I only need 46 dollars worth of apparatus," he said.

In my opinion, the best way to start doing research, whether a large or small company, or even an individual is concerned, is this: Take a piece of paper and write down the problems that are bothering you, say eight or ten of them. Think about the first one a while; if you don't get anywhere, try some of the others. It's like a cross-word puzzle: you pick out some place where you can get started, and what you do there gradually helps you in solving some of the other parts. You can't hire a man, put him off in a corner with some equipment, and say you have a research department. You must analyze your problems first. How do you know what kind of equipment you will need? You may start out thinking your problem is one of design, and it finally comes down to a question of metallurgy. Or it may even end up a matter of economics.

That is where the worker in an individual research laboratory differs from the so-called "pure science" man. You are always hearing discussions and comparisons of pure science versus industrial research. The worker in the former field is quite likely to have a very poor opinion of the man who lowers himself to work for industry on a salary basis.

But let us analyze the situation a little. The pure science man has to consider only two things, material and energy relationships. That is all he has to work with. In industry, however, the research man has these two factors, and also the factors of economics and psychology. Is the public going to like it? Can you build it for a price people will pay? Maybe it would cost you 100 dollars to build an article as you believe it should be built; but for 25 dollars you can produce one which is 90 per cent perfect. Is it economically feasible to spend that additional money?

After all, however, such distinctions do not matter a great deal. Scientists, engineers, research workers, or whatever terms you wish to apply to them, are striving toward a common goal. They are all attempting to increase our knowledge, to accelerate progress, and the result of all this is to make the world a better and more comfortable place to live in.

★ ★ **EDITOR'S CHOICE** ★ ★

Editors of contemporary technical radio publications have been asked to select from their magazines the articles which they deem most interesting to "Radio Digest" readers. This month, M. L. Muhleman, editor of "All-Wave Radio", names "Converting B. C. Superheterodynes for Ham Communications Service" as the most suitable "Radio Digest" material printed by his publication during November and December. It appeared in December, 1937, "All-Wave Radio."

Converting B.C. Superheterodynes for Communications Use

BY R. M. ELLIS

OF COURSE it is nice to build a new receiver from "scratch." It is grand to be able to select each component, then to plan the physical layout so that the best results will be secured.

But unfortunately the financial aspect of the constructor enters into the situation. Most amateurs are long on ideas and short on cash. One solution to the difficulty is to convert a broadcast superheterodyne for short-wave work. The older types of superheterodynes can be purchased for almost a song and have very acceptable components in the way of the power transformer, i.f. transformers, choke, heavy chassis, etc.

Consequently this article will treat the problem of converting broadcast receivers for communication work and will start with the assumption that such a receiver is available.

The diagram shows the circuit employed. No claim is made for the originality of any part of the circuit. On the contrary it is the result of a very careful survey that was made of a large number of commercial and home-built superheterodynes.

It will be noticed that the receiver makes use of the older type glass tubes, rather than the newer octal glass or metal tubes. This is a receiver conversion, and for obvious reasons it was desired to use tube types which duplicated the original tube complement as closely as possible. In building a brand new receiver we would suggest the use of the now standard octal base types.

The performance of the finished receiver was very satisfactory in every respect. It is hoped that the data given in this article will be of practical assistance to amateurs and s.w.l.'s who are contemplating the construction or conversion of a receiver by eliminating the necessity of wading through reams of sometimes conflicting data on the subject.

COIL SPECIFICATIONS

160-METER BAND COILS
(1½" diameter forms)
Antenna Coil

L_1—1⅜" winding of no. 27 single cotton enamel wire, close wound, tapped at 1¼ turns

Oscillator Coil

L_2—1" winding of no. 27 single cotton enamel wire, close wound

L_3—14 turns no. 27 single cotton enamel wire

80-METER BAND COILS
(1½" diameter forms)
Antenna Coil

L_1—30 turns no. 22 enamel wire, space wound to cover 1¼", tapped at 1¼ turns

Oscillator Coil

L_2—25 turns no. 22 enamel wire, space wound to cover 1"

L_3—9 turns no. 27 single cotton enamel wire

40-METER BAND COILS
(1½" diameter forms)
Antenna Coil

L_1—12 turns no. 18 enamel wire, space wound to cover 1⅜", tapped at 1 turn.

Oscillator Coil

L_2—11 turns no. 18 enamel wire, space wound to cover 1⅜"

L_3—6 turns no. 22 enamel wire

20-METER BAND COILS
(1½" diameter forms)
Antenna Coil

L_1—12 turns no. 18 enamel wire, space wound to cover ¾", tapped at ¾ turn

Oscillator Coil

L_2—5 turns no. 18 enamel wire, space wound to cover ¾"

L_3—3 turns no. 22 enamel wire

20-METER BAND COILS
(1" diameter forms)
Antenna Coil

L_1—8 turns no. 18 enamel wire, spaced the diameter of the wire, tapped at ½ turn

Oscillator Coil

L_2—7 turns no. 18 enamel wire, spaced the diameter of the wire

L_3—3¼ turns no. 27 cotton enamel wire

10-METER BAND COILS
(1" diameter forms)
Antenna Coil

L_1—4 turns no. 18 enamel wire, spaced the diameter of the wire, tapped at ⅓ turn

Oscillator Coil

L_2—3½ turns no. 18 enamel wire, spaced the diameter of the wire

L_3—1¾ turns no. 27 cotton enamel wire

Note: Inductances are mounted in coil shields with the socket flush with the base.

Top of L_2 is the ground end—bottom is the grid end.

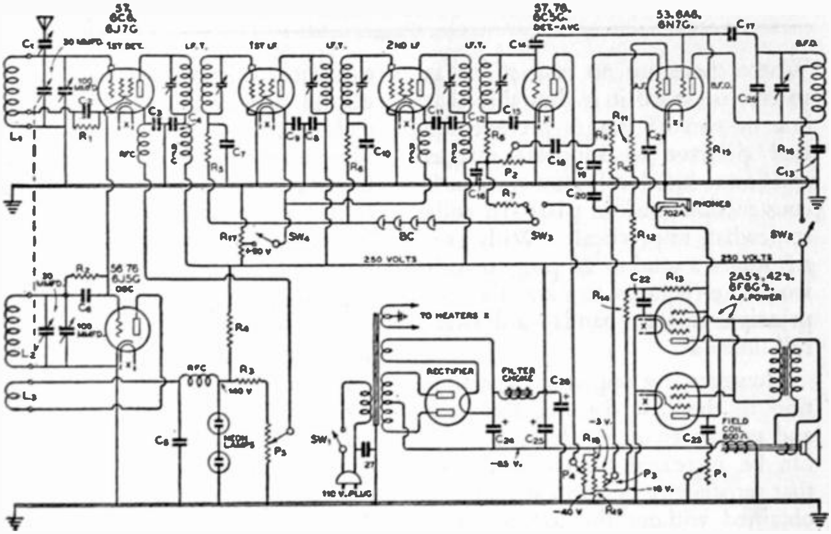
L_3. On all coils close wound, and spaced ⅛" from ground end of L_2.

The practical problems to be solved in making conversions are—

1. *Tuning method for ample band-spread.*
2. *Pre-selection or image suppression.*
3. *Addition of b.f.o. (beat-frequency oscillator).*
4. *Noise suppression.*
5. *Voltage distribution and filtering.*
6. *Voltage stabilization to prevent oscillator drift.*

• Input Circuit Considerations

In effecting the conversion of a broadcast superheterodyne one of the first things to be decided is the type of input circuit to be used.



CONDENSERS

C_1—5-35 μμfd. mica trimmer
C_2—Mallory TP436, .05 μfd., 200 volts
C_3—Mallory TP438, .1 μfd., 200 volts
C_4—Mallory TP428, .1 μfd., 400 volts
C_5—Mallory TP426, .05 μfd., 400 volts
C_6—Fixed mica, .0001 μfd.
C_7—Mallory TP436, .05 μfd., 200 volts
C_8—Mallory TP428, .1 μfd., 400 volts
C_9—Mallory TP438, .1 μfd., 200 volts
C_{10}—Mallory TP436, .05 μfd., 200 volts
C_{11}—Mallory TP438, .1 μfd., 200 volts
C_{12}—Mallory TP428, .1 μfd., 400 volts
C_{13}—Mallory TP428, .1 μfd., 400 volts
C_{14}—Gimmick—see text
C_{15}—.0005 μfd. mica
C_{16}—.0001 μfd. mica
C_{17}—.0001 μfd. mica
C_{18}—Mallory TP440, .25 μfd., 200 volts
C_{19}—Mallory TP426, .05 μfd., 400 volts
C_{20}—Mallory CS131, 4 μfd., 450 volts
C_{21}—Mallory TP428, .1 μfd., 400 volts
C_{22}—Mallory TP441, .5 μfd., 200 volts
C_{23}—Mallory TP415, .05 μfd., 600 volts (or TP413 for single tube)
C_{24}—Mallory CS136, 16 μfd., 450 volts
C_{25}—Mallory CS136, 16 μfd., 450 volts
C_{26}—Mallory CS136, 16 μfd., 450 volts
C_{27}—Mallory TP428, 0.1 μfd., 400 volts
C_{28}—.0001 mica

TUNING CONDENSERS

Band Setting — 2 Hammarlund MC-100-S 100 μμfd. midget variable condensers
Band Spread — Hammarlund MC-D-35-MX dual 30 μμfd. midget variable condensers

A.V.C. BIAS

B.C. — 4 Mallory Grid Bias Cells

RESISTORS

R_1—1,500 ohms, ½ watt
R_2—50,000 ohms, ½ watt
R_3—25,000 ohms, 1 watt
R_4—Mallory Truvolt Type A-100, 10,000 ohms
R_5—100,000 ohms, ½ watt
R_6—100,000 ohms, ½ watt
R_7—1 megohm, ½ watt
R_8—50,000 ohms, ½ watt
R_9—1 megohm, ½ watt
R_{10}—½ megohm, ½ watt
R_{11}—50,000 ohms, 1 watt
R_{12}—10,000 ohms, 1 watt
R_{13}—100,000 ohms, ½ watt
R_{14}—50,000 ohms, ½ watt
R_{15}—50,000 ohms, ½ watt
R_{16}—10,000 ohms, 1 watt
R_{17}—Mallory Variohm 5 AV 30,000 ohms
R_{18}—Mallory Truvolt Type A-.1 1,000 ohms
R_{19}—Mallory Variohm 5 AV 10,000 ohms

Note: ½ watt and 1 watt resistors are IRC Insulated Resistors, Types BT-½ and BT-1.

CONTROLS

Tone and On-Off Switch
P_1—Yaxley K12 50,000 ohms
SW_1—Yaxley No. 6-9 Switch
Volume
P_2—Yaxley N 500,000 ohms
Manual Squelch and B.F.O. Switch
P_3—Yaxley Y50MP 50,000 ohms
SW_2—Yaxley No. 6-9 Switch
Sensitivity and A.V.C. Switch
P_4—Yaxley Y50MP 50,000 ohms
SW_3—Yaxley No. 8 Switch
Standby Switch
SW_4—Yaxley 20
Detector Regeneration
P_5—Yaxley Y50MP 50,000 ohms
Beat-Frequency Oscillator
Hammarlund ST80-465
Two-Speed Vernier Dial
Crowe Name Plate No. 401 Micromaster

Where there are no restrictions as to cost or space it is desirable that one or two r.f. stages precede the first detector to suppress images and lower hiss level. However, such construction makes plug-in coils somewhat impractical. With two r.f. stages a total of 20 plug-in coils would be required to cover the five principal amateur bands—a drawer-full indeed!

However, by applying regeneration to the first detector the gain and selectivity of the detector stage can be increased tremendously, so that satisfactory performance can be obtained without the use of additional tuned circuits. Furthermore, this improvement is greatest at the higher frequencies were tuned r.f. stages lose much of their selectivity and amplification. The price paid for this simplification of construction is the addition of one comparatively non-critical regeneration control, the screen-grid potentiometer P_5.

- **Selection of 1st Detector Tube**

The selection of the proper first detector tube was a matter of concern since, in addition to providing satisfactory gain, the detector should respond smoothly to feed-back and should approach the oscillation point without having any tendency to spill over or become unstable. Low input and output capacity is desirable, particularly at the higher frequencies. Also the construction of the tube should be such to provide for convenient injection of oscillator voltage without introducing capacity coupling to the control grid. Capacity or inductive coupling between the oscillator and detector circuits must be avoided, otherwise an annoying interlocking effect of the tuning controls will occur at the higher frequencies.

A type 57 tube with a form-fitting shield was finally selected as being the most satisfactory. If your receiver employs 6.3-volt tubes, a 6C6 will give exactly equivalent results. Oscillator injection is through the suppressor grid and is accomplished simply by connecting the grid of the oscillator to the suppressor. According to tube data, maximum suppressor transconductance occurs when the suppressor is approximately 30 volts negative. In this circuit the suppressor grid is biased mainly by the grid current of the oscillator tube, and partially by the grid bias resistor, R_1, in the detector or cathode circuit.

Control of detector regeneration is accomplished by means of the 50,000-ohm linear taper control, P_5, which varies the screen voltage of the detector tube. The cathode tap of the detector coil should be placed so that oscillation occurs with 65 to 90 volts on the screen. If oscillation occurs at a lower voltage, the full gain of the first detector will not be realized. The oscillation point of the first detector also depends on the setting of the antenna coupling condenser. This condenser should be set for as little capacity as possible consistent with satisfactory gain.

In service, the screen voltage should be adjusted so that the first detector operates near the point of oscillation in order that maximum pre-selection will be obtained. Receiver volume should be adjusted by means of the sensitivity or audio gain control. The first detector should never be allowed actually to oscillate.

• Band-Spread Requirements

For c.w. work on the crowded 40-meter band it might be said that it is almost impossible to have too much band-spread, When QRM is bad, and you are copying an S5 signal against S9 interference it is easy to tune past the desired signal and lose it for a moment or two or perhaps for good. To overcome this it is desirable to build sufficient band-spread in the tuning unit to give as great as possible rotation of the condenser plates in covering the amateur bands and then to supplement this with a two-speed dial which will give further mechanical reduction.

• Electrical Band-Spread

There are a number of ways of achieving electrical band-spread, such as the use of tapped coils, series condensers, etc. The method adopted for the conversion was to use a low capacity two-gang tuning condenser (30 μμfd. maximum capacity) shunted by two 100 μμfd. midget condensers—these being provided with knobs so that adjustment can be made from the front of the panel. The degree of band-spread is regulated by the proportion of shunt fixed pad capacity to the capacity of the tuning condenser. Table I gives suggested coil specifications. If more band-spread is desired, simply reduce the number of turns so that more padding capacity is required. If less band-spread is desired, increase the number of coil turns.

In operation the oscillator pad condenser is set so that the center of the amateur band tunes at one-half rotation of the two-gang tuning condenser. Then the antenna pad condenser is tuned to resonance. Except when tuning the lower frequency bands, very little readjustment will be required of the antenna pad condenser. On the 160-meter band a slight amount of adjustment of the antenna pad may be required when tuning from one extreme of the band to the other. It is suggested that the dial settings of the pads be marked on the respective coil forms so that the receiver can be instantly adjusted to any amateur band.

• Mechanical Band-Spread

Since the receiver we are describing was to be used principally on the crowded 40-meter band we desired to add as much mechanical band-spread as practical. To this end we selected a dial with a two-ratio drive with a fast ratio of 18-to-1 and a slow-speed ratio of 100-

to-1 in 360 degrees. The dial also is provided with two pointers, which permits the close logging of stations, especially desirable for round-table QSO's or for keeping schedules.

• High Frequency Oscillator Considerations

The present wide-spread use of electrical refrigeration and other devices which place an intermittent load on the lighting circuit has created a real problem in communication receiver design. Unless special care is used in the design of the high-frequency oscillator, fading and detuning of signals will result from frequency change in the oscillator arising from variations in the plate supply voltage.

Another effect which may be noted in some receivers results from common coupling between the power tube and the high-frequency oscillator; plate voltage varying in step with the audio signal causes oscillator variation so that a received c.w. signal rises and falls in pitch like the signal from a poorly adjusted self-excited transmitter.

There are two ways of meeting these difficulties. It is possible to use a screen-grid tube in an e.c. oscillator and balance the components so that a certain compensation occurs.

However, the writer has desired to eliminate the trouble by going to its source and providing a simple neon tube regulator which will hold the oscillator voltage substantially constant regardless of fluctuations in the supply. An 874 voltage regulator tube is ideal, but rather expensive. Satisfactory results may be obtained by using two standard 2-watt neon lamps from which the series resistors have been removed. These lamps will maintain an almost constant voltage of 70 volts across their elements unless their maximum wattage rating is greatly exceeded, or unless the supply voltage falls below the ignition point. The two lamps in series provide a substantially constant 140-volt source of potential for the high-frequency oscillator.

• Preparing the Neon Lamps

To use common neon lamps for voltage-regulating purposes it is necessary that the limiting resistors be removed from the base. This can easily be accomplished by the following procedure:

First unsolder the lead in the center of the base bottom so that this wire is free. It is not necessary to unsolder the wire attached to the top of the screw base. Then hold the metal shell of the lamp in boiling water for a few minutes. This will soften the cement so that a firm steady pull will separate the brass shell from the glass bulb. Do not twist the shell—to do so may break the glass seal and spoil the lamp. The limiting resistor will be found attached to the short lead wire at the base of the bulb. Remove this resistor, solder extensions on the lamp leads, then remount the lamp either in the old brass base or in the base from a discarded radio tube; the latter mounting being preferred so that standard radio tube sockets can be used throughout the receiver.

Standard 2 or 3 watt, 115-volt neon lamps, with pear-shaped bulb and semi-circular electrodes are to be preferred for the service. Since in the circuit shown, the neon lamps are operated at about half the rated wattage, long life should be secured.

The voltage drop across the lamp will remain at approximately 70 volts regardless of wide fluctuations of line voltage.

Stabilized voltage for the high-frequency oscillator is taken from the junction of the 10,000-ohm dropping resistor, R_4, and the two neon lamps. The value of this resistor should be adjusted so that the neon lamps do not cease to glow with any adjustment of the receiver. About 10 milliamperes bleed through the lamps under conditions of normal line voltage will be satisfactory.

If the constructor does not wish to employ the neon lamp stabilizing scheme, oscillator voltage can be obtained directly from a tap on the voltage divider—though it is recommended that the lamps be used since the improvement in receiver performance is decidedly noticeable.

- Controls

The first control of the receiver is the tone control located at the left-hand side of the chassis. This control is of the conventional type consisting of a 50,000-ohm right-hand taper potentiometer. P_1, and a .05 µfd., 600-volt condenser, C_{23}, connected between the power tube plates and the chassis. If a single power tube is used, the tone control condenser may have a capacity of .03 µfd. Since the Yaxley K_{12} used is a left-hand tapered control, the center and left-hand terminals (when the control is viewed from the shaft end with terminals down) are used, and maximum bass will be with the control knob turned to the extreme left-hand position. The tone control also carries the off-on switch for the entire receiver.

The second control is the volume or audio gain control, P_2, which functions as a potentiometer to vary the output of the diode second detector. This circuit is familiar to every radio amateur and experimenter so that it will suffice to say that a 500,000-ohm left-hand taper potentiometer works very satisfactorily in this application.

The third control, P_3, is the manual squelch or class C audio control which functions to vary the bias on the first audio stage. A more complete description of the functions of this control is given elsewhere in this article. The control itself is a 50,000-ohm linear control. On the back of the control is an off-on switch which controls the beat-frequency oscillator. Combining these controls is satisfactory since neither the manual squelch

• Voltage Distribution

In making a superheterodyne conversion it may be practical to leave the present voltage distribution system intact. In many instances, however, it will be found that the resistors have aged so that they are noisy and their resistance values are no longer accurate. Also if B— is not off ground potential by 15 or 20 volts it will not be practical to install the manual squelch system for suppressing background noise. Consequently an outline of the voltage distribution system used in our receiver will be given.

The filter circuit consists of a condenser input filter, C_{24}, of 16 µfd. plus a choke in the positive lead of the power supply. This is followed by C_{25}, a second 16 µfd. condenser, and the speaker field in the negative lead. By placing the speaker field in the negative lead the voltage drop through this may be utilized to supply the various bias voltages required by the receiver. The output of the filter is terminated by a third 16 µfd. condenser, C_{26}. While the capacities indicated are considerably larger than commonly used for filter circuits, the added cost for the extra capacity is amply compensated for by the extreme quietness of operation.

Voltage distribution is made by means of two adjustable vitreous resistors, R_{18}-R_{19}, of the 50-watt size. Resistors of this rating are not necessary for the application, but are used to provide sufficient linear length so that intermediate voltage adjustments will not be excessively critical.

• Circuit Isolation

The schematic diagram shows a total of five r.f. chokes. Whether or not these may be required for your particular conversion can only be determined by experiment. For those not familiar with the action of the described circuit, it should be stated that the r.f. choke on the first detector screen lead, and the r.f. choke in the oscillator plate supply were necessary to prevent an apparent interlock between the sensitivity and regeneration controls. The addition of these chokes stopped all tendency of the i.f. amplifier to oscillate when the first detector regeneration control was advanced excessively. The balance of the r.f. chokes were necessary to secure complete stability of the i.f. amplifier.

• Selection of Components

In choosing the components for your receiver, select the best quality tuning condensers for the detector and oscillator. The tuning condensers should be of rugged construction and preferably should have ceramic insulation to prevent r.f. losses and to insure the absolute rigidity to prevent oscillator drifting. Some losses can be tolerated in an i.f. amplifier since this merely means a loss of gain, but losses in a detector circuit cannot be made up by subsequent amplification. The i.f. amplification is limited by the tube noises which are generated in the first detector circuit.

Filter condensers and paper r.f. by-passes should also be selected with care. Avoid so-called bargain condensers—nothing is harder to locate than trouble caused by a poorly constructed paper bypass condenser or a high power factor electrolytic, and a single defective condenser will ruin the performance of the best receiver.

• Mounting Parts

To eliminate the necessity of taping joints, and to provide support for resistors and condensers, little terminal connectors were used throughout the conversion. These terminal connectors consist of a small strip of bakelite upon which are fastened three double soldering lugs and a mounting bracket.

• Coil Specifications

Standard large size 4-prong coil forms, 1½" diameter and 2⅞" long, were used for winding the 160, 80 and 40 meter coils. Midget coil forms 1" in diameter and 1½" long were used for the 10-meter coils. The 20 meter coils were made on both sizes of forms, and exactly equivalent results were obtained. The coil specification table lists both types.

• Notes Regarding Oscillator Coils

If because of the availability of other wire sizes it is desired to alter the coil constants indicated in the coil specifications table, the following suggestions will be of help:

1. The number of tickler turns (L_3) should be just sufficient to insure strong oscillation with the condensers tuned to the lowest frequency of the coil range. Excessive tickler turns will cause a motor-boating effect at the high-frequency end of the band.
2. The use of small diameter wire for the tickler coil is recommended since the use of such wire will give the tickler coil a poor "Q" and lessen the effect described in the preceding paragraph.
3. The wire size of the grid tank (L_2) may be increased somewhat, but should not be decreased, or the efficiency of the coils will suffer.

●

ANCIENT and honorable is the variable resistor. It recently reached the age of 96 years.

ONE large electrical laboratory enforces the rule of keeping one hand in the pocket while working with high voltages. It is a simple yet effective safeguard against a circuit through the body and is worthy of adoption by all persons doing such work.

Condensed from I.R.E. Proceedings, Sept., 1937

---*Radiotelephony*---

Its Origin and Development

BY LLOYD ESPENSCHIED

Until now, nowhere has there been a unified account of the art of radiotelephony as a whole and of the relation of its technical substance to electric communications generally. This paper, originally delivered at the I.R.E. Silver Anniversary convention in New York this year, was written by a man who became acquainted with radio as an amateur wireless telegraphist, was associated with the founding of the I.R.E. and, for many years, has been a Bell System engineer. He has taken an active part in the development of both wire and radiotelephony.

(Illustrations given on Pages 51-53)
(Photographs and drawing courtesy of "I.R.E. Proceedings")

IT IS well to acknowledge, in the first place, the debt which radio owes to the more fundamental contributions from the physical sciences, the more pertinent ones of which, underlying as they do the entire art of electric communications, may be epitomized as three major waves of advance:

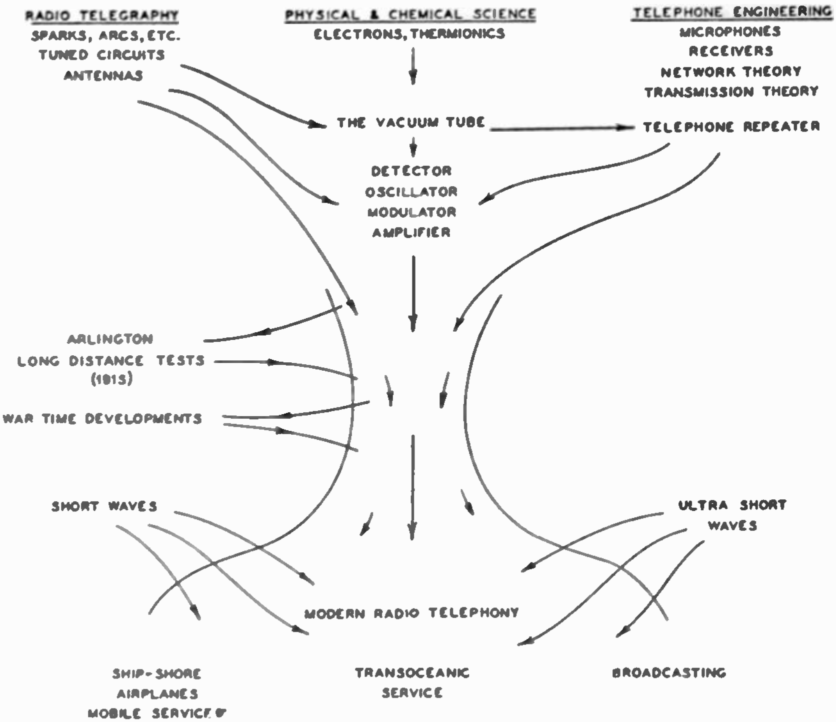
The great transition which occurred in the early 1800's from the electrostatic to the electric current and electromagnetic state of electrical science, which led to the telephone (to say nothing of electric power).

The conception and demonstration of electromagnetic wave propagation and electric oscillation, notably by Maxwell and Hertz. This advance applied to guided as well as unguided wave propagation and is the basis of the transmission art of both wire and wireless communication.

The proof of the corpuscular nature of electricity and its identity with matter, the basis of twentieth century physics and of electronics.

EARLY EXPERIMENTS

It happens that an early attempt at transmitting speech without wires was made by the inventor of the telephone himself, Alexander Graham Bell. Back in the 1880's he sent speech over a beam of light,



An attempt to diagram the flow of the art.

using reflectors in much the same way that ultra-short waves are directed today. He called the system the "photophone." Mercardier rechristened it the "radiophone" because it employed frequencies not limited to the visible range, and here we have the earliest use of the word "radio" in the sense employed today.

Of course, the more direct forerunners of radiotelephony were wire telephony and wireless telegraphy. The transmission side of both these arts came out of the early work of Maxwell and Hertz, but they developed for many years quite independently because of the great difference in the transmission frequencies involved. Early attempts at carrier-current telephony and telegraphy over wires, involving frequencies of ten of thousands of cycles and utilizing modulation, frequency circuits and detection, were unsuccessful because of the lack of suitable technique even for those frequencies, and were in general unknown to later wireless telegraph experimenters. The devices with which Marconi initiated practical wireless telegraphy were adapted to frequencies of the order of a million cycles, generated discontinuously by means of sparks. In time wireless telegraphy evolved toward the use of continuous waves and, by such means as the high-frequency alternator and the oscillating arc, bridge the gap between the radio and the wire frequency ranges.

In the period of 1906-1912 radiotelephony was an experimental fact but a practical non-reality. Many were the early experimenters who had succeeded in transmitting speech over distances of some miles, notably Fessenden and De Forest in America, and Majorana, Vanni, and Poulsen in Europe. In 1911 General Squier, of the United States signal corps, brought widespread attention to the possible application of the then wireless instrumentalities to high-frequency transmission over wires.

But, radiotelephony remained for the radio experimenter a golden goal of attainment, for there were wanting practicable means for generating the high-frequency currents, for controlling them in accordance with the relatively weak waves of speech, and for renewing at the receiving end the waves so greatly weakened in transit. The story which follows of the successful meeting of these problems, principally by means of the vacuum tube, is broken by the incidence of the Great War into three periods.

•

FORMATIVE PERIOD: 1912-1916

In retrospect, it is now apparent that by about the time of the formation of the Institute the general front of technical advance had reached the point of almost inevitably yielding the solution of the radiotelephone problem. The two-element and three-element vacuum tubes existed, knowledge of thermionics and means for attaining higher vacuua were accumulating, coupled tuned circuits were well-known, and in wire telephony the basis had been laid in the loaded-line theory for the electric wave filter and circuit network philosophy. But lest the attainment of radiotelephony seemed too easy, let us follow in a little more detail how the structure of the art was built.

Dr. Lee De Forest invented the three-element tube in 1906-1907, but it was not until about 1912 that he succeeded in adapting it under some circuit conditions to operate as a true amplifier. In the fall of that year he and an associate, John Stone Stone, demonstrated the audion to engineers of the telephone company in the role of an audio amplifier, a candidate for the solution of the telephone repeater problem.

The device was still a weak and imperfect thing, had in the grid circuit the familiar blocking condenser of the audion detector, and was incapable of carrying any considerable voice load without blue hazing; yet, it *was* capable of amplifying speech.

Among those in the telephone laboratory who witnessed De Forest's demonstration was one H. D. Arnold, then fresh from the study of electron physics in Dr. Millikan's laboratory of the University of Chicago. Whereas there had always been confusion of thought concerning the effect of gas upon the operation of the audion, Arnold immediately recognized that what was wanted was a pure thermionic effect, free of gas complications. He set to work to produce a higher vacuum tube, using evacuation methods then only recently available. He succeeded and, once and for all, took the three-element tube out of the realm of uncertainty and unreliability and made of it a definite, reliable, amplifying tool.

About the same time that Arnold was doing this in the laboratories of the telephone company,* principally in 1913, Langmuir, in the laboratory of the General Electric Company, studying the problem of X-ray tubes and power rectifiers, arrived at substantially the same result. In a patent contest lasting many years the supreme court of the United States gave to Arnold the credit of having been the first to attain the truly high-vacuum tube and agreed with Arnold's original viewpoint that this step, important though it was, did not constitute invention over the prior art.

By the time the high-vacuum tube was obtained, several gaseous forms of tubes had appeared. One of these was of the mercury-vapor type, employing magnetic control, which was being worked upon by Arnold as a telephone repeater at the time the audion was first called to his attention. Another was the tube of von Lieben and Reisz, of Austria and Germany, which employed a grid element. All such gaseous devices were soon eclipsed by the high-vacuum tube.

The high-vacuum tube was further improved in 1913 by the application to it of Wehnelt's oxide-coated cathode. The filament electron emission was thereby increased, producing the dull-emitter type of long-life tube. The vacuum tube in this form, stable, with adequate filament emission and long life, set the pace in the amplifier art from that time forward, and was the practical basis of the succession of further developments which resulted in practical radiotelephony.

• Oscillator

One of the next developments was, of course, the conversion of the vacuum tube amplifier into a generator of high-frequency currents. This was accomplished first by De Forest in 1912, according to a decision of the United States su-

* *By "telephone company" is meant the American Telephone and Telegraph Company and Associated Companies, including the Western Electric Company, and now also the Bell Telephone Laboratories, which comprise the Bell System.*

preme court. Others did it independently about the same time, notably Armstrong here and Meissner in Germany. Particular forms of oscillating vacuum tube circuits were developed by other investigators, including C. S. Franklin and H. J. Round, of the British Marconi company, and Colpitts and Hartley, in the United States.

The earliest uses known to have been made of the oscillator in radiotelephony are the experiments of Meissner in Germany in 1913, between Berlin and Nauen, using the von Lieben-Reisz tube, and of H. J. Round of England, early in 1914 in experimental transmission between two ships.

• Modulator

Another major step, the invention of the vacuum tube modulator, soon followed. This solved the problem of enabling low power voice energy to control the considerably higher power waves required for radiotelephone transmitting, enabled this control to be exercised remotely over a telephone line, thereby giving through-transmission between wire and radio circuits. The earlier attempts at radiotelephony had depended for modulation upon the carbon microphone, usually worked directly in the antenna ground circuit. Here, again, we have a case of several investigators arriving at the invention at about the same time, 1913-1914, with Alexanderson, of the General Electric company, and Colpitts, of the telephone laboratories, sharing the honors. Other modulating circuits followed. The telephone engineers had in mind doing the modulating at lower power and then amplifying the modulated current by means of a high-frequency amplifier.

• H. F. Vacuum-Tube Telephony

By the latter half of 1914 there was within grasp in the laboratories sufficient of the high-frequency technique, based upon the high-vacuum tube, to cause the telephone engineers to set about the development of high-frequency telephone systems. The first attempt was at the wire carrier-current problem. A two-channel multiplex system was set up using vacuum-tube oscillators, modulators, amplifiers, and detectors. The result was decidedly encouraging. Since the same instrumentalities were applicable to radiotelephony, there was next undertaken the development of a vacuum-tube radiotelephone system.

• Long-Distance Tests of 1915

Vacuum-tube radiotelephony was now to be taken out of the laboratory for a field trial. A vacuum-tube transmitter of a few watts output was developed and installed at Montauk Point, Long Island, and an amplifying receiver was located at Wilmington, Delaware, 200-odd miles distant. The distance was then stretched to some 600 miles by receiving the Montauk transmitter at St. Simons Island, off the coast of Georgia. These were one-way transmissions. For some of them the reception was brought back to New York by wire lines. The speech was itself clear, but was sometimes buried in noise due to the small transmitting power and the fact that it was the spring of the year. Wavelengths of 800 to 1800 meters were employed.

The success of these preliminary tests, together with the promise of laboratory developments for higher-power transmitting tubes, now led to a bold attempt on the part of the telephone engineers to overcome that great natural barrier of telephony, the oceans. Through the co-operation of the United States navy department, on the one hand, and the French administration, on the other, appropriate field stations were made available for the tests. The large antenna of the naval station at Arlington, Virginia, was used for transmitting. A new vacuum-tube radiotelephone transmitter was developed, employing hundreds of tubes, each having a capacity of the order of fifteen watts, and installed at Arlington. For reception the navy department made available their stations at the Canal Zone, on the Pacific coast, and in Hawaii. Through the kindness of General Ferrié, of the French administration, use of the Eiffel Tower station was permitted the American telephone engineers for receiving purposes.

By June all the distant receiving points were covered by engineers who had been dispatched from New York provided with the then latest receiving apparatus; the new telephone transmitter had been installed at Arlington; a great effort was being made in the laboratories to produce the necessary quantity and quality of power tubes. The tests continued on and off during the entire summer on a reduced power basis, during which the difficult atmospheric conditions were studied by the receiving engineers. As the transmitting power was built up, and as the conditions improved with the coming of fall, results began to be obtained, first from Panama; next, from the Pacific coast, representing transmission across the continent; then, from more distant Hawaii; and, finally, in November from Paris, where the receiving conditions had proven to be most difficult.

These were, of course, one-way transmissions.

Some of the technical features of the apparatus of these early tests were:

In the transmitting station, the use of the master-oscillator, power-amplifier type of circuit, operating in the 30- to 100-kilocycle range, with circuits designed to accommodate the "carrier and sideband" aspect of the modulated wave.

The development of power tubes of the order of fifteen watts, requiring new designs and more thorough pumping and degassing.

The operation of large numbers of tubes in parallel (as many as 500), in order to build up the necessary transmitting power. The problem of operating these tubes in parallel and preventing singing can well be imagined. An average power of two or three kilowatts was obtained in the antenna. A photograph of two banks of 250 tubes each is reproduced in figure 2, the tips of some of the tubes showing on the right. (See pages 51-54.)

Receivers employing a radio-frequency amplifying stage, plus two audio-frequency stages. Heterodyne detection was employed to find the carrier. Homodyne reception of the telephone signals was used at some of the receiving points.

The following year, 1916, tests of radiotelephony were made for the United States navy, which included what is believed to have been the first attempt at tying together radio and wire lines for through two-way radiotelephony. The secretary of the navy, Josephus Daniels, talked from his desk in Washington, D. C., with the commanding officer of the *U.S.S. New Hampshire,* off the Chesapeake Capes. During this year the important subject of modulation was advanced and Heising devised his well-known "constant-current" system of modulation. The simplicity of this system led to its use in the radiotelephone sets which were produced during the war and in the early radio-broadcast transmitters. Incidentally, early in this same year there was undertaken anew the problem of carrier-current telephony and telegraphy, this time looking toward commercial designs, utilizing the newly acquired instrumentalities of the vacuum-tube and the electric wave filter. The application of the vacuum tube amplifier to voice-frequency telephone circuits was also proceeding apace.

Radiotelephony was now progressing rapidly, building upon and, in turn, stimulating its antecedent and contemporary arts of wire telephony, wireless telegraphy, and electronics.

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THE WAR PERIOD

The war came to Europe before the new vacuum-tube art and radiotelephony had been fully born. Vacuum tubes were employed in the war by the European countries for radiotelegraphy, but radiotelephony is not known to have played a part on the continent. This may have been due in part to the lack of secrecy of this form of communication.

In the United States the normal development of radiotelephony continued, as we have seen, up to the time of this country's entry into the war. The new vacuum-tube radiotelephony had by then assumed real promise. The United States government undertook to develop two-way radiotelephone sets on a large scale for dispatch purposes on submarine chasers and airplanes. In

ARTS UNDERLYING RADIOTELEPHONY

Wire Telephony	Wireless Telegraphy	Electronics
Electroacoustics Transmitters, receivers, characteristics of sound, high-quality reproduction	Generators and receivers of high-frequency currents; selective circuits	Discovery and study of the electron (Crookes, J. J. Thomson and others)
		Thermionics (Richardson, Wehnelt and others)
Wire Transmission Propagation constant, characteristic impedance, transmission measurement, interference, carrier wave filters, and network theory	Antennas Dipole (Hertz), grounded (Marconi), directive	The Edison effect and the Fleming valve
	Wave Propagation Spreading and absorption, ground and sky waves, effects of solar and meteorological phenomena	De Forest 3-electrode tube
Amplification Microphone, repeaters		High-vacuum, high-power, and multielectrode tubes

the short space of a year or so, hundreds of thousands of tubes and thousands of sets were developed and manufactured. The apparatus was featured technically by:

General use of the high-vacuum, oxide-coated filament type of tube.

Employment of the constant-current type of modulation.

Attempt to make the operation of the sets simple and fool-proof, as by the elimination of filament rheostat and the standardizing of tubes and circuits to permit ready interchangeability.

Such apparatus was used in some quantity on submarine chasers of the navy, but the large production program for airplanes was not completed in time to enable radiotelephony to come into play in the army on the battle front. From the technical standpoint the program stimulated apparatus design and gave a useful experience in the standardization and quantity production of tubes.

Through the many military training schools in the United States the new vacuum tube radiotelephony art was "broadcast" to the most likely young men of the country, many of whom developed a real interest and after the war helped to swell the peacetime development.

POST-WAR DEVELOPMENTS

The peacetime development of the art was now immediately renewed, especially in the United States where the technical effort had been sustained throughout the war. It became evident to the several large companies, particularly the American Telephone and Telegraph company and the General Electric company, which were pursuing the vacuum tube art, that their inventions so interleaved as to require an exchange of patent rights. This took the form of an interlicensing agreement, entered into by these two companies in 1920. It enabled the telephone company to use tubes on its lines and to proceed with the development of two-way radiotelephony. The General Electric company and its affiliates, including the R.C.A., were free to proceed in other fields, principally radiotelegraphy, and, as it turned out, in broadcasting.

• Early Ship-to-Shore Telephone Experiments

The telephone company had by this time undertaken development work in marine radiotelephony, partly as a means of advancing the art and partly with an eye toward the eventual establishment of a mobile public telephone service connecting with the land line system. Experimental shore stations were provided, and ship apparatus capable of duplex operation was devised and tested on coastal vessels and on one of the transatlantic liners. This work was done in the frequency range then most available, that of the order of a million cycles. Shortly thereafter broadcasting preempted this range and because of this and of the post-war depression in shipping, these experiments did not then materialize into a service. Trial connections with the land line network extending across the continent and to Catalina Island served to demonstrate the possibilities of combined wire and radio. Some of the technical attainments in this work were:

Development of duplex systems for ship use.

Development of superheterodyne receivers.

Progress in placing radio transmission upon a quantitative basis by the measurement of received field strengths and the overall circuit equivalent of radio links, and in the setting up of radio links as integral parts of long land line connections.

Beginning of the volume indicator, used to insure the voice loading of the radio transmitter and later employed extensively on wires, as well as in radio.

• First Public Telephone Service by Radio

Another pioneering undertaking about this time, 1920, was the development of what has proven to be the first use of radiotelephony for public service, in the form of a point-to-point link on the Pacific coast between Catalina Island and Long Beach on the mainland, connecting thence to Los Angeles. Service was given over this link for about a year, when the frequency band being used was wanted for the then newly developing service of broadcasting. The telephone service itself came near being a broadcast one, so extensively were the conversations listened to by amateur radio enthusiasts. The system was replaced by a submarine cable.

From the standpoint of technical progress, this installation included a number of interesting features:

Full-duplex operation in the sense of separate channels for the two-directions of transmission, joined at the terminals to the two-wire telephone network by means of hybrid coils.

Through voice-frequency ringing, the first application to radio.

Superheterodyne receiving sets, incorporating wave filters in the intermediate-frequency stages which separated out.

A telegraph channel which was superimposed upon; i.e., multiplexed with, the telephone channel and used independently for telegraph service with the Island.

The provision toward the end of the period of means for rendering the telephone transmission private, comprising voice inverters, plus carrier-frequency wobbling, the first installation of this combination to have been made.

The picture of the Long Beach receiver in figure 4 shows at the top a portion of the loop receiving antenna; in center foreground, the circuit control desk; above, to the right, the speech inverter for privacy; and, in the left background, the apparatus of the superimposed telegraph channel. (See pages 51-54.)

• Broadcasting

By 1920-1921 the stage was set in the United States for radio broadcasting. A radiotelephone technique was becoming available in the relatively empty portion of the frequency range centering about one megacycle. Something of an audience existed in the thousands of amateur radiotelegraphists spread throughout the country, a lively public interest in radiotelephony had been aroused during the war, and all that was needed to excite the public generally into providing itself with receiving apparatus was to have the experience of hearing speech and music on the air.

Public interest was first fanned by amateur listening to the experimental telephone transmissions being conducted by various people, amateur and professional. Engineers in making tests frequently availed themselves of reports written in by listeners, as a means of checking in a general way the effectiveness of their transmitters.

Of all the experimental activity at the time, it happened to fall to the personal efforts of Frank Conrad, an engineer of the Westinghouse Electric and Manufacturing company, Pittsburgh, Pennsylvania, to give rise to broadcasting of a continuing nature. Starting with transmissions from his home, the activity was taken up by his company, which had been engaged during the war in making radio apparatus for the government, and the experimental emissions were evolved into a continuing program, accompanied by the entering of the company into the business of supplying receiving sets. The original transmitter of the now well-known station of KDKA is pictured in figure 5 as it appeared on the occasion of its first broadcasting, when it sent out the returns of the presidental election on November 2, 1920. Note that the room which housed the transmitter served also as the studio. Public interest mounted rapidly and within a few years transmitting stations were growing up throughout the country and a boom was on in receiving sets. (See pages 51-54.)

This great burst of activity brought with it real concern as to the character which broadcasting might assume and as to how it could be supported as a continuing service. It being a form of telephony, the telephone company undertook to explore the field from the sending end by engaging in broadcast transmitting. There evolved the idea of putting the transmitter at the disposal of others for hire (toll broadcasting), the sponsored program, and arrangements for the syndication of programs over the wire telephone network. Thus was demonstrated the ability to support broadcasting from the sending end.

One of the first five-kilowatt, water-cooled transmitters, that used in Station WEAF of the telephone company in 1924, is shown in figure 6. Aside from representing an advanced design at the time, this transmitter is associated with an interesting bit of technical history. A 500-watt transmitter, which had been used just before it, had shown bad quality when received in certain outlying sections of the city on the far side of groups of skyscrapers. This gave rise to the making of one of the first studies of the broadcast transmission medium, including the element of fading and coverage. The trouble proved to be due to the effect of the tall buildings in attenuating the direct transmission and making apparent interference between multiple paths. The effect of the interference upon quality proved to be exaggerated by a degree of frequency modulation occurring in the transmitter. The latter trouble was removed by the adoption in the five-kilowatt transmitter of the master-oscillator type of circuit, employing piezo-electric crystal control, one of the first transmitters so provided. (See pages 51-54.)

The intimate interplay which existed technically between telephony broadly and broadcasting is shown also in the high quality side of broadcasting, involving studio acoustics, high-quality microphone pickup and high-quality amplifiers. In the beginning of broadcasting the pickup and amplifying means were taken more or less bodily from the high-quality speech study work which had been going on in the telephone laboratories, and from public address systems. In 1919 a great public address demonstration had been made in New York upon the occasion of a Liberty Loan; and in the summer of 1920 such systems had played a prominent part in two national political conventions. Addresses delivered over such systems from a distance emphasized the need for high-quality lines. As a result of such experience and the considerable amplifier network technique which had been built up in the long-distance telephone field, it was possible at an early stage of broadcasting to adapt telephone lines to handle as wide a sound-frequency band as the economics of the situation justified.

• Broodcost Receivers

A realization of the progress which has been made in broadcast receivers is had by contrasting the modern, stable, and selective loud-speaker set with the ticklish crystal or regenerative battery set with which listeners first heard whispers in headphones. One of the first advances was to the high-frequency amplifying set, whereby sensitivity was achieved together with simplicity of adjustment. The stabilizing of these sets against singing stimulated the art of tube-balancing circuits and is remembered by Hazeltine's neutrodyne. The superheterodyne, the indirectly-heated cathode tube permitting operation from the alternating-current supply mains, the screen-grid tube, automatic gain control, featured the rapidly evolving receiving-set technique. Loud speakers progressed from the old horn type to the armature driven cone, to the electrodynamic, and multiple-unit system. While many of these advances had their origin elsewhere than in broadcasting, certainly the quantity production of broadcast receiving sets has been a powerful leaven in advancing the weak-current technique generally.

• Tronsoceonic Telephony

As broadcasting was getting started, continuing research in the laboratory gave promise of considerably greater transmitting powers, in the form of the copper-anode, water-cooled tube. This and the other advances which had occured since the original transoceanic experiments of 1915 indicated that it might be timely again to undertake the problem of extending telephony overseas.

A powerful water-cooled amplifier, the first of its kind, was developed and in 1922, in co-operation with the R.C.A., was installed at the transatlantic transmitting station at Rocky Point, Long Island. Success attended the first objective of developing an antenna power of the order of 100 kilowatts and the transatlantic project was vigorously pushed. This work being in the then relatively low frequencies, it was possible to adopt single-sideband, carrier-suppressed transmission by borrowing that feature more or less bodily from the wire art, whereby the transmitting effectiveness was multiplied by a factor of about ten. The transmitting path to England was studied by making measurements there, in collaboration with the engineers of the British post office, of the diurnal and seasonal variations received and of the noise levels. A further improvement was obtained by borrowing from the wireless telegraph art the newly-developed directive antenna known as the Beverage wave antenna.

• Higher Frequencies and Mobile Services

The extension or radio to the higher frequencies, or shorter waves, gave new opportunity for the development of radiotelephone services because of the greater message-carrying capacity of the higher frequencies and the greater transmission range.

Following the introduction of short waves to transatlantic telephony, the ship-to-shore problem was undertaken anew on a short-wave basis and service was initiated on the North Atlantic in 1929. On the shore end the essential facilities comprised a duplicate of one of the transatlantic point-to-point installations, including directive antennas pointing out along the transatlantic shipping route, and means for effecting two-way operation and for connecting into the wire network. The ship installation included a transmitter of 500 watts capacity, employing a new screen-grid power tube. As a result of "stay noise," there was adopted the "cut carrier" method of transmission. As it has turned out, no American ships yet have been equipped permanently for service, but most of the larger foreign vessels are so equipped and marine telephone service is being given from both sides of the Atlantic.

A related form of marine telephone service is that to small boats. In the United States this started somewhat as a continuance by the coast guard of the submarine chaser installations of the war. In Europe fishing trawlers have been provided with simple radiotelephone sets in considerable numbers. In these installations the intention has been to enable the boats to talk with each other and with certain land stations; not with the landline telephone users. Small-boat telephony linked with the landline network is a more difficult matter. It is now under active development in the United States on both the east and west coasts, and on the Great Lakes, and in some countries in Europe. The installations in the United States are of crystal-controlled sets, designed to be used directly by the officer of the ship without technical attendance. Many of the ships are equipped to be "rung" individually as wanted by the shore station. The small boat telephony works generally in the medium-frequency range of two to three megacycles.

Another type of mobile service is that being used throughout the airways of the United States in maintaining contact between the planes and the ground stations. Telephony has proven particularly useful here because of the facility it offers the pilots of communicating directly on a two-way basis with ground stations. The service is operated generally in the three to six-megacycle portion of the spectrum. The apparatus is crystal controlled, of special design for lightness, simplicity of operation, and reliability. This type of service was well started about 1929.

A third type of mobile radiotelephone service, and one which has become quite important in the United States, is that of the various city and state police departments, used to direct patrol cars. Most of these services are limited to one-way talking to the cars, and operate on intermediate frequencies. Now that ultra-high frequencies are becoming available, some of these systems are being extended to two-way service. The apparatus is generally similar to that employed in the aviation service.

• Ultra-High Frequencies

The recent extension of the radio technique to ultra-high frequencies brings new opportunities and also new problems for radiotelephony. One of the earliest practical trials of these frequencies for telephony, and one representing at the time a very large jump in frequency, was the seventeen-centimeter wave propagation across the English Channel in 1931, accomplished by the system developed by the laboratory of Le Matérial Télephonique of Paris, using the Barkhausen type of oscillator. Further experience has shown frequencies as high as this to be susceptible under some circumstances to rather serious transmission instability, resulting, it has been suggested, from changing moisture content of the air or from turbulent atmospheric conditions. A number of short radiotelephone links are now being operated in various parts of the world on somewhat lower frequencies, generally in the range of 40 to 100 megacycles.

It appears that as rapidly as the message-carrying capacity of radio is enlarged by extension to the ultra-high frequencies, the demand increases on the part of the older services and of entirely new services, such as television. How much of the spectrum may be available for telephony will naturally be influenced by relative usefulness and economics. One problem is how to obtain radiotelephony sufficiently economically to "prove it in" for the shorter distances which characterize the useful range of these waves. Another is the one of preserving the privacy of communication by relatively simple means. It may be that the principle use of these waves for telephony will be for mobile services, thereby helping telephony keep pace with our increasingly mobile way of living.

• Leaven of the Art

In describing the rise of radiotelephony we have spoken principally of physical things such as the vacuum tube, the filter circuit, etc. Another cross section of the art would be the leaven of ideas which gave rise to it, the analyses and the reductions to measurement which enabled results to be obtained by design. That radiotelephony is particularly rich in this respect will be evident from the following citation of some of the more outstanding analytical contributions.

One of the first is that of van der Bijl's early study of the operation of the vacuum tube. In 1913-1914 he derived approximate expressions for the plate current in terms of plate and grid voltage, and presented the concept of the amplification factor μ. This work was published toward the end of the war and was the forerunner of his 1920 book on the vacuum tube, an authority for many years.

One of the earliest elucidations to be published on the operation of the audion as detector was the 1914 paper of Armstrong.

Next, there is the more exact mathematical solution of the plate current in terms of the tube constants and grid voltage variations, given in an I.R.E. paper in 1919; and the treatment of the vacuum tube as a part of a circuit network published the same year.

A potent factor has been the growing appreciation throughout the electric communication art generally of Fourier's theorem and the steady-state concept of transient phenomena. Related thereto is the band idea of wire telephone transmission which developed out of the frequency-band nature of speech itself, the characteristics of line, and the necessity of suppressing reflections at circuit junctions. Campbell, using the loaded-line theory, combined the band idea of telephony with the sharp selectivity feature of radiotelegraphy to secure the wave-filter characteristic of a uniform transmission band, plus a sharp cutoff. This was a milestone in the development of circuit network theory.

Related to both vacuum tubes and the band conception were Carson's analysis of the modulated wave into the component carrier and sidebands and his invention of single-side-band transmission, made as far back as 1915, and the general extension of the signal-band idea to high frequencies, which has meant so much to both wire carrier-current telephony and radiotelephony.

In the field of measurement and standardization there are the technique of making single-frequency measurements throughout a band, the decibel unit of attenuation, the volume indicator and the concept of volume range, and the measurements of the field strength of desired signals and of noise.

Figure 1 represents an attempt to diagram the flow of the art as a whole.

FUTURE

Radiotelephony may be said to have "arrived" and to be still young. Looking toward the future, the writer likes to think of radio and wire telephony as increasingly dovetailing together to form one general front of advance. The principles and technical tools being fundamentally the same for both, a technical advance in one is likely to help the other. Thus radio has led the way to the higher frequencies and this has benefited wire communication, as we see in the carrier-current and wide-band coaxial cable development. As regards services, we observe that radio and wire telephony are one and the same thing in respect to the overall result, that of the delivery of sound messages. Where one or the other is to be used will be a matter of natural adaptability of the medium of transmission and of the economics of the situation, with the meeting line shifting from time to time, but with the main emphasis upon integration rather than differentiation. Thus does radiotelephony become an integral part of telephony and of the whole field of electric communications.

Chicago Museum To Open Radio Section

SHORTLY to open in the Communications section of Chicago's Museum of Science and Industry is an elaborate exhibit which will trace the rise of radio from its earliest days to the present. Among the equipment to be installed is a wide range of "ancient" radio material donated by Allied Radio Corporation of Chicago.

Young as the radio industry is, it has already progressed to the point where a complete history is in order; it is this history that the museum intends to portray.

World Radio Convention

IN KEEPING with the celebration commemorating the 150th anniversary of the foundation of Australia, which is being held in Sidney, New South Wales, from January to April of this year, the Australian Institution of Radio Engineers plans a World Radio Convention. The Marchesa Marconi, widow of the late Guglielmo Marconi, will be guest of honor. David Sarnoff, president of NBC and RCA, will be another of the eminent guests. Great Britain will be represented by Sir Noel Ashbridge, chief engineer of the BBC, who is arranging to proceed to Sydney after he attends the radio conference in Cairo in February.

The convention commences April 4, and concludes April 14.

Inquiries concerning the convention may be addressed to the General Secretary, Institution of Radio Engineers (Australia), 30 Carrington Street, Sydney (N.S.W.), Australia.

From The Bell System
Technical Journal,
October, 1937

U.H.F. Negative-Grid Triode Oscillator and Amplifier

BY A. L. SAMUEL

THE AUTHOR describes three negative-grid triodes of unusual design which operate both as oscillators and as amplifiers at ultra-high frequencies. The power output of the smallest tube as an oscillator at 1500 megacycles is 2 watts, and it is still capable of an output of 1 watt at 1700 megacycles with an oscillation limit of 1870 megacycles corresponding to a wave length of 16 centimeters. This tube also offers possibilities as an amplifier at frequencies as high as 100 megacycles. Such capabilities of the negative-grid triode are notable since this device has appeared to lag behind the magnetron as an *oscillator* at frequencies of above roughly 500 megacycles, while the only successful power *amplifiers* which have been described for frequencies of the order of 300 megacycles are multi-element tubes.

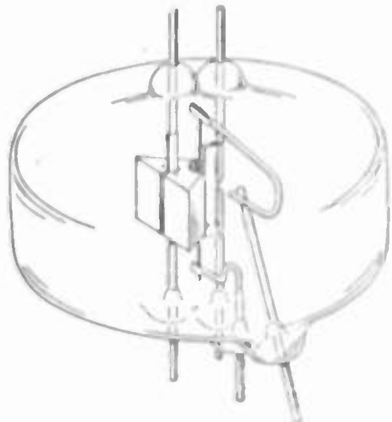


Figure 1. Section view of tube. Note the unusual lead arrangement which possesses a number of unique advantages.

The triode as used at radio frequencies differs from the multi-element tube chiefly in the manner in which interaction is prevented between the input and output circuits. This is obviously a circuit limitation, as contrasted with the electron transit time limitation which has received so much attention. The

*Digest of a paper presented before International Scientific Radio Union April 30, 1937, at Washington, D. C. Published in *Proc. I. R. E.*, October, 1937.

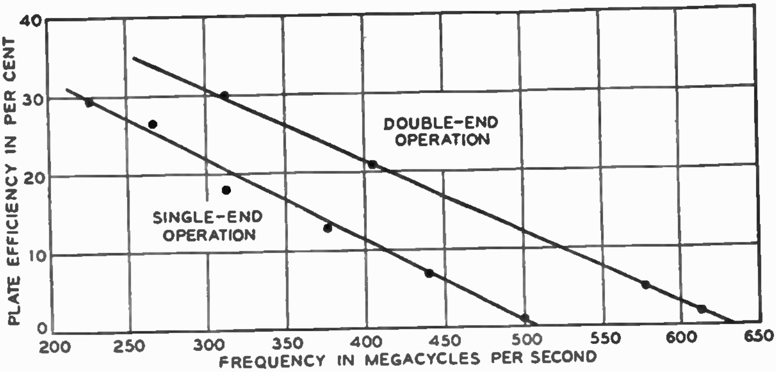


Figure 2. Comparison plot of output efficiency for the large tube when operated single-ended and double-ended.

greatest opportunity for improvement seems to be in the direction of improved circuit design. The tubes described in this paper were developed from this point of view.

They differ from previous designs primarily in the lead arrangement. From the section view of one of these tubes, shown in figure 1, it will be observed that the grid and plate elements are supported by wires which in effect go straight through the tube envelope providing two independent leads to each of these elements. The filament leads are at one end only and one of these leads is extremely short. This unusual lead arrangement possesses a number of unique advantages.

In a typical oscillator circuit, the tube is mounted at the center of a half-wave Lecher system. This arrangement provides a higher natural frequency circuit than that of the quarter-wave Lecher system formed by removing one set of leads. Since only half of the total charging current to the inter-electrode capacitances flows through each set of leads, the losses due to the lead resistances are also reduced. In the tubes under discussion the electron transit time limitation has been met by the use of extremely small inter-electrode spacings so that full advantage may be taken of the increased frequency range.

For the purpose of confirming the above conclusion, efficiency curves have been obtained on the large size tube, when operated both single- and double-ended. The results are shown in figure 2. It will be observed that the efficiencies for double-ended operation are always higher than for the single-ended case over the range covered by the experimental data. In fact, usable outputs are obtained at frequencies well beyond the point where the single-ended tube fails to operate. The ratio of the cut-off frequencies for the two tubes happens to be 1.23 for the particular conditions under which these data were obtained.

Output and efficiency curves for the large size tube are shown in figure 3. The values of 60 watts at 300 megacycles and 40 watts at 400 megacycles compare quite favorably with outputs reported from radiation-cooled magnetrons. When the problems of modulation and the complications of the magnetron's magnetic field are considered, the advantages of the negative-grid triode become more apparent. The improvement in power output made possible by this departure in design is illustrated by the comparison plot shown in figure 4.

The double-lead arrangement is also responsible for an increase in the upper frequency limit at which stable operation as an *amplifier* may be secured.

The primary cause for instability of the triode amplifier is the interaction between the input and output circuits which results from the admittance coupling between these circuits provided by the grid-plate capacitance. A second source of coupling is that caused by common impedances in the two circuits in the nature of the self and mutual inductance of the tube leads. At moderately high frequencies this latter coupling is usually of negligible importance. Stable operation is thus possible when suitable means are provided to compensate or "neutralize" the admittance coupling. At ultra-high frequencies lead - impedance coupling can no

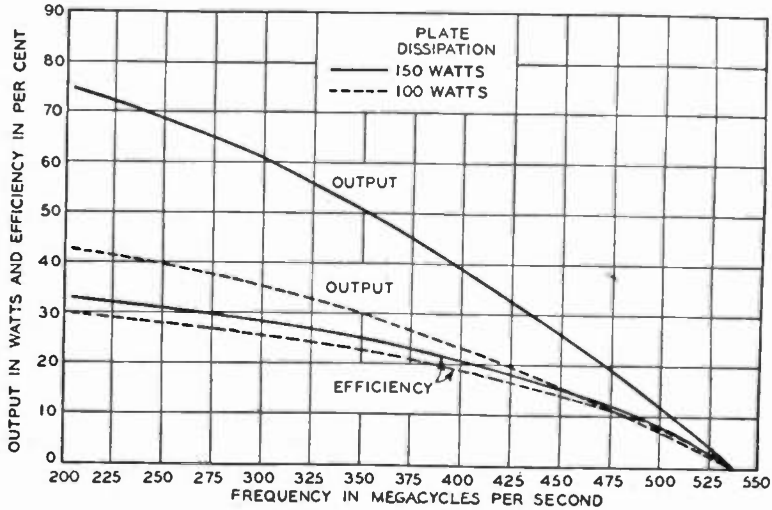


Figure 3. Output and efficiency as a function of frequency for the large tube.

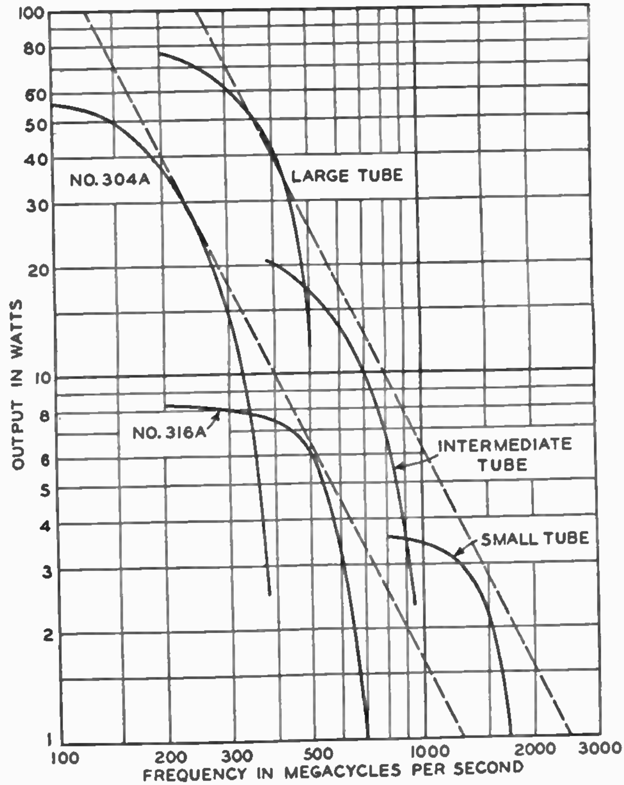


Figure 4. Comparison plot of the outputs of the double-lead tubes and of commercially available tubes.

longer be neglected. It may, of course, be minimized by the use of short leads. The ultimate solution is to provide independent leads for the input, output and admittance neutralizing circuits. The double-lead tube is an attempt to fulfill these conditions. It will be observed that the only common impedance remaining is that caused by one filament lead and that this lead is extremely short.

In the present investigation the method of neutralizing admittance coupling has been that disclosed by H. W. Nichols in U. S. Patent 1,325,879 and involves the resonating of the offending admittances at the desired operating frequency so that the resulting parallel admittance is reduced to a very low value. This takes the form of an inductance connected between the grid and plate of the tube and adjusted to resonate with the grid-plate capacitance. For ease of adjustment a somewhat lower fixed inductance may be used and tuned by the adjustment of a small variable condenser in parallel. This form of neutralization is commonly referred to as "coil" neutralization. At ultra-high frequencies where unavoidable inductances are already present in the form of lead inductances, this "coil" scheme possesses outstanding advantages over the more usual "capacitance" schemes. These advantages become even more pronounced with the availability of the double-lead tube.

Verifying this analysis, a "coil-neutralized" two-stage amplifier using two of the largest size tubes was found to yield an output of 60 watts at 144 megacycles for class B operation. Stability, distortion, and band width were quite comparable to the results obtained on a pentode of similar rating. A four-stage amplifier employing the intermediate tube gave comparable results and although experimental data are not yet available, it seems reasonable to assume that the small size tube will permit stable operation as an amplifier at frequencies as high as 1000 megacycles.

The double-lead tube is therefore seen to possess a number of distinct advantages, both as oscillator and as amplifier, in the frequency range from 100 megacycles to 1000 megacycles. While the ultimate limit to which such developments may be pushed is still a matter of conjecture, it seems safe to predict that the triode will be able to meet the demands of the circuit designer at least for some time to come.

What, No Ground Wave?

For many years radio engineers, hams, etc., have accepted the conception that there was radiated by a vertical radiator and to a less extent by a horizontal radiator a certain component called the "ground wave" or the "surface ray." This ray was thought to be guided by the earth in the same manner that a wave is guided by a pair of wires. Recent investigation by C. R. Burrows of the Bell Telephone Laboratories has proved this assumption to be incorrect.

Since transmission of this so-called surface ray would be best over a good dielectric, Mr. Burrows performed his experiments over a very deep lake of fresh water, Seneca Lake in New York. The receiver was installed in a small power boat and the transmitter was towed behind at varying distances. In addition, curves were plotted across the lake at greater distances.

The results of the experiment were in very good agreement with Weyl's formula, which has no term that corresponds to the surface wave. The experimentally determined values were very much smaller than the values that would be predicted through the use of Sommerfeld's formula (which includes the surface wave). This changes the concept of radiation as obtained from certain types of radiators frequently used by the amateur fraternity.—RADIO.

RADIOTELEPHONY'S HISTORY

.... Told Pictorially

These photographs are the figures referred to in the article "Radiotelephony — Its Origin and Development" on pages 30-45 of this issue.

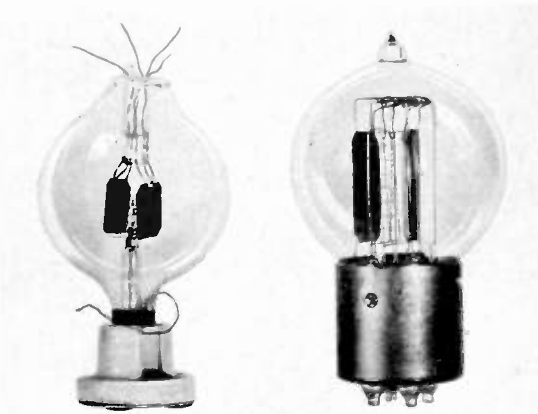
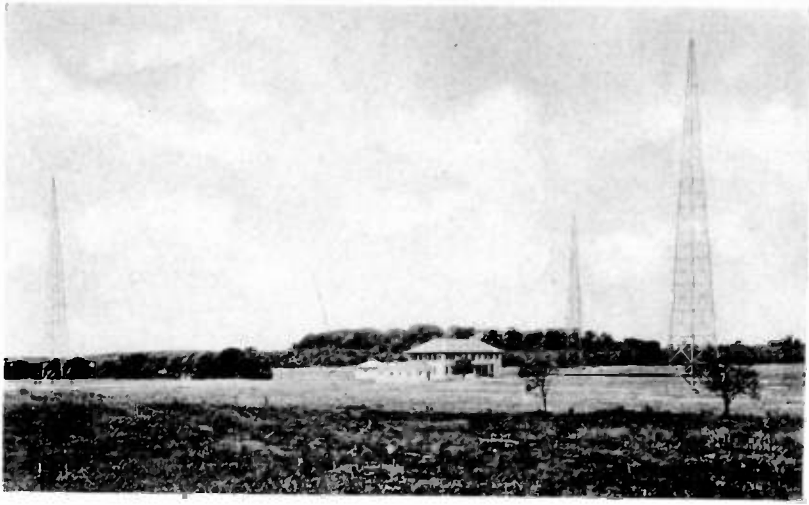


Figure 1 — Early De Forest audion and telephone repeater tube —about 1914.

Figure 2—Power amplifier of the Arlington, Virginia, experimental transmitter, 1915.

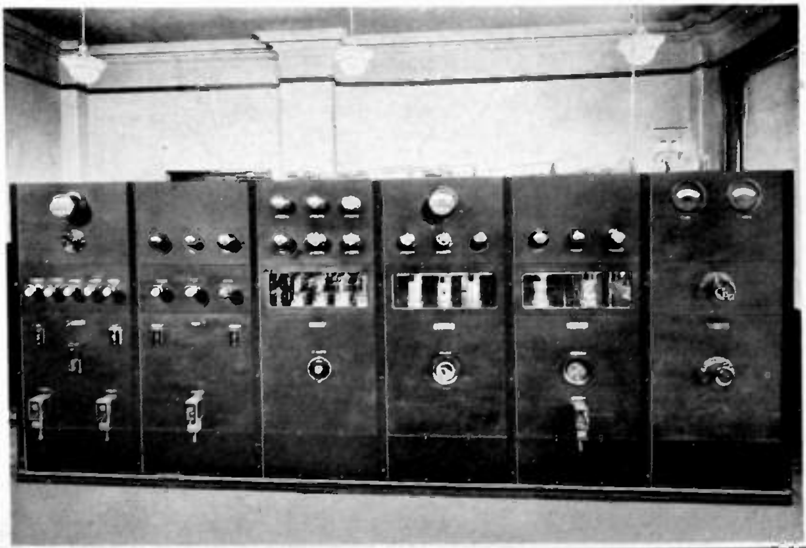


(Opposite page)
Figure 3 — The station at Deal Beach, N. J.

Figure 4—Long Beach, Calif., receiving terminal of Catalina Island radiotelephone link, 1920.

Figure 5—(Above) First KDKA Transmitter, Pittsburgh, Pennsylvania, 1920.

Figure 6 — (Below) Early Five-Kilowatt Transmitter of WEAF, Crystal Controlled, 1924.



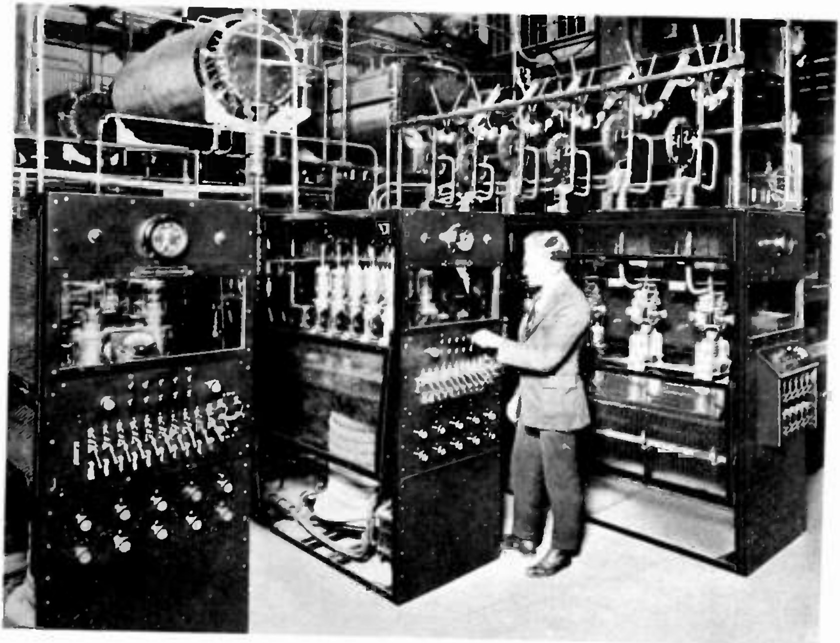


Figure 7—Power stage, in two units, with rectifier, of the first transatlantic radiotelephone transmitter at Rocky Point, Long Island, 1923.

From Radio, January, 1938

Dynamic Symmetry Used For Better Radio Design

BY R. A. ISBERG
KOA, National Broadcasting Co., Denver, Colo.

DYNAMIC SYMMETRY is the science of proper relationships of the areas making up a design. It is the type of symmetry found in nature and it comes from an old Greek term which means *commensurable in power.* It was used to describe the relationships between the sides and ends of dynamic rectangles. Dynamic rectangles are made up of lines which bear a root relationship to each other.

The principles of dynamic symmetry were known to the Egyptians as early as 5000 B.C., but they applied the principles only in their buildings. The Greeks elaborated on the Egyptian art and discovered that definite dynamic ratios exist in the bodies of humans, animals, and plants. They developed and applied this knowledge extensively in their statuary, buildings, jewelry, etc., and produced the most perfect examples of classic art known to civilization. This perfection of form and design was lost when the Romans conquered the Greeks in the second century B.C. The Romans interpreted the Greek art as being based on relationships of lengths rather than areas and they developed a "modulus" which they used in planning their creations. Thus the Roman art, and the art of the civilizations to follow until the present day, was based on static symmetry and lacked the vitality and realism peculiar to the Greek art.

For many centuries archeologists and historians tried to re-discover the secret of the Greek artists. It was only twenty years ago that Mr. Jay Hambidge, an art professor at Yale University, announced that the beauty of ancient Greek art was due to the application of simple geometrical formulae rather than to "born artists". His theories have been proven conclusively and are now generally accepted and practiced.

Application to Radio Design

This article can only be a synopsis of this fascinating subject and is largely a review of publications, a complete bibliography of which is included. It will be of interest to those who design apparatus which must present a finished appearance. What little knowledge I have gained of the subject has been invaluable to me in panel layouts and cabinet design. It gives me a feeling of security when I begin a design to know that it will look right when it is finished. I am a sincere believer in the axiom that "Function should dictate design", but I have yet to see a piece of apparatus that could not be improved by proper proportioning of areas and an orderly arrangement of components.

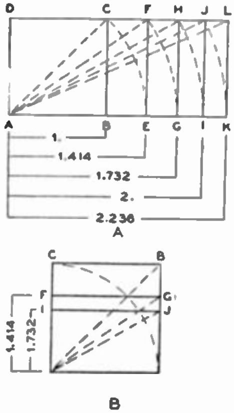


FIGURE 1

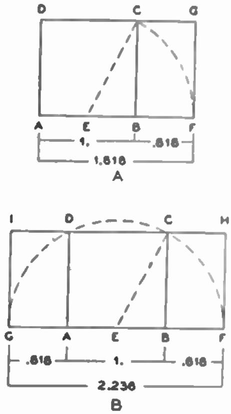


FIGURE 2

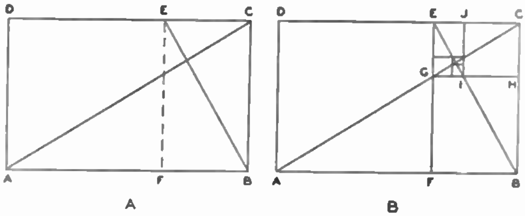


FIGURE 3

Illustrating the derivation of root rectangles and whirling squares (1.618 rectangle).

Probably the most useful and necessary application of dynamic symmetry to radio is in the design of cabinets and escutcheons for broadcast receivers. It would be advantageous for the engineer to understand the elements of dynamic symmetry in order that the fundamental and basic layout work could be completed before the design is turned over to the artist or cabinet designer.

A little knowledge of dynamic symmetry should be very helpful to the amateur who builds his own regalia, particularly if he is the type of a "ham" who wants classy, commercial-looking equipment that will be untiring to look at and a pleasure to show his friends.

All that is necessary to understand dynamic symmetry is a little elementary geometry and enough patience to draw some simple diagrams. A thorough knowledge of the elementary dynamic shapes is essential. Above all things do *not* get the idea that it is complicated and too difficult to be worth while. The most difficult part of the mastery of the subject is to remember that one is dealing with relationships of areas rather than lengths; hence, one must learn to think geometrically rather than arithmetically.

While it is true that the 1.618 rectangle and the root 5 rectangles are preferred shapes, one is not by any means restricted to their use alone. In fact, many critics of dynamic symmetry have raised the objection that it is *too* flexible, because there are an infinite number of shapes that can be systematically subdivided into commensurable unit areas.

- Root Rectangles

The fundamental dynamic shapes are simple to construct from a square. The square and its diagonal furnish the series of root rectangles. Figures 1A and 1B illustrate two methods of their construction. In figure 1A the square ABCD is assumed to have a side of unity. With the diagonal AC as a radius and using A as a center, describe the arc CE, extend AB and DC. Draw EF perpendicular to AE. AEFD is known as a root two rectangle because one side is equal to $\sqrt{2} = 1.414$. Then with AF as radius and A as center, describe the arc FG. Draw GH perpendicular to AG and the result is a root three rectangle because one side is equal to $\sqrt{3} = 1.732$.

The root-four and root-five rectangles are similarly constructed and the process could be carried out to infinity but for all practical purposes no rectangles beyond root-five need be considered. The root-five rectangle and its divisions are the shapes most prevalent in nature.

In figure 1B, the same result is obtained in a different manner. Given the square ABCD, and using A as center and AC as radius, describe the arc CD. Draw diagonal AB, draw FG through E parallel to CB. Then ADGF is a root-two rectangle within the square ABCD. Draw diagonal AG and the line IJ through the point H. ADJI is a root-three rectangle within the square ABCD and so on.

- "Whirling Squares"

The next fundamental shape that should be considered is the rectangle of the whirling squares. This rectangle furnishes the basis for the remarkable shapes found in plants and human figures.

In figure 2A, given the square ABCD, bisect AB at E and draw CE. Using E as center describe arc CF. Extend AB and DC. Draw FG perpendicular to AF. This rectangle AFGD is known as the rectangle of whirling squares or the 1.618 rectangle.

The next rectangle, and one of the most important, may be constructed in the same manner as the rectangle of the whirling squares. Draw a square ABCD as in figure 2B and bisect one side as at E. Using EC as a radius, describe the arc FCDG. Extend AB to F and G and draw FH and GI perpendicular to FG at the points F and G respectively. Extend CD to H and I. The result is a root-five rectangle because the ratio of end to side is $1:\sqrt{5}$ or 1:2.236, hence it is known as a 2.236 rectangle and it contains 2.236 units of area. It is evident from the diagram that the 2.236 rectangle is made up of a square plus two .618 rectangles; or a 1.618 rectangle plus a .618 rectangle.

The next construction is interesting not only because it explains how to construct a rectangle whose area is the reciprocal of the parent rectangle, but also how the "1.618 rectangle" became known as the rectangle of "whirling squares."

Figure 3A illustrates a 1.618 rectangle, ABCD; draw diagonal AC, then draw EB perpendicular to AC. Draw EF parallel to BC. The area of the rectangle EFBC is the reciprocal of the rectangle ABCD and is equal to $1/1.618 = .618$. This construction, of course, may be used for any rectangle to obtain its reciprocal.

It is apparent that ABCD was divided into a square and the reciprocal which is also a whirling square or 1.618 rectangle (the ratio of the side EC to CB is 1:1.618 even though ths area is .618). Continued division of the reciprocals of the 1.618 rectangle will result in more squares and 1.618 rectangles even if carried to infinity.

Figure 3B is a reproduction of figure 3A with some of the continued reciprocals. The diagonals AC and EB enable us to readily draw these reciprocals. The diagonal AC intersects the line EF at G. Draw GH parallel to EC. The area EGHC is the reciprocal of the area EFBC and area EGIJ is the reciprocal of the area EGHC, etc. The numbered areas 1, 2, 3, 4, etc., are all squares. Thus the 1.618 rectangle is known as the rectangle of whirling squares because its reciprocals cut off squares arranged in a spiral whirling to infinity around a point. This spiral is very common in nature and is found in leaf and seed arrangement and in the shape of sea shells.

Another interesting feature of the 1.618 ratio is that it is derived from the *Fibonacci series,* which is a geometrical progression of the following numbers: 1, 2, 3, 5, 8, 13, 21, 34, 55, 89, 144, etc. The series is derived by making each term equal to the sum of the preceding two terms. This series is true only as far as is representable in whole numbers. A much more accurate series is obtained with the following numbers: 118, 191, 309, 500, 809, 1309, 2118, 3427, etc. One term of this series divided into the next equals 1.618, which is the ratio underlying phyllotaxis in plant design and which has been referred to as the "Golden Mean" or the "Golden Section." The series is also interesting because each term is a dynamic ratio and is found abundantly in nature and ancient Greek art.

The list of side to end ratios of dynamic rectangles will be useful for reference. The most important ratios are indicated by an asterisk.

SIDE TO END RATIOS OF DYNAMIC RECTANGLES

Ratio	Reciprocal	½ Ratio	½ Reciprocal
1.	1.	.5	.5
1.118	.8944	.559	.4472
1.1545	.8661	.5772	.433
1.191	.8396	.5955	.4198
1.2236	.817	.6118	.4085
1.236•	.809	.618	.4045
1.309•	.764	.6545	.382
1.382	.7236	.691	.3618
1.4045	.712	.702	.356
1.414•	.707	.707	.3535
1.4472•	.691	.7236	.3455
1.472	.679	.736	.3395
1.528•	.654	.764	.327
1.545•	.6472	.772	.3236
1.618•	.618	.809	.309
1.7135	.584	.856	.292
1.809•	.5528	.9045	.2764
1.854	.5393	.927	.2696
2.236•	.4472	1.118	.2236
2.309•	.433	1.1545	.216
2.4472•	.408	1.2236	.204
2.472•	.4045	1.236	.202
2.618•	.382	1.309	.191
2.764	.3618	1.382	.1809
2.809•	.3559	1.4045	.1779
2.8944	.3455	1.4472	.1727
3.236•	.309	1.618	.1545
3.427	.2918	1.7135	.146
3.618•	.2764	1.809	.1382

An infinite number of shapes that can be systematically subdivided can be obtained from these ratios by simply adding or subtracting 1 (a square), or adding or subtracting the reciprocal of the ratio, or half of the ratio. The possible ratios obtainable are too numerous to list and the more advanced student of dynamic symmetry can readily adapt them to his problems.

In figure 4 are a number of dynamic shapes and their reciprocals. Careful study of these examples and the list of ratios will be helpful when you are ready to apply dynamic symmetry to your own needs.

- "Dynamic" Radio Cabinets

The following table gives the dimensions and dynamic ratios of a few of the cabinets available at radio supply houses. Those which are recommended as good dynamic shapes are indicated with an asterisk.

Height x Width x Depth	Dynamic Ratio of Panel (Side divided by End)	Nearest Correct Dynamic Ratio
60 x 19 x 13	3.16	3.236•
37 x 19 x 13	1.95	1.854
35 x 19 x 13	1.842•	1.854
26¼ x 19 x 13	1.383•	1.382
17½ x 19 x 13	1.086	1.118
10½ x 19 x 13	1.809••	1.809
8¾ x 19 x 13	2.17	2.309•
12 x 18 x 11	1.5•	1.5
9 x 15 x 11	1.668•	1.618•
8 x 16 x 8	2.00•	2.00
7 x 14 x 7½	2.00•	2.00
7 x 12 x 7¼	1.714•	1.7135
7 x 10 x 6	1.43•	1.4472•
7 x 7½ x 7½	1.07	1.118

- A Dynamically Symmetrical Receiver

There are two methods of approach to any design problem. In one we have a general outline of the problem and we work inwardly locating and sizing the interior parts. This method is known as the *convergent* method and is the one followed by the amateur or engineer who must build his apparatus for a particular panel or cabinet. The other method, known as the *divergent* method, requires that the plan center around a certain part or requirement and work outwardly. This method may be used if a panel or cabinet is to be designed for a specific need.

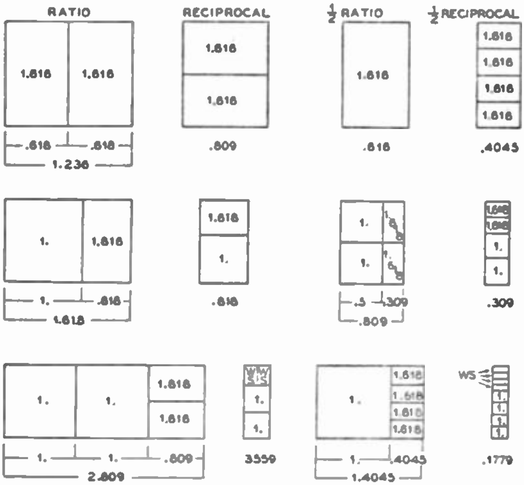


FIGURE 4

thing to do is to cheat a little by making a new basic rectangle using dynamic ratios and dimensions which will enclose the dial. This may be done by multiplying 2.5" (center to top dimension of dial) by 1.618. The answer 4.045" is the new width of the rectangle enclosing the dial. The error introduced is .0175" (1/64+) and may be neglected. By making the other small rectangle the same size, another small error of 1/16" is introduced but it is in the opposite direction.

An illustration of the divergent method is shown in figure 5, the design of a panel for a receiver. A rectangle enclosing the extremities of a National type N dial is used as the basic shape in this layout. The overall dimensions of the dial are 4.0625"x4.9375". A rectangle having these dimensions will have a side-to-end ratio of 1.215. This ratio is a poor one because it cannot be easily divided or expanded. Further inspection of the dial reveals that the center divides the rectangle formed by the outline of the dial into two smaller rectangles as shown in figure 5A. The top rectangle 4.0625"x 2.5" has the ratio 1.623 and the bottom rectangle 4.0625"x 2.4375" has the ratio 1.668. These ratios likewise form poor dynamic shapes but they differ only a small amount from the basic dynamic ratio 1.618. The

The new basic rectangle, figure 5B, is made up of two 1.618 rectangles and has the ratio 1.236 and its dimensions are 4.045"x 5.0". The small error introduced by the modification will not be detectable in the design. A slide rule will be very helpful in making modifications of this type or in figuring ratios. The index is set on the desired ratio and the side and end dimensions appear under the hairline indicator.

The next requirement is that the chassis be approximately 3" high to accommodate the plug in coils (coils plug in front of panel). By dividing 4.045" by 1.236 we obtain the dimension 3.27" as the height of the rectangle bounding the space below the dial. We could have used any other ratio that is

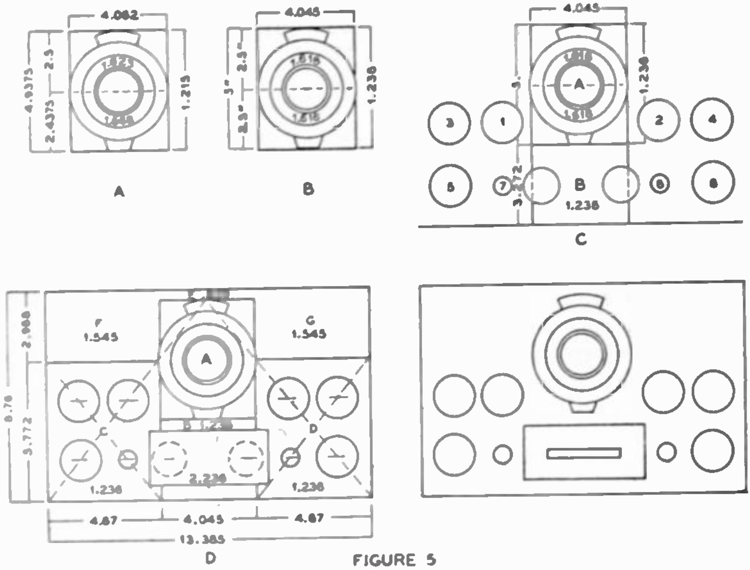


FIGURE 5

related to 1.618, such as 1.309, 1.414, 1.472, 1.809, etc., but the 1.236 ratio satisfies the requirement that the space for plug in coils be approximately 3" high.

The areas at either side of the dial are dependent upon the space requirement of the controls which will be mounted in these areas. The actual controls, or pieces of paper cut to represent them, may be used in these determinations. The placement of controls should be governed by wiring and mechanical construction. The chassis and panel layouts should be considered simultaneously because they influence each other. One is utilitarian and the other artistic.

The controls to be mounted on the panel are (1) first detector trimmer, (2) oscillator trimmer, (3) first detector regeneration, (4) i.f. regeneration, (5) a.f. gain, (6) r.f. gain, (7) beat frequency oscillator switch and (8) a stand-by switch in the negative lead of the high voltage supply. The a.c. switch is mounted on the r.f. gain control.

The trimmers are located above the chassis and on either side of the dial in order to permit short leads to the tuning gang. The other controls were arbitrarily located, as in figure 5C, with sole regard to short leads and convenience in operation.

An examination of figure 5C reveals that the controls on either side of the dial can be enclosed in a rectangle, one side of which is made up of 3.272" plus 2.5". A rough measurement indicates that approximately 4.5" is required for the other side of the rectangle. The ratio 1.236 divided into 5.772" gives 4.67", the correct width of the rectangle.

Diagonals are drawn in the rectangles C and D, as in figure 5D. One-half of the height of rectangle B (1.636") measured from the top and bottom of rectangles C and D establishes the centers of the controls. Thus the centers of the controls form the corners of similar rectangles inscribed within C and D.

The location of the two plug in coils in rectangle B is governed solely by mechanical and electrical considerations. The coil forms are 1¼" in diameter and are spaced 3⅜" between centers. The distance between the two coils, 2¼", allows about 1 3/32" between the windings and the baffle shield between them. This distance is about the minimum that should be used without a loss of efficiency due to a reduction in Q.

In order to facilitate changing of coils and also to carry out the design scheme, a cover plate is used. The dimensions of this plate are 5"x 2.239", forming a 2.236 rectangle.

Counter sunk screws through the cover plate into wooden plugs fastened into the ends of the coils afford a good mounting for the coils. A small chromium plated drawer pull available at any hardware store sets off the panel and makes coil changing easy.

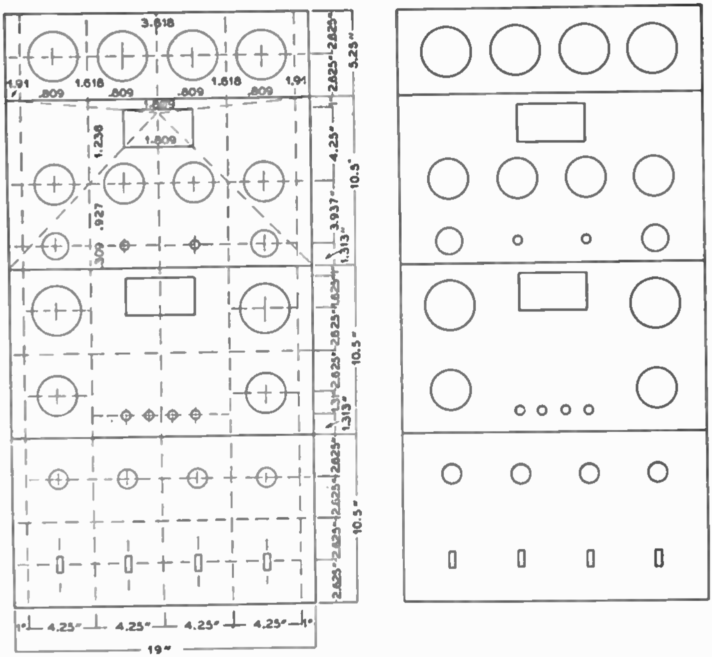
Only one dimension, the height of the panel, remains to be decided upon. This is governed by the distance from the top of the dial to the edge of the panel. An arbitrary value of one-half inch was added to 8.272". The length of the panel, 13.385", divided by 8.772" gives the ratio 1.525. The nearest correct ratio, 1.528, was then divided into 13.385" to obtain 8.76", the correct height of the panel. The areas F and G are 1.545 rectangles and the area E is an 8.29 rectangle which can be subdivided into six 1.382 rectangles. Thus the panel is made up of a number of rectangles which bear a dynamic relationship to each other and to the panel as a whole. This gives the panel coherence and correctness which cannot be obtained by an unorganized arrangement of components.

• Convergent Method of Design

The convergent method is in some cases a little more difficult to apply because one has to find components which will harmonize with the dynamic ratio of the whole. However, this is usually not very difficult because such things as dials, meters, etc., are available in quite a variety of sizes and shapes and ordinarily are contained within the boundary lines of a square.

• Application to Transmitter Construction

An example of the convergent method is shown in figure 6, in the design of the panels of a transmit-



A FIGURE 6 B

ter. The plan calls for an 807 oscillator, 807 doubler, and two 801's in push pull in the final modulated by push pull 6L6's. Meters are to be provided for measuring oscillator, buffer, amplifier and modulator plate current; grid current in the r.f. stages; and percentage of modulation. The oscillator plate, buffer plate, amplifier grid and amplifier plate tuning condensers will be mounted on the panel. The antenna is to be fed by a low impedance line, hence, no antenna-tuning condensers or meters will be necessary at the transmitter. Two tap switches, one for selecting crystals and the other for connecting the grid meter in the grid return leads of the r.f. stages, a 60 ma. pilot light bulb to indicate crystal current, and a switch to open the plate circuit of the 801's are to be included on the r.f. panel. If space permits, a tuning card showing the dial settings for the various frequencies is also to be provided.

The audio amplifier and modulator unit will incorporate degeneration and a filter which will pass only the voice frequencies (300-3000 cycles). Two tapped controls, one for degeneration and the other for amplifier gain, a switch to short the secondary of the class-B output transformer when using c.w., and a switch for cutting out the filter are to be mounted on the panel. The purpose of the filter is to limit the side-bands and to achieve a greater percentage of useful modulation in the voice range. A low-range milliameter used to measure percentage of modulation and two monitoring jacks, one for listening to the output of the audio amplifier and the other for checking the quality of the rectified carrier, complete the panel requirements for the modulator.

The two power supplies are to be mounted on one chassis. The panel must accommodate four switches and four pilot lights. The switches are to be the large tumbler type and will control the following power supplies: r.f. filament, r.f. plate, audio filament and audio plate.

The proposed transmitter is to be housed in a steel cabinet with the components mounted on standard relay rack panels. The choice of a desirable panel size is the first consideration in a convergent dynamic design. A good standard relay rack panel size is 10½"x 19"—a 1.809 ratio. This panel is large enough for the r.f. unit, modulator, or the power supplies of the proposed transmitter. The standard meter panel, 5¼"x 19", is a 3.618 ratio, which is two times the ratio 1.809. Three 10½"x 19" panels and one 5¼"x 19" panel require a relay rack or steel cabinet 19"x 37"—a 1.9472 ratio. This ratio is not a vital one but it is at least dynamic.

A large sheet of wrapping paper or bristol board is useful in making the initial layout. The actual dials, etc., or pieces of paper cut to represent them can be juggled until one obtains the desired result. In some cases I have found it worth while to make the layouts in three dimensions, using cardboard boxes and mounting the actual components on them. This method is especially helpful if space is at a premium.

The first consideration is to get a rough idea of where the dials and meters are to be placed. The next step is to divide systematically the panels into suitable areas which will accommodate them.

Figure 6A shows the essential layout and sets up the requirements for the individual panels. The meter panel at the top is to have four 3¼" meters. This necessitates that the panel be divided into four equal areas and two smaller areas. Dividing the 5¼"x 19" panel (3.618 rectangle) in the middle we obtain two 1.809 rectangles having the dimensions 5¼"x 9½". Each 1.809 rectangle less one 1.618 rectangle, 5¼"x 8½", leaves one .191 rectangle, 5¼"x 1", at either end as a margin. This margin is sufficient for all the components to clear the sides of the cabinet or the I-beams of a relay rack. An interesting and helpful point about how the .191 ratio is derived from 5¼"x 1" dimensions is that in dividing ratios, *always divide the same way,* i.e., height into width, or the results will be rather exasperating.

The two 1.618 rectangles are divided into four .809 rectangles having the dimentions 4¼"x5¼". The meters will be mounted in these areas.

The dividing lines of the .809 rectangles extended down the diagram divide the succeeding panels into dynamic rectangles. The 10½" panels, divided by horizontal lines through their centers, form a number of dynamic rectangles equal in area and ratio to the rectangles of the meter panel.

The mechanical layout of the r.f. unit requires that the tuning condensers be mounted at about the center of the panel. They are placed on the horizontal center line in line with the centers of the meters.

The locations of the tap switches, pilot light, and final amplifier plate switch are roughly determined by the arrangement of parts under the chassis. About 1⅛" is the minimum distance permissible between the centers of the tap switches and the bottom edge of the panel. The .809 rectangle must be divided at a suitable point to locate the correct centers of the controls. This is easier if we consider its reciprocal, 1.236, because our division will be made on the long side of the rectangle. It is clear that the 1.236 rectangle is composed of a square plus a .236 rectangle. Since the square would be 4¼"x 4¼" and the rectangles 4¼"x 5¼" the .236 rectangle would be only one inch high. This height is insufficient so after examining the table of dynamic ratios, we decide to try the ratio .309. This ratio, .309, multiplied by 4.25" gives us 1.313" as the distance from the edge of the panel to the center of the controls.

The best shape and size of a tuning card and its location is the last problem on the r.f. panel. The length of the tuning card frame is made 4¼" because that is the distance between the centers of the dials and meters. The upper edge of the tuning card was tentatively placed 1" below the upper edge of the r.f. panel and centered at this position. A simple geometric method of drawing a similar rectangle within a rectangle is used here for purpose of illustration because it will work in any rectangle, dynamic or static. Diagonals are drawn from the two upper corners of the r.f. panel through the upper corners of the tuning card frame intersecting the center line at A. Diagonals are drawn from the two bottom corners of the rectangle to the intersection A. A line drawn through the intersections of the lower diagonals and the sides of the rectangle is the proper location for the base of the tuning card frame. Of course, in this case it would have been almost as easy to draw a 1.809 rectangle having a length of 4¼".

The modulator panel is somewhat simpler. The two meters, modulator plate current and percentage of modulation, are located in the centers of the two outside .809 areas. The gain control and the degeneration control are respectively located below the meters. The radio and audio monitoring jacks, the filter switch and the phone-c.w. switch are grouped in line with their centers 1.313" from the bottom edge of the panel.

If desired, a plate of the same size and shape as that of the tuning card can be placed in the area between the meters. This card or plate could bear the call letters of the station or information relative to the gain and degeneration control setting and performance of the transmitter.

The power supply panel is simplest of all. All that is required is to locate the four pilot lights and switches. These automatically fall in line with the meters and dials in the centers of the .809 areas.

Each panel is a unit complete by itself and the combination of the four panels presents a correct and harmonious appearance. Dynamic design applied to apparatus mounted on relay rack panels is almost necessary if future panel additions are to harmonize with the original design scheme.

Dynamic symmetry can only serve as a guide in any design. How well it is applied and how good the results are depends upon the designer and the parts making up the design.

The principles of dynamic symmetry are most useful to those who cannot instinctively choose forms which are most pleasing. Though the work of such artists is not likely to be as effective as that of talented artists, it will be much more acceptable than if it were not guided by a basic plan.

Too much emphasis cannot be given to the statement that the time and effort spent in the study of dynamic symmetry is well worth while even if the first attempts of its application are difficult and unfruitful.

Acknowledgement is made to the following publications and in particular to the works of Arthur Van Dyck and Jay Hambidge. Figures 1, 2, 3, 4 and their explanations have been reproduced by permission of the Yale University Press.

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[illegible] Communications,
December, 1937

Instantaneous RECORDING NEEDLES

BY MAJOR [illegible] BARBER

SHARPNESS is not the only requirement in a cutting needle for instantaneous recording. As might well be expected, a needle ground in the shape of a fine chisel would cut a record with great facility and with practically no weight on the cutting head, but the surface noise resulting on the finished record would be terrific. A stylus for instantaneous recording must do double duty: first, it must present a keen edge against the advancing recording material and second, it must burnish the resultant groove with a ball like surface directly back of the cutting edge.

To make such a stylus, a hard material must be selected which is free of blow holes, homogeneous, and which will take a cutting edge that will not fracture. Sapphire, both natural and synthetic, is the hardest material yet available that will fulfill these requirements. The diamond is, of course, much harder, but its crystal structure does not lend itself to the sharp angles required in groove cutting, without extreme care in grinding and use. The sapphire itself is none too rugged against misuse and flaws in records, but it does give the neatest recordings yet achieved. For sturdiness, the cobalt-chromium-tungsten alloys are particularly serviceable as proven by tests on the stellite recording needles. This alloy takes a high polish and has a low coeffi-

TABLE I

[illegible]	Designation	Recording	—Playback Percentage— Sharp Stylus	Dull Stylus
[illegible]	[illegible] 1	100%	100%	100%
[illegible]	[illegible] 2	50%	50%	50%
[illegible]	[illegible] 4	2%	3%	12%
[illegible]	[illegible] 4	1.5%	5%	10%
[illegible]	[illegible] 1	2.5%	5%	5%
[illegible]	[illegible] 2	1.5%	3%	4%

This table shows clearly the effect that a dull recording needle has on the amount of distortion introduced into the recording. The cross-modulation is especially affected.

cient of friction, which makes for an ideal stylus.

The needle material is mounted in a shank for grinding and use. In grinding, the first operation is to grind the chisel-like shape. This gives the correct angles to the sides and back. Automatic guides determine these angles, although the actual grinding is hand fed. The development of a keen edge between each of the chisel faces is observed microscopically. First, relatively coarse diamond dust is used in the grinding, and then the very finest diamond dust obtainable for the final lapping.

• Breaking Back Cutting Edge

After the chisel shape has been attained, it is then necessary to break back the cutting edge in a very accurate and precise way. This is done on a very fine, small, high-speed diamond-dust lapping wheel, with the progress observed directly under a high-power microscope. The actual point is first rounded off carefully, and then the edge around the front face of the chisel is ground back in a curve which goes slightly downward from the front cutting edge of the needle, and gives a distinct highly polished ball shape to the bottom of the finished needles.

The action with this needle is as follows: the record material is cut at the front edge of the needle face with a one to three degree drag; the resulting groove is then polished by the ball curve which is pushed down into the groove by the weight of the cutting head. This action is necessary on all types of material; some require a little more of it than others. It is quite necessary in cutting the so-called "acetate type" records, which are really lacquer coated. No lacquer has yet been found which will leave a smooth shiny cut when engraved with a sharp tool. It is the very toughness of the lacquer, which is the characteristic that makes the record durable, that makes it tend to pull apart rather than be actually cleaved. But this is what mitigates against the polished cut. To produce the polish in the rough cut, the burnishing action is necessary. This is best done by the stylus itself

TABLE II

F	Designation	Recording	Playback Percentage 1	2	3	4
700.00	fund. 1	100%	100%	100%	100%	100%
1000.00	fund. 2	100%	92%	117%	133%	142%
300.00	diff. f.	2%	4%	7%	2%	2%
1700.00	sum f.	1%	4%	5%	11%	2%
1400.00	second 1	4%	8%	10%	11%	10%
2000.00	second 2	2%	4%	8%	6%	10%

Four recordings made with four stelli needles with final angles varied slightly give a clear picture of the importance of the correct angles in the finished product to give the best reproducion. The cross-modulation frequencies are the most important to keep down.

TABLE III

F	Designation	Recording	Playback Percentage 1	Playback Percentage 2	Playback Percentage 3
680.00	fund. 1	100.00%	100.00%	100.00%	100.00%
1000.00	fund. 2	100.00%	80.00%	70.00%	60.00%
320.00	diff. f.	.35%	2.00%	1.60%	2.00%
1680.00	sum f.	.30%	2.00%	.80%	3.50%
1360.00	second 1	.30%	1.60%	.60%	2.00%
2000.00	second 2	.80%	1.60%	1.00%	2.00%

The column under recording shows the percentage of frequencies applied to the recording head. Column 1 gives the percentage of frequencies in the output of the play-back amplifier, when the play-back needle has a fine point and the recording was made near the center of the record. Column 2 has the same conditions, except that the recording was made on the outside of the record. These first two were made at 78 r.p.m. of the turntable. Column 3 has the same original conditions, except that the recording was made with a turntable speed of 33 r.p.m. on the inside of the record.

in the double function of first cutting and then burnishing. The burnishing ball on the bottom of the stylus also reacts back to keep the cutting edges at exactly the right uniform depth in the material, exactly as the advance ball does in wax recording.

Now, the larger the burnishing ball on the bottom of the stylus, the higher the polish and the lower the surface noise, which is all very well if one is concerned only in getting low surface noise. But obviously the main function of recording is not just in making golden silences. It corresponds in this sense to the best method of eliminating static, which is to disconnect the antenna! For high-fidelity recording, all the useful frequencies must be registered. The particular difficulty comes with the highs. With too large a ball, the highs disappear. Of course, it is possible to "compensate" by overemphasizing the highs both in the recording and the spring suspension, which holds the needle armature. But as in all engineering, this compromise may easily be carried to the point of distortion.

• Cross-modulation

The second quality factor and one which has not been given the attention it deserves is cross-modulation. When two tones are presented to any amplifier system, there is a certain amount of cross-modulation which gives rise to the production of sum and difference tones. For example, if seven hundred cycles and one thousand cycles enter an amplifier, there will be found in the output not only the seven hundred cycles and the one thousand cycles, but also the sum, seventeen hundred cycles, and the difference, three hundred cycles. Besides the resulting unharmonious tones which are thus introduced, there are the double and triple frequencies introduced by non-linearity in the amplifier. These also cross-modulate. If all these harsh tones have an r.m.s. value greater than two per cent of the desired tones, there is a marked deterioration in the quality.

TABLE IV

F	Designation	Recording	Playback Percentage 1	2	3
1000.00	fund. 1	100.00 %	100.00 %	100.00 %	100.00 %
2000.00	fund. 2	100.00 %	80.00 %	80.00 %	80.00 %
3000.00	fund. 3	100.00 %	120.00 %	120.00 %	120.00 %
4000.00	fund. 4	100.00 %	60.00 %	65.00 %	60.00 %
5000.00	fund. 5	100.00 %	10.00 %	15.00 %	1.50 %
6000.00	fund. 6	100.00 %	2.00 %	5.00 %	.30 %

Each frequency is recorded separately so there is no cross-modulation in this chart. The first two columns under playback were made using fine playback needles, and the last one, using loud playing needle. In the latter case the high frequencies are attenuated very badly. This table was made from the results obtained on a portable recorder.

Now, when the two steps of recording and play-back are added, a new and very ready means of introducing further cross modulation is inserted. With too large a burnishing ball on the bottom of the stylus, twelve per cent cross modulation may easily be realized. The play-back needle and amplifier itself are often accused of being the weak spots when it is just the cutting needle. Distortion is caused in the case of too large a ball by obliteration of a higher frequency by a lower at certain points of travel of the needle. If the obliteration were continuous it would not be so bad, but being non uniform introduces the frequencies.

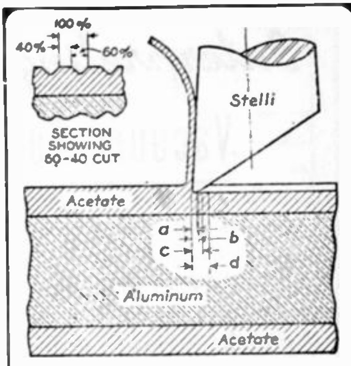
The best value of ball size will reduce the cross-modulation to one per cent over the straight amplifier. This may be considered excellent recording at the present state of the art. Cases have been observed where there is actually less cross modulation after the introduction of the recording play-back step than with the straight amplifier, due, no doubt, to the production of sum and difference frequencies out of phase with each other in first, the amplifier, and second the recording.

But the small amount of ball for the best work means that there is very little tolerance in the adjustment of the cutting angle of the stylus to the advancing record material. The recording engineer must place the needle accurately in position to be sure that the needle presents the proper angle to the record. This adjustment may well be made by eye, after a little experience. The spring adjustment on the cutter head brings the groove depth to the desired sixty per cent width of cut to forty per cent wall between cuts. But a nice shiny bottom and sides to the groove must be observed by the hand or fixed microscope to be sure that the needle is the right angle to the record.

Obviously with the adjustment limits confined to such a narrow range, it is not possible to obtain good recordings if the recording head is bobbing up and down as the turntable revolves, changing the angle of the cutting needle all the time. The turntable must be true, and the record must be flat. If they are not, the readily recognized swish on each revolution of the play-back turntable is obtained, indicating the positions on the record where the cutting stylus was not in its correct angular position. Also the depth of the cut will vary at these swish points. Both are most undesirable effects.

• "Echo" Reduced

Another good result of having the small burnishing ball, is the reduction in "echo" caused by the recording in one groove affecting the adjustment grooves. This phenomena is again due to the fact that the lacquer is not a completely "dead" material, and instead has a certain amount of resiliency. To bring the echo to the vanishing point and still make the sides of the groove quiet, a nice adjustment in the size of the ball diameter is required to polish the sides of the groove and still not pile up the material which produces strains affecting the adjacent grooves. This is done in the final lapping of the stylus.



COMPARATIVE DIMENSIONS WITH NEEDLE POINT
a - ½ ~ @ 5000 ~/sec @ 8" Dia. @ 33⅓ R.P.M.
b - ½ ~ @ 5000 ~/sec @ 4" Dia. @ 78 R.P.M.
c - ½ ~ @ 5000 ~/sec @ 15" Dia. @ 33⅓ R.P.M.
d - ½ ~ @ 5000 ~/sec. @ 11" Dia. @ 78 R.P.M.

While these precautions have been given rather strenuous emphasis, they make for the possibility of a very good signal level "packed" on the record. High-level recording leads to the obvious advantages of requiring less amplification, and the pickup and the relative reduction of undesired noise energies such that they are completely ridden over by the desired signal energies.

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AN F. C. C. order requires that thousand-watt T-20 lamps be installed in rotating aviation beacons.

ONE early authority predicted laws against listening-in on commercial wavelengths when radiotelephony "should become commercial and widespread."

THE powerful signals which we hear from so many of the short-wave diathermy sets make us wonder if any of the r.f. from these outfits ever reaches the patient.

¶ From Service,
November, 1937

Interpreting Vacuum Tube Characteristics

A SATISFACTORY working knowledge of vacuum tube characteristics can be gained from any one of the many available characteristics charts which show base diagrams, dimensions, characteristics under conditions of voltage common to a majority of receivers, and sometimes capacitance values for the tubes. The charts form an important part of every service man's library of information. To the service man looking for complete information or the engineer designing electronic equipment, the data chart is of limited value. On the other hand, complete characteristic curves provide no useful information unless a clear interpretation of their meaning can be made.

In the chart and in the published characteristics on radio tubes only those characteristics which apply under one or two voltage conditions can be given. In the characteristic curves, however, everything one could want to know about a tube will be found. It will be shown later that two tubes which seem to be alike, according to the values on the chart, are dissimilar in operation with one distinctly superior to the other.

To demonstrate the utility of curves as a means of comparison, the plate "families" for the 6C5 and the more recent 6J5 are shown in figure 1. The plate "family" is the most common form of presentation of characteristics to be found. The data or "points" through which each curve is drawn are taken by holding the grid-bias voltage constant and noting the plate current as the plate voltage is raised from zero, or the voltage where plate current starts up to a value which produces as much plate current as the tube will ever pass in service.

For receiving tubes, it is usual to show the rise in plate current with rising plate voltage for zero bias and for values of negative bias down to negative control-grid voltages which limit the plate current to a small amount at the highest plate voltage the tube will ever have impressed on it as an instantaneous peak. Thus, in figure 1 for the 6J5, the upper limit of plate

BY
R. M. PURINTON

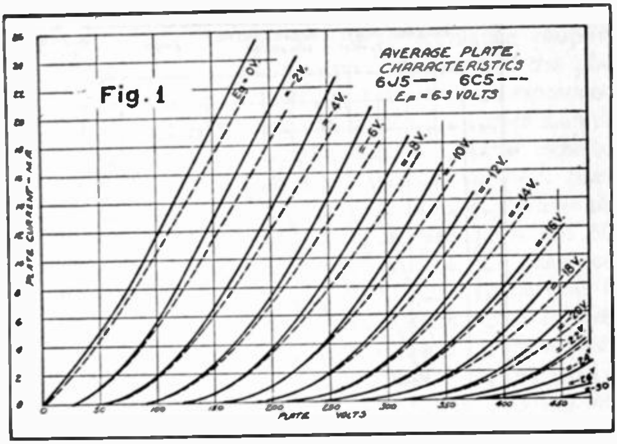
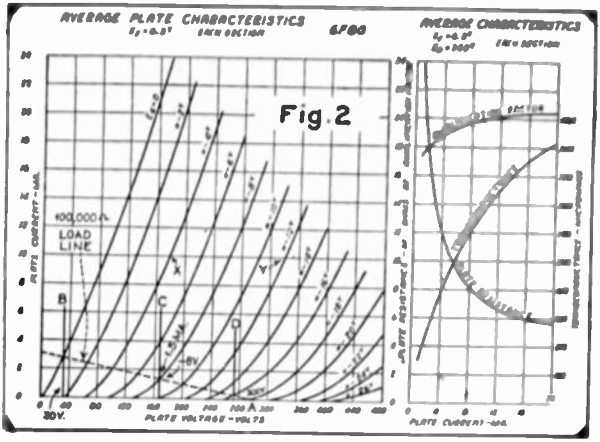


Fig. 1

current at zero control-grid bias is about 25 milliamperes reached at a plate voltage of approximately 185 v. The plate current could be made to go higher but it is not necessary to show higher values since higher instantaneous plate current will not be drawn in any normal use.

It will be noted that with the control-grid set to —30 volts, plate current does not start to flow until the plate voltage is 450 v. This potential is the upper limit of instantaneous plate voltage so the measurements are stopped at that point. Continuing with reference to the solid curves for the 6J5, it will be noted that as the negative grid-bias values are made more negative, it takes more plate voltage to start the flow of plate current. Thus, for a bias of —16 volts, 250 volts must be applied to the plate before current starts. Putting it another way: —16 volts is the "cut-off" point for a plate potential of 250 volts. Since class B audio tubes are operated at or near "cut-off," the plate family will tell the designer what the "cut-off" bias should be for whatever voltage the power supply happens to deliver. In triode tubes, it is desirable that the "cut-off" be sharp at normal working voltages. From 250 volts down, the 6J5 characteristics for "cut-off" are quite good. The long, gradual arc at the foot of each of the higher bias curves in the lower right corner of figure 1 would not be desirable at lower bias voltages. A good oscillator must have sharp "cut-off," and the 6J5 is a good oscillator.

The explanation of the 6J5 curves in figure 1 could include some other factors, but those of major importance have been covered. Returning to the comparison between the 6J5 and the older 6C5, characteristics of which are shown in dotted curves



in figure 1, it will be noted that for each value of grid-bias voltage, plate current starts for each tube at the same voltage. However, as the plate voltage increases, the plate current in the 6J5 climbs at a faster rate than in the 6C5. The two tubes have the same amplification factor. Therefore, the difference between them indicates that the 6J5 must have the lower plate resistance of the two. The amplification factor of a tube divided by the plate resistance gives the tube's mutual conductance in micromhos. Since both tubes have the same amplification factor, the 6J5 with its lower plate resistance has the higher mutual conductance. For most purposes, the lower plate resistance and higher mutual conductance make it a better tube for general use.

The plate "family" of the 6F8G (one triode section) in figure 2 has been utilized to show some additional information. For one thing, one can determine the amplification factor of the tube by simply noting what change in plate voltage is required to maintain the plate current constant with a change in grid bias voltage. Measurements should be made near the center of the group of plate curves. Take 10 milliamperes as a convenient plate current to be maintained as the constant. At point X, it will be noted that the plate current is 10 milliamperes with a grid bias of —4 volts and a plate potential of 180 volts. Moving to the right along the 10 milliampere line to point Y, it will be noted that the plate current has been maintained but that the negative grid bias is now —12 volts and the plate potential is 340 volts. The grid bias has been changed by 8 volts and the plate voltage by 160 volts to maintain the plate current constant. Thus it has been necessary to change the plate voltage twenty times as much as the change in grid bias, showing that the amplification factor of the tube is 20.

Another useful determination which can be reached through graphical work with the plate "family" is shown at the lower part of this group of curves in figure 2. The data chart does not tell what the grid bias should be for operation of the 6F8G in resistance-coupled circuits. It does say that the plate resistance is approximately 7700 ohms. With that value of plate resistance, a plate load resistor having a value of 100,000 ohms would be satisfactory for straight voltage amplification.

Assume a plate supply voltage of 300 v. With resistance coupling there is no inductance in the plate circuit to produce instantaneous peak-signal voltages higher than the supply voltage so it can be expected that the instantaneous peak plate-signal voltage on the positive side will not be greater than the 300 volts supplied. Also, this peak positive voltage at the plate can be realized only when there is minimum plate current (point where the signal voltage on the grid is most negative). Accordingly, a load line representing 100,000 ohms is drawn on the plate "family" with one end placed at point A where the plate voltage is 300 v. and the plate current is zero. The slope or angle of the load line with respect to the base line is determined by

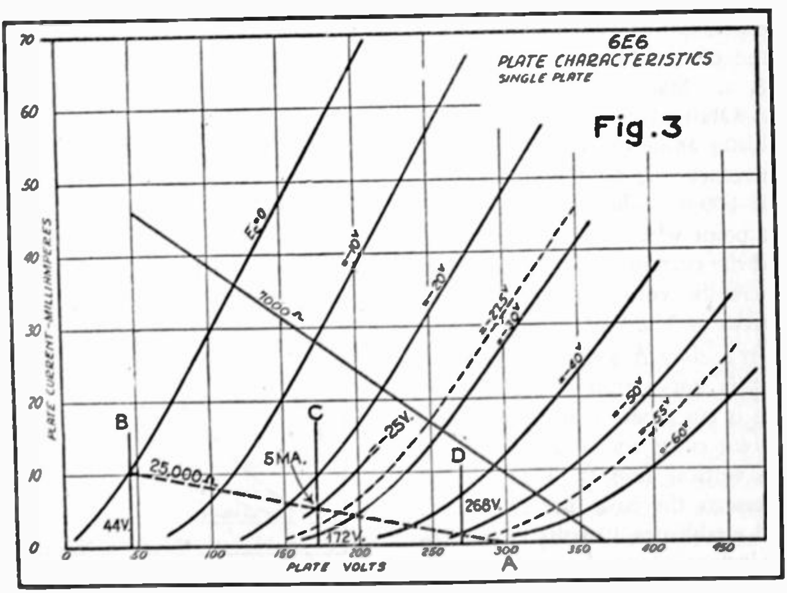
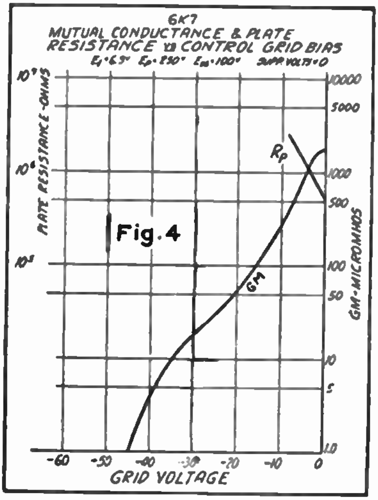


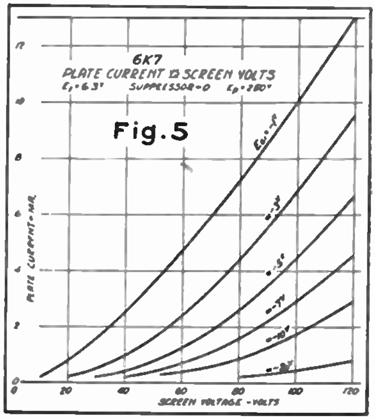
Fig. 3



simple calculation: under Ohm's law, I = E/R. The value of R has been chosen as 100,000 ohms. The value of E is the supply voltage, 300 v. Substituting these figures into Ohm's law, I = 300/100,000 or .003 ampere (3 milliamperes). Therefore, the load line, to represent 100,000 ohms, should connect the point where the voltage is 300 and the current zero with the point where the voltage is zero and the current is 3 milliamperes.

In a class A amplifier, grid current is not permitted so the load line is cut where it meets the plate current curve for zero grid bias by the vertical line B. This line, B, intersects the base line at 30 volts and establishes 30 volts as the lowest instantaneous plate voltage to be reached. If the highest instantaneous voltage is the supply value, 300 volts, and the lowest is 30 volts, then the average instantaneous plate voltage should be midway between the two or 165 volts. The line C drawn up from the base line at 165 volts establishes the correct operating point where it intersects the load line. Note that this new point lies on the plate current curve for a grid bias of —8 volts and that the vertical height of the operating point corresponds to a plate current of 1.5 ma. Using Ohm's law again to determine what value the cathode resistor should have, R = E/I or R = 8/.0015 = 5333 ohms. A 5000-ohm resistor would be satisfactory.

If both sections of the 6F8G are used similarly and their cathodes are tied together, the cathode bias-



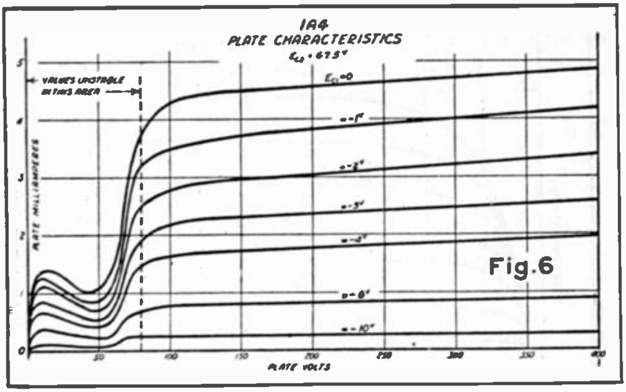


Fig.6

ing resistor should be half that for a single section or 2500 ohms. The load line is not a mysterious factor at all. Drawn between the points of extreme signal - voltage fluctuation in the plate circuit, it represents the instantaneous values of plate current and plate voltage present at the tube plate as the signal changes the instantaneous control grid voltage above or below the fixed grid bias voltage.

In figure 3, another problem in determining proper operating conditions is presented. Type 6E6 is used primarily as an output tube, but its power capabilities and high plate current recommend it as a driver tube where voltage gain is not important. With 300 volts as the plate supply voltage and 25,000 ohms selected as the load resistor, the 25,000 ohm load line is drawn in. Here the line was started at the 300 volt, zero plate-current point and for convenience was drawn through the 50 volt, 10 milliampere point. By Ohm's law this gives the load line a slope equivalent to 25,000 ohms since for a change in plate voltage of 250 the current rise is 10 milliamperes ($R = E/I = 250/.010 = 25,000$). The intersection of the load line with the zero grid-bias plate-current curve is shown by the vertical line B, which cuts the base line at 44 volts. Thus 44 volts is established as the minimum swing of the instantaneous plate voltage.

Half way between this minimum of 44 volts and the maximum or supply voltage is the operating point, 172 volts. The vertical line, C, erected at this point intersects the load line about midway between the plate-current curve for a bias of —20 volts and the curve for a bias of —30 volts. A plate-current curve for a grid bias of —25 volts would pass through or very close to the operating point and therefore —25

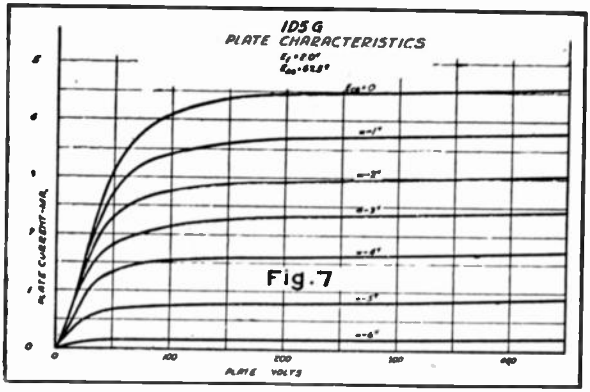


Fig. 7

volts is established as the operating bias voltage. The height of the operating point above the base line is equivalent to a plate current of approximately 5 milliamperes. Using Ohm's law, it is determined that the cathode bias resistance for a single section of the 6E6 would be 5000 ohms.

However, this tube has a common cathode and since it would be used as a push-pull driver in most cases, the cathode resistor should be 2500 ohms theoretically. In practice, it may be necessary to lower this value to 2000 ohms because it is appreciable compared with the plate load resistor.

In both figure 2 and figure 3, a vertical line D will be noted. This vertical which passes through the intersection of the load line with the plate-current curve representing twice the operating bias voltage (—16 volts in figure 1 and —50 volts in figure 2) establishes the actual upper limit of the plate-voltage swing during amplification of a signal which has a peak voltage equal to the bias. The crest-to-crest signal-output voltage will be approximately the plate voltage at D minus the plate voltage at B. The peak signal-output voltage will be half this value (middle to one crest), and the r.m.s. signal at the plate will be 0.7 of the peak-signal voltage.

This method of determining proper operating conditions for new plate voltages not covered by published figures is easy to carry out. It must be understood that it provides approximate results and that final adjustment of bias with an oscillograph to check wave form, or, lacking the oscillograph, an ear test should be made. The method gives a very close approximation to the values suggested for a few types on which resistance coupling information is given.

Figure 4 shows how the mutual conductance of the 6K7, or type 78, varies when the control-grid bias is changed. This tube is of the variable-mu type developed to reduce cross modulation and consequently the control grid must be made quite negative to reduce the mutual conductance or gain of the stage using it. The shape of the mutual conductance or G_m curve is followed in the design of volume controls.

One factor of interest to the service man is the flattening of the curve as zero bias is approached. Actually, a tube of this type should never be operated with less than approximately —1.5 volts bias if the full mutual conductance is to be realized. A lower value of bias will generally cause instability and, by permitting the total cathode current to rise above the normal, will bring up the "rush" noise level of the receiver.

Figure 5 is shown to illustrate the effect of the screen-grid voltage on plate current in tubes similar to the 6K7. The service man will find this kind of information valuable in determining proper cathode-bias resistance values for r.f. or i.f. stages where the screen voltage furnished within the receiver under test or repair is not the screen voltage specified under the limited ratings on the usual data chart. In screen-grid tubes of all types, the screen

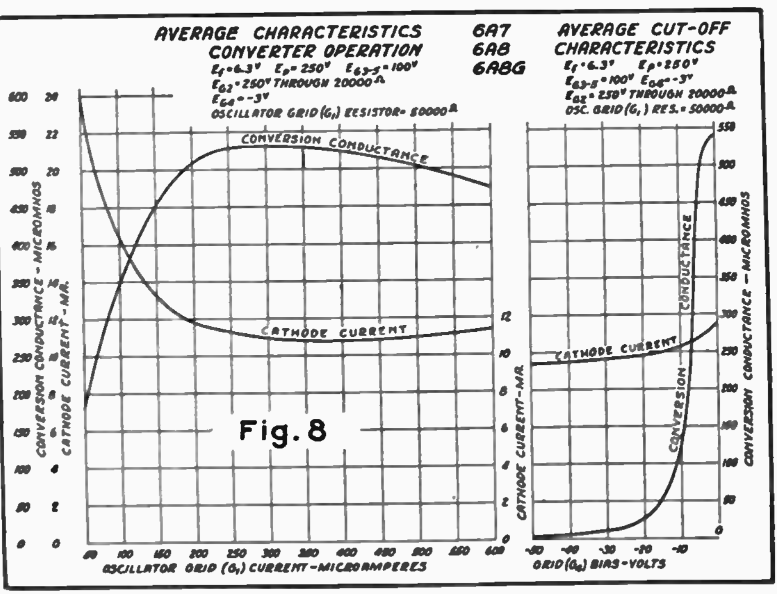


Fig. 8

voltage and the control-grid bias determine the plate voltage higher than the screen voltage.

Figures 6 and 7 should be studied together. They illustrate (in figure 6), the effect of secondary emission in the tetrode 1A4, and (in figure 7) the elimination of this effect in the pentode 1D5G. In data chart ratings, the two tubes appear to be similar. The plate "families" for each tube show them to be quite different in the region where the plate voltage is equal to or less than the screen voltage. The addition of the suppressor grid in the 1D5G raises the effective gain of the tube and provides better performance. Some receivers, designed for the tetrode 1A4, will not take a pentode 1A4 without developing oscillation trouble induced by the higher gain of the improved tube. Consequently, manufacturers are now beginning to mark the 1A4 with a suffix letter T to indicate tetrode construction or with a suffix P to indicate that the tube has a suppressor grid.

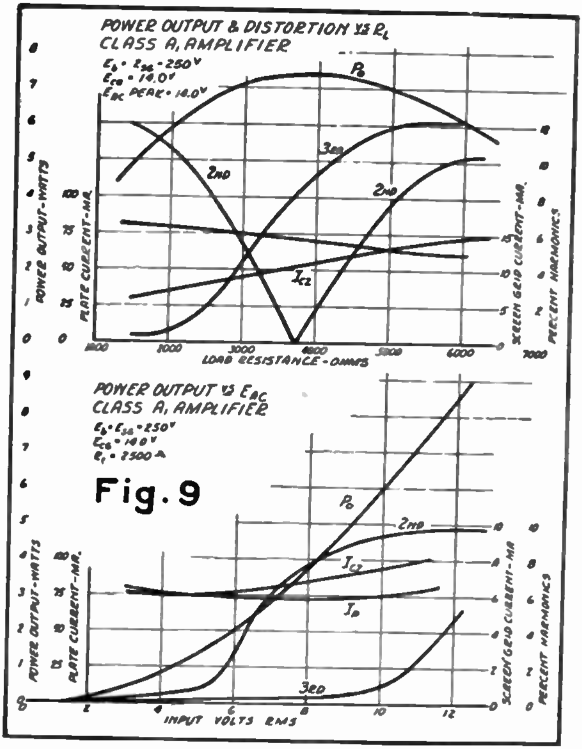


Fig. 9

Figure 8 shows interesting relationships for the 6A7 mixer tube. To determine whether or not a tube of this type—6A7, 6A8 or 6A8G—is working at maximum conversion conductance, the grid leak connection to the cathode of the tube should be opened and the grid-leak current read on a microammeter or 0-1 milliammeter while the receiver is tuned completely over each band. If the meter is inserted between the cathode end of the grid leak and cathode, it will not interfere with the operation of the oscillator. Note that the figures given are for a 50,000-ohm grid leak. Some receivers use a 25,000-ohm grid leak and these should show considerably higher values of current than will be found where the leak has a resistance of 50,000 ohms.

The curves showing average cut-off characteristics for the 6A7 illustrate the sharp cut-off characteristic of the signal control grid. Most receivers having one r.f. stage operate the 6A7 with fixed bias and apply the a.v.c. voltage only to the r.f. and i.f. amplifier tubes.

Figure 9 shows the output power and distortion characteristics of the 6L6 and 6L6G type tubes. While the curves explain themselves clearly, the information they present could not be given in understandable form without some reference. In audio work, particularly, curves offer a comprehensive view of inter-related data which would mean very little if considered alone.

Another complete story is told by the curves, in figure 10, which represent the effect of a straight resistance as compared with the ballast action of the new NB tube for voltage regulation in battery-operated receivers. The curves, shown for operation with a 3-volt "A" pack, indicate that a straight resistance will limit the initial voltage of 3.1 to 2.4 volts on the tube filaments, whereas the NB regulator permits the tube voltage to reach 2.25 volts. At the end of battery life with the battery-terminal voltage at approximately 2.0 v. the straight resistance drops the filament voltage to approximately 1.53 v. while the NB regulator delivers 1.65 volts to the filaments. Since modern two-volt tubes will work down to approximately 1.6 volts, the NB regulator saves the filaments from over-voltage at the start and permits the battery to be completely used at the end of life.

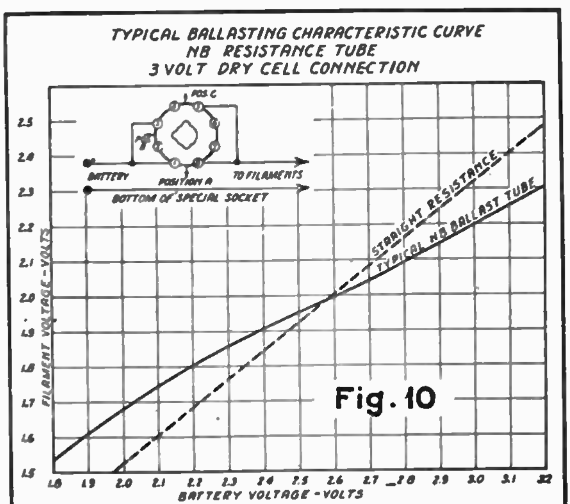


Fig. 10

From Electronics
October, 1937

Applying Police Radio

—to the varying needs of different communities requires a careful analysis of the terrain, the noise level, and the type of service expected. Methods of performing this study are here presented as well as the results.

BY R. N. HARMON
Radio Division, Westinghouse E. and M. Co., Chicopee Falls, Mass.

IN CONSIDERING the installation of a police radio communicating system, it is essential that an analysis be made of the area to be served to provide accurate operating specifications and estimate of costs. An accurate engineering analysis should include a study of the following to determine the best site and accurate equipment and installation expense:

1. Size and shape of the area to be served.

2. Character of the soil (sandy, marshy, level, hilly, and so forth).

3. Character of the settlement (manufacturing, business, residential or rural).

4. Electrical noises present (automobile, trolley car, x-ray, diathermy, neon signs and atmospheric static).

5. Chances of interferences from other stations with similar services.

6. Charting o fa map of the area to be served in order to show the field strengths required for satisfactory service. In preparing this chart the following must be known:

(a) Noisy intensity present on the frequency used at various points throughout the area.

(b) Type of service desired (Just barely satisfactory or entirely saisfactory.)

Considerable material has been prepared from studies of the above subject. A recent investigation by the C.C.I.R. entitled, "Study of Question No. 9", and submitted for the Fourth Meeting of that Committee in May, 1936, contains this data:

MEDIUM HIGH FREQUENCIES
1500-3000 KCS.

Microvolts Per Meter Required	*Barely Satisfactory*	*Entirely Satisfactory*
Concentrated Business District	707	5012
Residential	251	1778
Rural	.63	4.5

ULTRA HIGH FREQUENCIES
30-42 MEGACYCLES

Microvolts Per Meter Required	*Barely Satisfactory*	*Entirely Satisfactory*
Concentrated Business District	50	355
Residential	10	79
Rural	Receiver Noise Only	10

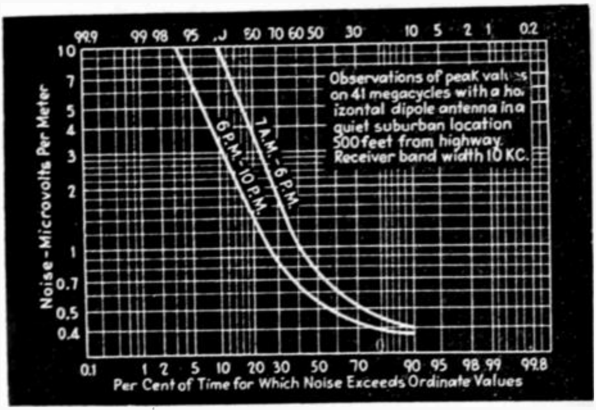


Figure 1—Noise levels encountered 500 feet from road in quiet suburban areas.

- Man-Made Noise a Large Factor

Operation in the medium high frequency band, 1500 to 3000 kcs., is limited by man-made noise in the concentrated business districts where the electrical noise level is extremely high. The same is true, but to a lesser extent, in the residential areas. In rural areas the degree of service is limited maily by atmospherics and receiver noise, plus possible adjacent channel interference.

In the ultra high frequency range, 30 to 42 megacycles, the degree of service is again limited by man-made noise in the concentrated business and residential areas. However, the type of electrical noises that interfere with this service are usually found to originate in an electrical discharge, such as automobile ignition, leaky power lines, defective neon signs, and so forth.

Curves K and L (figures 1 and 2) of the C.C.I.R. paper previously referred to show clearly the advantage to be gained by locating ultra high frequency receiving antennae in quiet locations. Referring to figure 2 which gives noise levels received by a receiver located 150 feet from a road, it may be seen that 10 per cent of the time noise peaks exceed 115 microvolts per meter, whereas 50 per cent of the time they are below 34 microvolts per meter. On the other hand, figure 1, which gives noise levels received by a receiver located 500 feet from a road in a quiet, suburban area, indicates that 10 per cent of the time noise peaks are in excess of 10 microvolts per meter, while 50 per cent of the time noise peaks will be below 0.8 microvolt per meter.

- Determining Power Requirements

Having charted the area to be served, with the signal strength required for the type of service desired, the next step is to determine the transmitter power to produce thise signal strengths in the area of interest.

For medium high frequencies

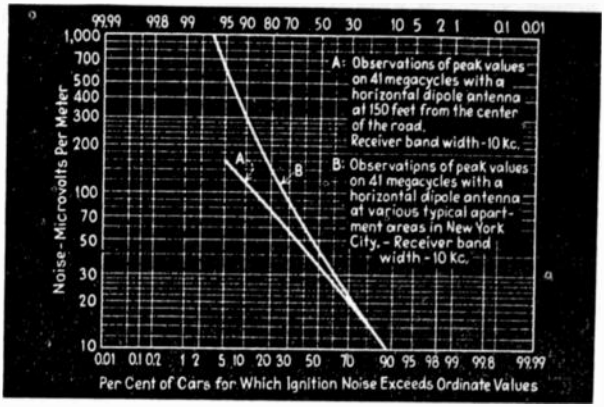


Figure 2—Noise levels (A) 150 feet from road (B) in apartment areas in New York City.

there is available a wealth of material which will enable practically anyone to determine the type of antenna and the power of the transmitter required to produce a given signal strength at any given distance over different types of soil. Particular reference is made to the National Association of Broadcasters' engineering manual, which is complete on the subject. Figure 1D (figure 3) of this manual shows the increase in signal to be obtained as the antenna length is increased. That figure indicates an antenna 1/10 of a wave length long should produce a field strength of 3.5 millivolts per meter per watt, while a quarter-wave antenna should produce 5.4 millivolts per meter per watt, and a half wave antenna 7.5 millivolts per meter per watt.

Numerous formula have been developed to predict the field strength which can be expected at various distances from a given transmitting antenna but development of these equations is beyond the scope of this paper. A bibliography is given at the end of the paper for those who may be interested in such equations. Other curves on this same subject have been prepared by the Federal Communications Commission engineers an dare available to the public. These curves indicate that the limit of useful service in a residential area for a 50 watt transmitter with a short antenna, operating on 2500 kcs., for ground of excellent conductivity, is thirteen miles; and for ground of poor conductivity, five miles, (see figures 4 and 5). For a 500-watt transmitter under similar conditions, the distances are twenty-five miles and eight miles respectively.

• U. H. F. Data

In the ultra high frequency range there is at present only a moderate amount of literature available to

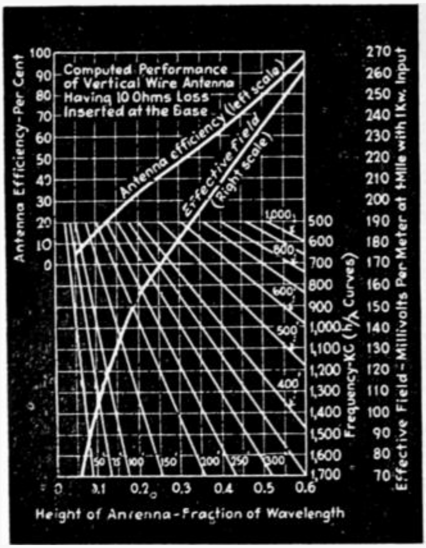


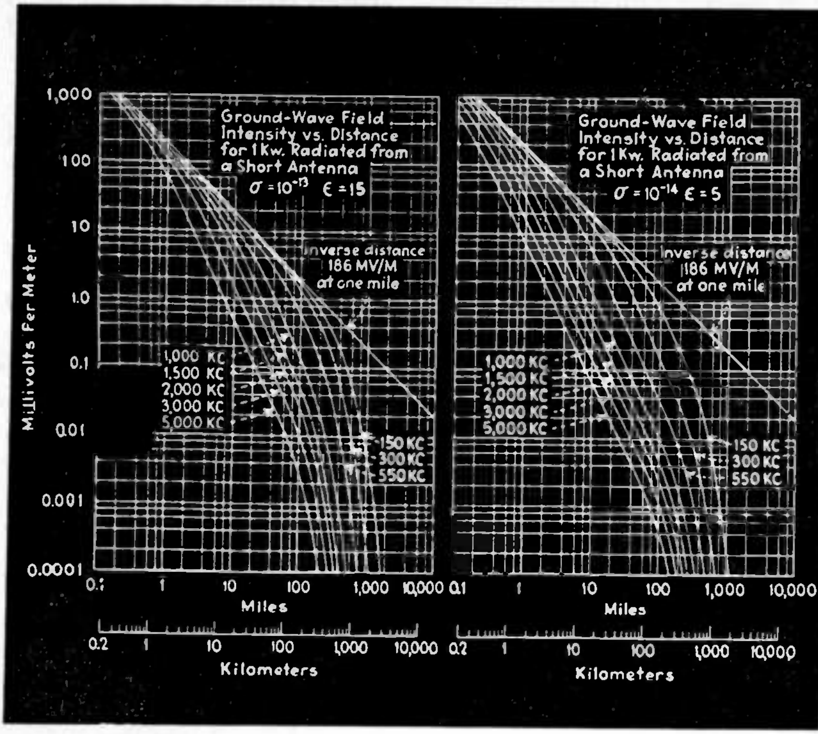
Figure 3—Antenna efficiencies and field strengths vs. antenna height and length.

the public, and its accuracy has not been proven. This is due mainly to the youthfulness of the development of ultra high frequency equipment and its application. In general, the field strength received from a given transmitter is a function of the product of the transmitting and receiving antenna heights above ground, the square root of the transmitter power, and the square root of the antenna length, all divided by the wave length and the square of the distance between the transmitting and receiving antennae.

Two curves, figure 6), show the field strength to be expected at distances from one to six miles from both a 50-watt and 15-watt ultra high frequency transmitter when the antenna eeights are 150 feet and 3 feet respectively for the fixed and mobile units. These curves show that the range for the 50-watt transmitter is limited to three miles for an entirely satisfactory signal and seven miles for a barely satisfactory signal in residental areas. The limit of range of the 15-watt mobile unit will depend upon the quietness of the remote receiver location and should be two and a half miles for the average residential location and five or six miles rof the best possible location.

In the medium frequency range moderate hills and irregularities of the ground have little effect on the transmission, while serious shadows are cast by even moderate hills when ultra high frequencies are employed. Thus, considerable caution must be used in locating ultra high frequency antennae to minimize the chance of such shadows.

Considerable time may be expended in developing a logical choice of equipment and data to enable the proper location of that equipment within a given area. These data must be used in conjunction with other factors which are mainly economic or political. In deciding upon the location for the headquarters transmitter, these data must be considered along with the fact that it usually must be located on city property, preferably at police headquarters, although this should not exert too much weight as remote control may be used if the headquarters building is suitable to give a practical antenna



Figures 4 and 5—Field strength intensity as a function of distance, ground conductivity and dielectric coefficient, for frequencies from 550 to 5000 kc.

location. A suitable room for the transmitting equipment, proper telephone and power facilities must be provided.

The installation costs of various heights of antennae should be weighed against the probable gain in signal as indicated in figure 4. For installations employing lower powered transmitters the cost of the antenna and transmitter is a large percentage of the entire cost, and special care should be taken to obtain the most efficient installation for the least expense. New and novel developments, such as the shunt-excited antenna, which is merely a steel pipe of proper length grounded directly at the base, are helpful in reducing installation costs.

• Care Needed with "Talk-Back" System

If the installation is to employ mobile "talk-back" transmitters, the receiver locations must be care-

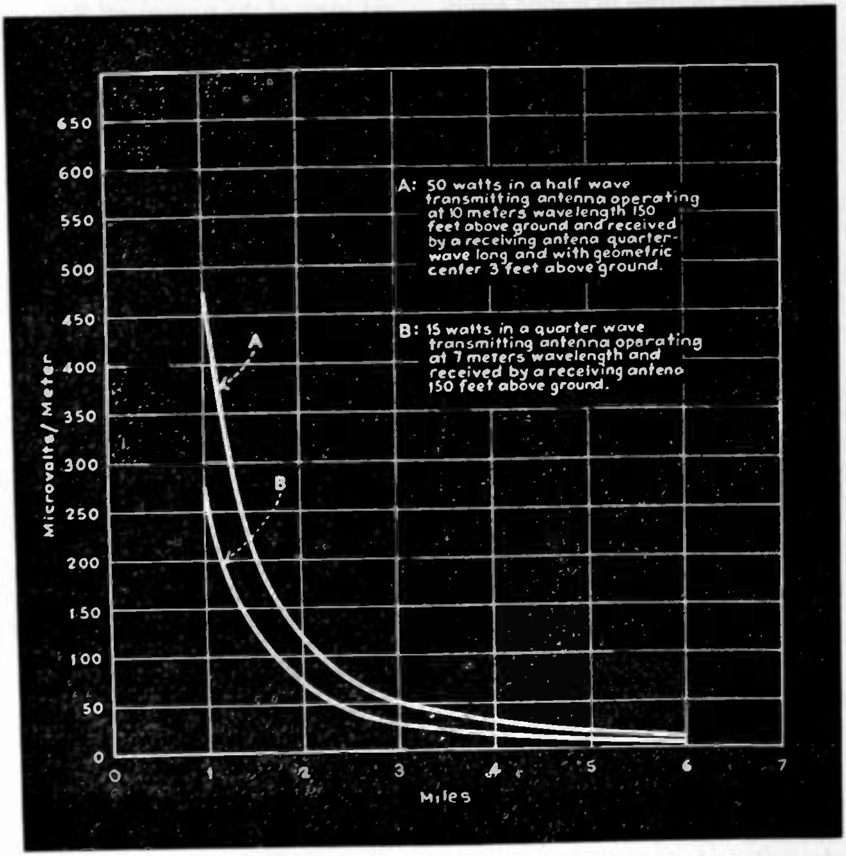


Figure 6—Field strength at ultra-high frequencies (10 and 7 meters) as a function of distance from transmitting antenna.

fully picked. References to figures 1 and 2 showing probable noise levels existing in different types of areas, together with figure 6, of signal strength received at different distances from the mobile unit, will be helpful in locating these receivers. Too much importance cannot be placed upon the necessity of selecting a location which is both quiet and high above the surrounding territory. Other factors which must be considered are buildings suitable for antenna installation, telephone and power facilities, accessibility to the operator, and control from headquarters.

The installation of medium high

frequency receivers in mobile equipment is relatively simple and will not be discussed other than to indicate that most of what applies to ultra high frequency installations also applies to installations of this type.

In any mobile installation, great care must be exercised to make the installation as mechanically sound as possible. Even with the best care, the constant excessive vibration and shock will eventually loosen or break various parts which are not fastened securely to the automobile. Care should also be used to make the installation in such a manner and with such proper materials that the equipment may be removed and re-installed where the cost of the transmitting and receiving equipment is usually a large percentage of the cost of the car. The life of the automobile itself is much less than that of the radio equipment.

• Hints On Mechanical and Electrical Maintenance

The maintenance of any police radio equipment may be divided into two main divisions, one mechanical and the other electrical. The mechanical maintenance will consist of a regular and careful check and cleaning of all mechanical parts of the equipment. Particular care should be given all mobile equipment, rotating equipment, and contactors. A regular periodic check should be the rule, and complete records should be kept of all the checks and work done on individual units.

The electrical maintenance should consist of proper checks to see that the equipment is operated in accordance with the rules of the Federal Communications Commission regarding frequency, power, modulation, and radiations. These checks should be made with sufficient instruments to show that all parts of the circuits of each piece of apparatus are properly and efficiently operating. Other checks should include measurement of filament voltage, plate and grid voltages and currents, antenna current, microphone current, percentage modulation, and so forth. Here, as in the mechanical maintenance, a regular systematic schedule with complete records of adjustments made and results obtained is of the utmost importance.

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●

SOMETHING new in the line of using radio transcriptions is about to descend into the midst of collegiate circles. The College of the Pacific at Stockton and the University of Redlands are going to hold a debate through the exchange of recordings.

The two sides of the question will be exchanged on discs as well as the rebuttal. Both institutions are equipped with Universal professional recording machines.

¶ From Broadcast News, Nov., 1937

External CROSS MODULATION

BY DUDLEY E. FOSTER

SOMEWHAT over a year ago reports began to be heard concerning a type of interference with broadcast reception which had never before been noticed. The interference occurred only in localities having high field strength from one or more local stations, and its new characteristic was that the program of the strong local station was heard when the receiver was tuned to one particular other station, but not to still others. The effect was not due to lack of selectivity because when tuning the receiver, the local station could be tuned out and then would reappear when a certain other station was tuned in. Occasionally two local stations would be heard together on a frequency which was quite different from that of either of them.

• Peculiarities

This type of interference also had other peculiarities. In the area in which it occurred, it would be found in one house whereas the house next door would be free from interference even when the same set was used. In those houses where it occurred, any make or model of receiver, including battery sets, experienced it. Still another puzzling factor was that the interference was not constant, being much more severe at some times than at others, and occasionally disappearing entirely for a period. In one case the interference was eliminated by opening the window through which the antenna lead-in passed, and in another case the interference was heard only when a certain bedroom light was turned on.

These characteristics led to the deduction that the interference was not caused in the radio receiver, but by some agency external to the receiver itself. This was further proven by laboratory experiments with two signal generators simulating the desired and interfering stations. In the laboratory, inputs of three or four volts applied to the receiver did not cause interference, whereas, in the field at those locations having this type of interference, field strengths causing less than half a volt signal to be impressed on the receiver were present. Furthermore, decreasing the length of antenna did not eliminate the interference.

A survey was made to determine whether interference of this nature had been noticed in other parts of the country. Reports as a result of this survey showed it to be present in certain areas in or near the following cities: Cincinnati, Chicago, New York, San Francisco, Seattle and Washington.

Since by this time it was evident that the trouble was some form of cross modulation, and since it was exterior to the receiver, this type of interference was designated "external cross modulation."

A location was found where the cross modulation existed consistently and a study was made to determine the fundamental cause and a remedy. In this location, a battery receiver with a short antenna exhibited cross modulation inside the house, but when the receiver was a few feet outside the house, cross modulation ceased. A trap circuit in the antenna was of no benefit, which was further proof that the difficulty was external to the receiver. It was observed that at this location, as well as at others where the effect was serious, that the house wiring was of the knob and tube type and the service mains from the distribution transformer were overhead. A filter near the receiver, consisting of two 0.1 μfd. condensers across the line with the center point grounded had only a slight effect on the interference, but an additional condenser across the line where it entered the house greatly decreased the cross modulation. It was further found that by placing the antenna at a distance from the power lines and using a shielded lead-in, the external cross modulation disappeared.

• Spurious Frequencies

This experience showed that the cross modulation was due to rectification of radio frequencies in the power wiring, with resultant new, spurious frequencies being induced in the antenna or lead-in. Radio signals were picked up by the power wiring or other metallic conductors near the receiving antenna and at some point along the conductor were impressed on a rectifier or non-linear circuit element. The characteristic giving the output current of a rectifying element is commonly expressed as a series expansion in ascending powers of the applied voltage, the applied voltage in this case being the radio-frequency signals present on the power wiring or other conductor. The power-series representation of the rectifier characteristic discloses the new harmonic and combination frequencies which result from the rectification process. A simple laboratory test confirmed the observations. Two antennas were placed a few feet apart and to one of them a radio receiver was connected. An impedance was connected between the other antenna and ground, and when a simple diode was connected across this impedance, cross modulation of the signals in the first antenna occurred.

The question arises as to where the rectifier may exist in the field. Wherever there is a poor connection between any two metallic bodies, especially if oxidation is present, rectification can take place. The poor contact may be in the lighting lines, in piping, or even in the antenna itself. In one case the trouble was located at a point where a pipe passed through metal wall lathing. Bonding the pipe and lath together eliminated the interference. In another case two pipes were found to be touching and insertion of a block of wood between them cleared up the cross modulation. When such a rectifier exists and one or more powerful signals are present, new frequencies are generated by the rectifier. Where only one powerful signal is present, the only new frequencies made by the rectifier are multiples of the fundamental, that is the second harmonic, third harmonic, etc. of the signal frequency. Where two strong signals exist, a number of cross modulation combinations take place. Let us call the frequency of one of the strong stations *a*, and that of the other *b*, then the rectifier generates the following frequencies:

a + b	2a — b
a — b	2b + a
2a	2b — a
2b	3a
2a + b	3b

An effect also takes place whereby the modulation of station with frequency *a* is heard on station *b*, and the modulation of station *b*, is heard on *a*.

It should be noted that these spurious frequencies do not depend upon the presence of a second harmonic from either of the stations. If both stations are entirely free from harmonic radiation, these same frequencies are generated if a rectifier is present.

Let us suppose that two stations are so located that in the region between them signal strengths of 0.1 volt per meter occur from both, and that one station is on 650 kc. and the other on 750 kc. Then the following table shows the frequencies produced.

a =	650 kc.
b =	750 kc.
a + b =	1400 kc.
a — b =	100 kc.
2a =	1300 kc.
2b =	1500 kc.
2a + b =	2050 kc.
2a — b =	550 kc.
2b + a =	2150 kc.
2b — a =	850 kc.
3a =	1950 kc.
3b =	2250 kc.

These same frequencies are shown diagrammatically in figure 1. In this example these two stations would produce five new frequencies in the broadcast outside the broadcast band where one or both the stations together would be heard. It can be appreciated readily that a large amount of interference will be

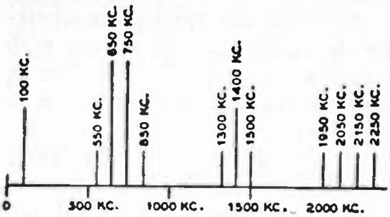


FIGURE 1

produced in this manner. The interference produced by station of frequency *a* on frequency *b* and vice versa has been found to be serious only when the rectifying action is particularly severe, because the modulation of the strong desired station usually masks the interfering modulation.

• Possibility of Hum Modulation

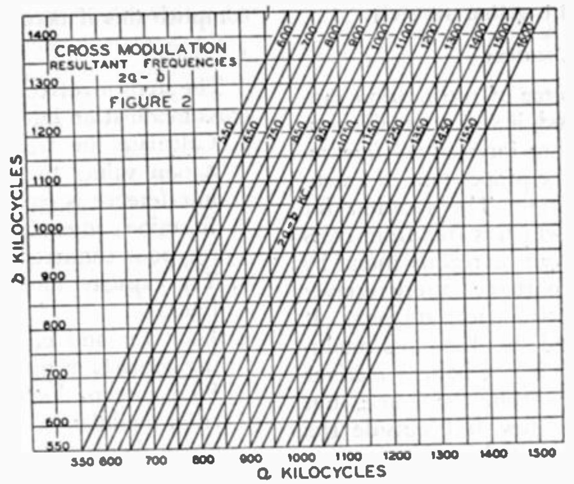
It may be seen also that there is a possibility of hum modulation being introduced when a rectifying condition exists in the power wiring. In this case, one of the frequencies is that of the signal carrier and the other that of the lighting system, which is usually 60 cycles. The rectifying action then imposes a 60-cycle modulation on the carrier. Some instances of modulation hum in receivers at certain locations have been traced to this source. Hum of this type would be present in a battery receiver at the same location. The remedy is the same as for interference between stations, namely elimination of the rectifying condition or changed installation of the antenna to avoid pick-up of resultant spurious frequencies.

Knowledge of the frequencies produced is helpful in determining whether a case of interference is due to external cross modulation or not. Most of the combination frequencies are readily calculated when the frequencies of the two stations having high field strength are known. The combinations $2a - b$ and $2b - a$ are usually in the broadcast band and for that reason are troublesome. Figure 2 is a chart for reading the spurious frequency $2a - b$ for any value of *a* and *b*. By reversing the designation of *a* and *b* the chart can be used for finding $2b - a$ also.

In investigating a situation where interference exists, the first step should be to determine whether or not it is due to external cross modulation by observing the frequencies at which intererence exists. For example, with the two strong signals at 650 kc. and 750 kc., if the program from both is heard at 550 kc., 850 kc., and 1400 kc., it may be safely assumed that the trouble is due to external cross modulation. If the interference is not due to external cross modulation, shortening the antenna or installation of a wave trap tuned to the interfering signal, or both, will remedy the situation.

• Checks for Type

Cross modulation may, of course, be produced in the radio-frequency or first-detector stage of the receiver if the tubes are not of the remote cut-off or variable-mu type or if the operating bias is, for any reason,



incorrect.[1] Cross modulation occurring in the receiver can be differentiated from that due to external causes by use of a short antenna, a wave trap tuned to the strongest interfering station, or by substituting another receiver. These expedients will eliminate, or greatly reduce, cross modulation which takes place in the receiver, but will not affect external cross modulation.

As seen from some of the cases, the rectifying element may be in the power wiring, piping, or in the antenna itself. Therefore, the first step in eliminating the trouble should be to make sure that the antenna and ground connections to the receiver have secure, tight joints throughout, soldered joints in the antenna being preferable. If this does not cure the interference, the next step is to endeavor to find the rectifying element elsewhere. If the rectifier is in the power wiring, connection of two 0.1 μfd. condensers across the lighting lines, with the center point going as directly as possible to a good ground, should produce at least some decrease in the cross modulation. In this connection it should be remembered that steam or gas piping, and in some cases water piping, may have joints which are electrical rectifiers, and in this event use of such piping as a ground for the receiver will intensify cross modulation. The house should be examined for indications of pipes or electrical conduits which touch each other. If such points are found, they should

[1] "Reduction of Distortion and Cross-Talk in Radio Receivers by Means of Variable-Mu Tetrodes." Stuart Ballantine and H. A. Snow. *Proceedings of the Institute of Radio Engineers*, December, 1930.

be separated by a block of wood or else bonded together securely.

• Antenna Location

If the source of rectification cannot be located, it still is usually possible to secure interference-free reception by the proper type of antenna installation. The location for an antenna which is free from cross modulation can be readily found by the use of a portable battery receiver equipped with a short antenna. It will be found that the cross modulation occurs in the battery receiver when it is within the house, but disappears a few feet outside the house. By this exploration means, a location for the antenna is to be found where cross modulation does not exist. The spurious frequencies will, however, be picked up on the lead-in unless it is thoroughly shielded.

In some cases metallic braid shielding may not be good enough and concentric transmission line cable, which is now available in small sizes, must be used. Since the shielded cable is low in impedance, it is necessary to use matching transformers at the antenna and at the receiver to obtain maximum efficiency. If such transformers are used, they should be examined for possibility of poor connections which will cause rectification and resultant cross-modulation interference. It must be remembered also that the ground lead of the receiver is capable of picking up radio-frequency energy so that it should be as short and direct as possible. The receiver should be re-located to accomplish this if necessary.

• Resume

The steps involved in eliminating cross modulation interference are:

1. Calculate the frequency combination values to make sure the interference is cross modulation.
2. Examine antenna and ground for poor connections.
3. Try capacity filter across light lines.
4. Look for and eliminate rectifying contacts in piping or wiring. Find antenna location free from cross modulation and install antenna there with shielded lead-in to set.

The discovery of the source of the external cross modulation phenomenon has led to proper analysis and elimination of many cases of interference which formerly were mysterious in origin and therefore difficult or impossible to remedy. The basic facts of the external cross modulation theory have been corroborated by laboratory and field observations, but the technique of elimination of the resultant interference has not yet reached a stage where complete freedom from interference can be secured in every case.

This technique will undoubtedly improve as more experience is gained and as the basic causes become more widely known among service men. It is the service men who will in general be called upon to eliminate cases of external cross modulation since neither the transmitter nor the receiver designer can control this type of interference. Some benefit may be secured in the future by broadcast station allocation such that two high-powered stations are not located too close together geographically. Frequency and geographical allocation to prevent external cross modulation interference is difficult, however, because of the complexity of the broadcast allocation structure, and because allocation from the standpoint of external cross modulation alone may cause other types of interference to be aggravated.

The Crosley Radio Corporation has investigated external cross modulation extensively and presented a report to the F.C.C. at the January 18th, 1937 Engineering Conference in Washington, describing and analyzing its results in eliminating external cross modulation in nearly one thousand receiver installations.

- Theoretical Discussion

A rectifier or non-linear element has a characteristic which may be expressed by a power series expansion:

$$\frac{i}{k} = m_0 + m_1 e + m_2 e^2 + m_3 e^3 + \ldots \quad (1)$$

where

i is output current of rectifier
k is rectification constant
e is applied voltage
m_0, m_1, etc. are coefficients of the rectification characteristic.

$$e = E_1 \cos a + E_2 \cos b \quad (2)$$

where

E_1 is amplitude of signal with frequency a.
E_2 is amplitude of signal with frequency b.
E_1 and E_2 vary at modulation frequency if signals are modulated.

Substituting (2) in (1) the resultant output of the rectifier becomes:

$$\frac{i}{k} = m_0 + m_1 E_1 \cos a$$

$$+ m_1 E_2 \cos b + \frac{m_2}{2} E_1^2$$

$$+ \frac{m_2}{2} E_1^2 \cos 2a + \frac{m_2}{2} E_2^2$$

$$+ \frac{m_2}{2} E_2^2 \cos 2b$$

$$+ m_2 E_1 E_2 \cos (a + b)$$

$$+ m_2 E_1 E_2 \cos (a - b)$$

$$+ \frac{3m_3}{4} E_1^3 \cos a$$

$$+ \frac{m_3}{4} E_1^3 \cos 3a + \frac{3m_3}{4} E_2^3 \cos b$$

$$+ \frac{m_3}{4} E_2^3 \cos 3b + \frac{3m_3}{2} E_1 E_2^2 \cos a$$

$$+\frac{3m_3}{4}E_1E_2^2\cos(2b+a)$$

$$+\frac{3m_3}{4}E_1E_2^2\cos(2b-a)$$

$$+\frac{3m_3}{2}E_1^2E_2\cos b$$

$$+\frac{3m_3}{4}E_1^2E_2\cos(2a+b)$$

$$+\frac{3m_3}{4}E_1^2E_2\cos(2a-b). \quad (3)$$

From this expression may be seen the large number of resultant frequencies and their relative magnitudes. The second order term results in new frequencies carrying the modulation of one or both of the signals. The third order term shows that rectification increases the modulation depth of the signal and also that the modulation of one signal becomes impressed on the frequency of the other signal. The third order term produces additional new frequencies carrying the modulation of one or both of the signals.

- The Luxembourg Effect

About three years ago an effect was noticed in Europe whereby the modulation of the Luxembourg station, which is a high-powered long-wave station, was noticed in Holland on the frequencies of stations in the broadcast band, and caused interference with those stations.[2] This phenomenon was called the "Luxembourg effect" and was ascribed to a possible non-linearity of the transmission medium. Later this phenomenon of interference from the Luxembourg station was noticed in several other European countries. It is entirely possible that the effect was due to some non-linear element in the neighborhood of the receiving location and was therefore what we have called external cross modulation, especially since the Luxembourg effect is the first phenomenon which would indicate the possibility of a non-linear medium of propagation. Examples have been found in this country of external cross modulation at distances from the interfering station of over 100 miles, which are similar to the observations of Luxembourg effect. In general, when the interfering station is at such a distance, it has been found that the interfering station has high power and that there are high-tension lines extending in the direction where the interference was found, so that field intensity of the interfering signal was high at those points.

[2] "Interaction of Radio Waves" by Balth. van der Pol and J. van der Mark. Publications of N. V. Philips Gloeilampenfabrieken, Nos. 964 and 1036.
A. G. Butt, "Radio World," April 28th, 1933.
B. D. H. Tellegen, "Nature," June 10th, 1933. "Hochfrequenz Technik und Electro Akustik," 48:181-186, 1935.
"Onde Electrique" 14, No. 188, 80-808, 1935.
"Wireless World," February 26th, 1937.

THE TECHNICAL FIELD

in Quick Review

BY RAY L. DAWLEY

RADIO DIGEST briefly summarizes for its readers the contents of leading radio articles in current technical publications, some of which may appear later in RADIO DIGEST.

All-Wave Radio

JANUARY, 1938
Manson Publications Corp.
16 E. 43 St., N.Y.C.
25c a copy—$2.50 yearly

THE AWR AUTOMATIC, *by G. S. Granger*—A high-fidelity receiver with push-button tuning and automatic frequency control. A complete discussion of the construction of this well-designed receiver, both mechanically and electrically. Complete chassis layouts are shown. The receiver described has six selector push-buttons; any one of six local or semi-local stations may be picked up merely by punching the proper button.

SIMPLE A.C.-D.C. 5-METER TRANSMITTER, *by Guy Forrest*—This transmitter was designed for one way of a two-way radiotelephone circuit, particularly for emergency work. It is adaptable to either fixed or mobile operation, is very simple and rugged, employs only three tubes (a 6J7, a 41 and a 6A6), and is capable of supplying from 2 to 5 watts to the antenna with a very minimum of demand for operating power.

NEWCOMER'S C.W.-PHONE TRANSMITTER, *by C. Watzel, W2AIF, and W. Bohlen, W2CPA*—A self-contained rig, 40-45 watts c.w., 20-25 watts phone, designed to cover the range from 10 to 160 meters. The complete rig is built into a small metal cabinet. The r.f. lineup comprises a 6F6 oscillator, a 6F6 doubler and an 807 in the final amplifier. A 6N7 speech amplifier drives another one as a modulator for the 807 stage when it is to be used for radiotelephone operation. Complete chassis and panel layouts are given for the transmitter.

December, 1937—

IT GOES OUT—THERE, *by W. E. McNatt, W7GEZ*—A discussion of the vertical angle of radiation from vertical half-wave dipoles when operated at different electrical heights above the earth. The improved radiation characteristics obtained through the use of a good ground are discussed; the best methods of laying the radials are mentioned as are the methods of determining the angles between these radials.

A further Proving Post review of the Silver Masterpiece VI is shown, as is one of the MB-100 transmitter kits. A number of additional notes are given on the Wide-Range System of reception as first discussed by Watzel and Bohlen in the Sept. and Oct. issues of *All-Wave Radio*. These notes should be of interest to builders of the original instruments who wish to improve the performance thereof.

COMMUNICATIONS

DECEMBER, 1937
Bryan Davis Pub. Co., Inc.
19 E. 47 St., N.Y.C.
25c a copy—$2.00 yearly

LIMITING AMPLIFIERS, *by John P. Taylor* — A complete discussion of the various types of manufactured peak-limiting speech amplifiers. Circuit diagrams, characteristic curves and photographs are shown.

RECTIFIER TYPES AND APPLICATION, *by Bernard H. Porter* — There are a number of commercially-manufactured different types of rectifiers, such as mercury arcs, hot-cathode high-vacuum units, hot-cathode gas and vapor filled types, cold-cathode gas types, electrolytic arrangements and junction designs. All are discussed and the best services for each are mentioned.

THE HARMONIC PRODUCER, *by C. H. Bidwell* — A discussion of the non-linear inductance method of producing an accurately-controlled series of harmonics from a fixed standard. The author deals mainly with the method of operation of the non-linear harmonic generator. He indicates that the system is most commonly used in the production of a series of harmonics for a multi-channel, carrier-telephone system.

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November, 1937—

COAXIAL-CABLE TELEVISION TRANSMISSION. A review of the results obtained and the methods of obtaining them through the transmission of television images on the New York to Philadelphia coaxial cable circuit. Single-sideband transmission was used to carry the video signal of the motion pictures that were transmitted.

RADIO TOWER LIGHTING AND MARKING, *by Arthur R. Nilson*—Mr. Nilson, of textbook fame, discusses a number of different methods of tower lighting and the control arrangements associated with each. Approved methods of tower painting are also covered.

A TALK-BACK AND LOUDSPEAKER CONTROL SYSTEM, *by P. S. Gates*—A very ingenious system is presented whereby six speakers, distributed throughout the monitoring, audition, reception, and audience rooms may be connected to either of two amplifiers and used for any common studio purpose. Talk-back provision is made on five of the six speakers; it is assumed that the sixth one will be in a position where this provision will not be needed.

FREQUENCIES AND STANDARDS, *by Albert F. Murray* — Mr. Murray, acting chairman of the RMA television committee and television engineer of the Philco Radio and Television Corp., discusses the standards recommended by the RMA to the FCC, and the ones set down by the FCC to go into effect in the latter part of 1938. The reasons for these recommendations that were, for the most part, accepted by the FCC are set forth. A comparison of foreign and American standards is given.

DISC RECORDING — RECORD PROCESSING, *by T. L. Dowey*—An article thoroughly covering the major considerations of disc recording: (1) Preparing a suitable surface to receive the record engraved by the cutting stylus, (2) Making the recording permanent, (3) Reproducing any number of copies of the original in such form as to permit their reproduction.

electronics

NOVEMBER, 1937
50c a copy—$5.00 yearly
McGraw-Hill Pub. Co., Inc.
330 W. 42 St., N.Y.C.

NEWS PICTURES BY WIRE. Since about June, 1935, major news syndicates have been using ordinary telephone lines for the transmission of news pictures from one point to another. This article discusses the various types of portable and fixed transmission and reception equipment used by the various syndicates and their method of operation.

PHONOGRAPH PICKUP TRACKING ERROR VS. DISTORTION AND WEAR, *by Benjamin Olney*—For several years past a feature of phonographs produced abroad has been an arrangement for minimizing the so-called tracking error. It is only lately that such devices have made their appearance in this country. Mr. Olney gives an extensive theoretical analysis of the need for and the operation of these devices.

SCREENS FOR TELEVISION TUBES, *by I. G. Maloff and D. W. Epstein*—A review of phosphorescent screens used in television cathode-ray tubes, including their influence on the contrast of reproduced images.

DISTORTION OF SAW-TOOTH WAVE FORMS, *by Manfred von Ardenne*—Amplitude distribution of the frequency spectrum of various saw-tooth waveforms with different retrace times is given; effect of eliminating higher order harmonics investigated. The effects of phase shifts of fundamental frequency is considered.

December, 1937—

A VOLUME LIMITER, *by C. F. Schaeffer*—A peak chopper for broadcast transmitters which raises the average level of modulation and makes impossible overmodulation for any extended period. A new system of approach to the already large number of systems for peak limitation. This one, however, has advantages of its own.

W2XE SHORT-WAVE TRANSMITTER, *by John P. Taylor*—A very well illustrated article showing the new RCA-built 10-kw. short-wave transmitter of the Columbia Broadcasting System.

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QST devoted entirely to AMATEUR RADIO

JANUARY, 1938.
25c a copy—$2.50 yearly
American Radio Relay League
West Hartford, Conn.

CAIRO, *by A. L. Budlong.*—How the amateurs got their present bands, what the Cairo conference means to amateur radio, how a conference such as this does business—all these are discussed by Mr. Budlong in this part of a series of two articles on the subject.

A FIVE-BAND EXCITER WITH FRONT-OF-PANEL BAND-CHANGING, *by Donald W. Exner, W8ZU.*—In this article is described an ingenious low-powered exciter using an 89 and a 6L6G, and featuring coil switching, alternative electron-coupled-oscillator control and a number of unusual constructional features.

TRUE NORTH FROM OLD SOL, *by A. L. Budlong*—A short article indicating the proper procedure for determining true north in any latitude by taking simple bearings upon the sun.

DIRECTIONAL ANTENNAS WITH CLOSELY-SPACED ELEMENTS, *by John D. Kraus, W8JK.*—In this article Mr. Kraus discusses a number of the considerations in the design of the now justly-famous flat-top beam.

CIRCUIT ELEMENTS IN MODERN TELEVISION RECEPTION, *by Marshall P. Wilder, W2KJL.*—In this article, the second of a series, Mr. Wilder discusses the various circuits of a modern television receiver with the idea of clarifying the process involved in reassembling the transmitted pictures.

December, 1937—

INTRODUCTION TO MODERN CATHODE-RAY TELEVISION RECEPTION, *by Marshall P. Wilder, W2KJL.*—A complete discussion of the make-up of the television signal, the method of scanning, and the methods of synchronizing the receiver with the transmitted signal.

APPLYING INVERSE FEEDBACK TO THE UNIVERSAL SPEECH AMPLIFIER, *by George Grammer.*—Modifying the universal speech amplifier as described in the November issue by the incorporation of feedback to improve the frequency response and power output.

DESIGNING THE FIRST STAGE OF THE SPEECH AMPLIFIER, *by Thomas A. Gross, W1JZM, VE1IN.*—A discussion of the proper circuit considerations for the high-gain pentode in the first stage of speech amplification.

A COMPLETE OSCILLOSCOPE WITH I. F. INPUT AMPLIFIER, *by Earl I. Anderson, W8UD.*—A complete description of a 913 oscilloscope with self-contained power supply, built-in sweep amplifiers, and built-in saw-tooth oscillator.

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RADIO

JANUARY, 1938
30¢ a copy—$2.50 yearly
RADIO, Ltd.
7460 Beverly, Los Angeles

THE COMPACT UNI-DIRECTIONAL ARRAY, *by Walter van B. Roberts, W3CHO.* An ultra-compact, "plumber's-special" array that is really simplicity itself. An unusual gain and front-to-side discrimination is had.

A MODERN SELF-CONTAINED KW. PHONE, *by Frank C. Jones, W6AJF.*—A compact relay-rack mounted transmitter using a pair of 100TH's in the final, modulated by another pair of 100TH's in class B.

MULTI-BAND EXCITER WITH INSTANTANEOUS FREQUENCY SWITCHING, *by Roy Raguse, W6FKZ.*—The ultimate in simplicity with reasonable power output. An 808 is used in the last stage of this exciter to provide an output of about 200 watts to the final. Due to the one low-C tuned circuit, the exciter may be moved to any part of the amateur bands by switching crystals without retuning.

FADING—WHAT CAN BE DONE ABOUT IT?—An analysis of the problem and a suggested solution in the form of more sharply vertically-directive receiving antennas.

CHASSIS CONSTRUCTION HINTS, *by C. B. Stafford, W9KWP.*—A "shop-notes" article listing a number of helpful suggestions to the amateur or other constructor who is inclined to build his own.

A DE-LUXE SUPERHET WITH VOLUME EXPANSION AND TWO-CHANNEL I.F., *by Raymond P. Adams*—A really de-luxe receiver that incorporates all the doodads. The two-channel i.f. amplifier allows the selection of either high-fidelity or high-selectivity.

CONTROLLABLE ANTENNA DIRECTIVITY—Three systems are discussed under this title. (1) OPTIONAL END-FIRE DIRECTIVITY WITH THE FLAT-TOP BEAM, *by Robert R. Sprole, W8QJT, and John D. Kraus, W8JK.*

(2) AMATEUR APPLICATION OF MODEL-C ANTENNAS, *by Nick C. Stavrou.*—(3) A SIMPLIFIED FLAT-TOP ROTARY, *by Forrest Donkin, W6MZD, and Rod Richards, W6FKK.*

RADIO'S REVIEW OF THE AMATEUR TRANSMITTERS FOR 1938.

A GLANCE AT THE 1938 COMMUNICATIONS RECEIVERS.

THEORY OF ANTENNA OPERATION, *by E. H. Conklin.*—An analysis of the mechanics of antenna operation from the practical standpoint. Numerous illustrative photographs and graphs are shown.

IMPROVING THE PERFORMANCE OF ULTRA-HIGH-FREQUENCY RECEIVERS, *by Grote Reber, W9GFZ and E. H. Conklin, W9FM*—A discussion of the application of concentric lines and acorn tubes to u.h.f. receivers. The unusual results to be obtained are cited. Also included in this issue are a large number of additional features, both editorial and departmental; space is too limited to list more than the more outstanding ones above .

December, 1937—

ROTARY "FLAT-TOP BEAM" ANTENNAS, *by John D. Kraus, W8JK.*—Every amateur is well aware of the excellent bi-directional results obtainable with the flat-top beam. Mr. Kraus herein describes, in considerable mechanical detail, two rotatable flat-top beams which he has used, one with a 30-foot spread and the other with a 60-foot wingspread.

GROUND SYSTEMS FOR EFFICIENCY, *By E. H. Conklin*—Some rather interesting and helpful results have been uncovered by Messrs. Lewis, Brown and Epstein of RCA Communications in regard to the importance of a good ground system for low-frequency transmission. The results of their experiments that will pertain to amateurs on 2 Mc. and 4 Mc. work have been set down by Mr. Conklin in this short article.

AUDIO TRANSFORMER CHARACTERISTICS, *by E. F. Kiernan, W6EOO.*—While doing some development work on audio amplifiers, the author had occasion to investigate the characteristics of various transformer components. Methods of altering some of the undesirable characteristics are discussed by Mr. Kiernan.

SURVEYING AN ANTENNA LOCATION, *by C. B. Stafford, W9KWP.*—To assist the amateur in the laying out of his back yard or the nearest hillside for an antenna location, Mr. Stafford has written this article on elementary surveying.

PORTABLE A.C. POWER SUPPLIES, *by George M. Grening, W6HAU.*—Unusually complete constructional information concerning the winding procedure for both a separately-excited and a self-excited motor-driven alternator. A Dodge-4 generator is used. Sources of driving power are also discussed.

"SPARKS" WITH THE TUNA CLIPPERS, *by A. F. Penniwell, W6EZK.*—Wherein the writer, a "ham" who has gone to sea at his chosen vocation, tells of one of the lesser-known branches of radio operating.

THE AMATEUR'S FREQUENCY METER, *by John L. Reinartz, W1QP.*—In this article Mr. Reinartz describes a very much simplified method of making accurate frequency measurements. The equipment that is used is quite simple, but it is the novel method of employing this equipment that allows of such accuracy.

R.F.—BY THE PANFUL, *by George S. Davis, W6SJ.*—An ingenious semi-band-switching exciter-transmitter using a single-ended 35T Eimac in the last stage. A vari-gap crystal is featured.

PHONE AND C.W.—500 WATTS, DRESSED UP IN AN ENCLOSED RACK, *by Ray L. Dawley, W6DHG.*—This transmitter, employing a number of comparatively recent improvements in circuit design, was constructed for W6PDB by F. R. Gonsett. It is described in some detail in this article.

40 WATTS ON SIX BANDS—INSTANT QSY, *by M. A. McCoy, W6OMP.*—Two crystals and five single-winding coils cover five bands at full power output; instantaneous QSY is possible on all bands through the use of a variable-gap crystal holder.

APPLICATION OF 6L6'S AS DRIVERS, *by Douglas Fortune, W9UVC.*—With the mere mention of the 6L6 as a driver possibility, a lot of well-informed engineers would throw up their hands. But, through the use of stabilized feedback, their plate impedance can be lowered to such a value as to suit them very well as drivers.

RADIO NEWS AND SHORT WAVE RADIO

JANUARY, 1938
25c a copy—$2.50 yearly
Teck Publications, Inc.
461 Eighth Ave., N.Y.C.

SEVENTEEN YEARS OF BROADCASTING—KDKA INSTALLS TALLEST TOWER.—The world's highest tower is now in service at Saxonburg, near Pittsburg, Pa. It is of welded-steel construction, weighs 60 tons and is 718 feet high. A general history of KDKA from its inception in 1920 until the present day.

THE SINGLE-UNIT SERVICER, *by Allen J. Loeb.*—The author describes a readily-portable home-made service instrument which provides every kind of a check or measurement encountered in actual service.

THE "RADIO NEWS" PROGRESSIVE TRANSMITTER, *by Chester Watzel and Willard Bohlen*—The second of a series of four articles describing a "unit-at-a-time" transmitter that the amateur can build. The modulator is described this time.

December, 1937—

HOW SOON TELEVISION? A discussion of the race between CBS and NBC to decide which will be the first one to give general television program service to the New York "lookers." The recent steps of each are cited.

A SURVEY OF THE LATEST TRENDS IN TOUCH TUNING BY PUSH-BUTTON CONTROL SYSTEMS—The systems used on the various console and midget sets are covered.

CALIBRATION OF TEST OSCILLATORS, *by Kendall Clough.*—Means of obtaining the calibration by the use of WWV transmissions.

AN ULTRA-MODERN DIRECT-COUPLED AMPLIFIER FOR THE HOME, *by Gerard J. Kelly.*—A three-watt amplifier using a single triode connected 6L6 in the last stage direct coupled by its grid circuit to a 6J7 voltage amplifier.

DATA ON SINGLE AND NEW DOUBLE-TYPE "J" ANTENNAS, *by A. J. Haynes.*—Methods of erection and construction of simple single section and two-section "J" antennas.

THE T&R BULLETIN A JOURNAL FOR RADIO EXPERIMENTERS

DECEMBER, 1937
1/6 a copy
Radio Society of Gt. Brit.
53, Victoria St., London

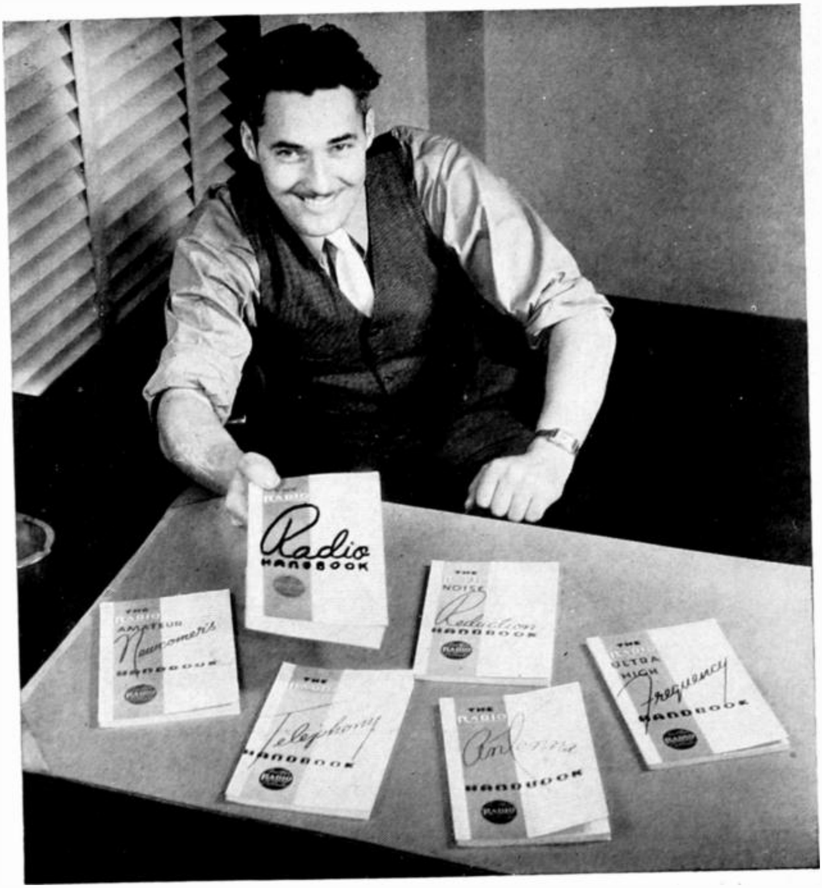
A 50-WATT 56-MC. C. C. TRANSMITTER, *by J. N. Walker, G5JU.*—A complete mechanical and electrical description of this transmitter using two 6L6's in the exciter and a pair of T20's in the output stage.

POLYSTYROL RESINS FOR THE ULTRA-HIGH FREQUENCIES, *by D. W. Heightman, G6DH, and G. F. Bloomfield, Ph.D.*—A discussion of the advantages of polystyrol resins (called "victron" most commonly in this country) for u.h.f. use.

November, 1937—

HARMONIC SUPRESSION, *by Bryan Groom, GM6RG.*—The method used by Mr. Groom in eliminating harmonic radiation from his transmitters and the improvements in efficiency resulting therefrom.

REDUCTION INTERFERENCE DUE TO RADIATION OF THIRD HARMONICS, *by H. A. M. Clark, G6OT.*—A systematic analysis of the reasons for the interference, and a number of suggestions concerning the use of filters, to attenuate the harmonics before they have a chance to leave the transmitter.



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