# EVERYMAN'S GUIDE TO
# RADIO

AUDIO-FREQUENCY AMPLIFICATION
RADIO-FREQUENCY AMPLIFICATION
FIXED AND VARIABLE CONDENSERS
COILS
IMPROVEMENT OF BROADCAST RECEPTION

# EVERYMAN'S GUIDE TO RADIO

## A PRACTICAL COURSE OF COMMON-SENSE INSTRUCTION IN THE WORLD'S MOST FASCINATING SCIENCE

## VOLUME II

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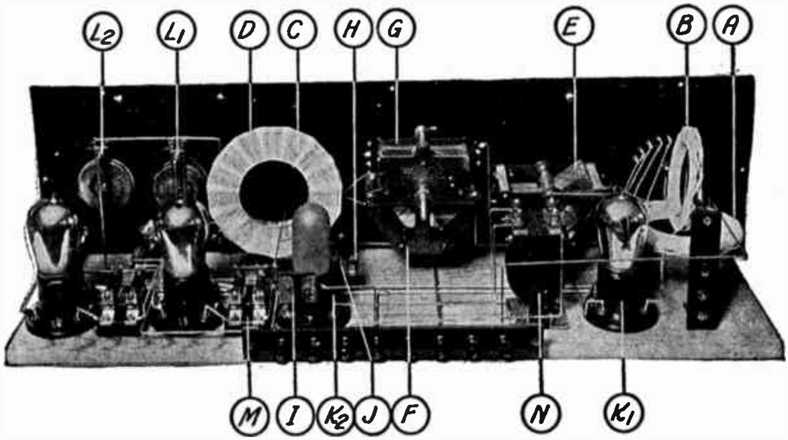

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## SECTION VII

# Audio-Frequency Amplification

Amplification is a term that is usually misunderstood by the novice. It is often thought that amplification involves "blowing up" a small amount of energy into a large amount of energy just as one might inflate a balloon. This is not a true idea of the process. In the case of increasing the strength of weak radio signals with vacuum tubes, we do not in a really true sense amplify, we merely *add to*. Each vacuum tube enables us to take energy from a local source and add it to the incoming signal or music. The vacuum tube allows us to take energy from a B battery and to add small quantities of this energy to the tuned signal. This process of adding energy to incoming impulses involves many delicate conditions and functions as we shall see.

There are two fundamentally different types of amplification. We have radio-frequency amplification and audio-frequency amplification. Radio-frequency amplification (which will be described in Part 8) is amplification that takes place before the incoming signal has had the opportunity of reaching the detector tube. In other words it is amplification before detection and the tubes and other appurtenances used for this purpose are always placed between the detector and the aerial. Audio-frequency amplification is amplification that takes place after the signals have been reduced to the audio frequency range. It is well to think of radio "before" and audio as "after."

L. M. Cockaday has supplied this portion of our study with a comprehensive treatment on the subject of audio-frequency amplification and the reader will gain from it much that is of value.

"The problem of vacuum tube amplification is somewhat different from that of vacuum tube detection, although the same essential theory of operating the tube is observed.

"The vacuum tube is a voltage operated (voltage controlled) device. This same principle is used for amplification.

"Dr. Lee De Forest saw the feasibility of using the amplifying qualities of the vacuum tube when he took out his patents on the 'cascade amplifier,' as he called it. This system uses a number of vacuum tubes connected in cascade, coupled together by means of transformers so that the output circuit of the detector tube is connected to the input circuit of the first amplifier tube, and so on with the second and third amplifier tubes. It is not good practice to use more than two stages of this type of amplification, on account of 'tube noises' which are amplified along with the signals and which tend to blur reception.

"Audio-frequency amplification is

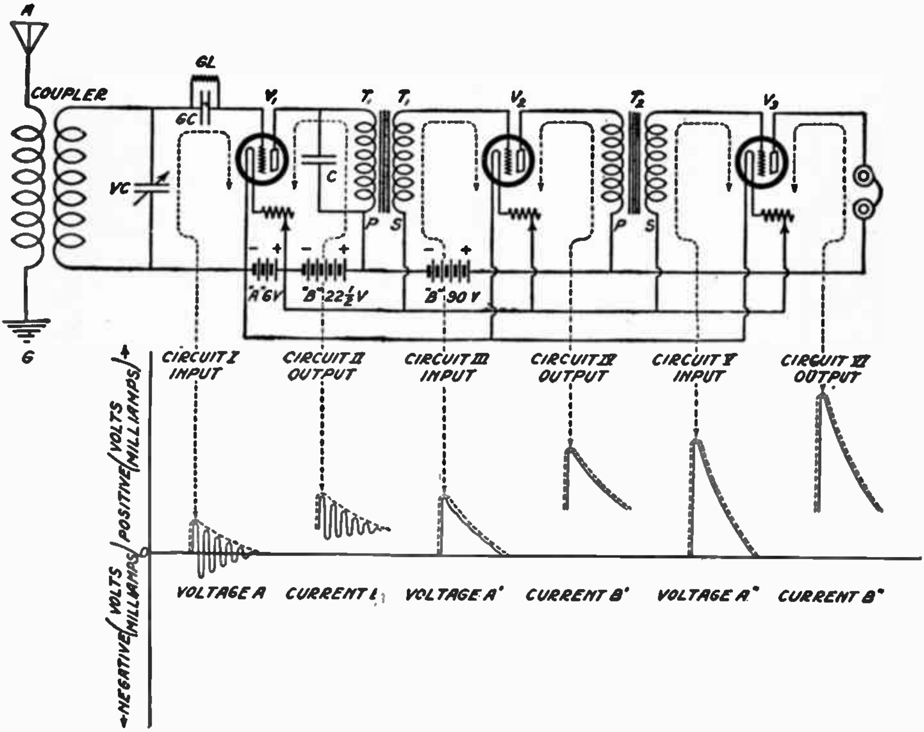
cascade amplification of the rectified impulses which are flowing in the plate circuit of the detector tube. These impulses are of an audio or audible frequency and the successive stages of amplification are coupled together with a transformer called an 'audio-frequency amplifying transformer,' which will step up the voltage of an audio-frequency impulse and supply it to the grid or input circuit of the next tube.

"For the present we will look into the inner workings of the audio-frequency amplifier.

"First of all, let us investigate how the series of tubes used in this method are connected.

"In Fig. A we have a standard hookup for an inductively coupled tuner with a vacuum tube detector; added to this is a two-stage audio-frequency amplifier. The first stage consists of a transformer, $T^1$, and a vacuum tube, $V^2$; the second stage likewise contains similar instruments, $T^2$ and $V^3$.

"The secondary circuit of the receiving coupler receives the energy collected by the antenna circuit; this energy supplies the grid of the detector tube with a radio-frequency oscillating voltage wave



HOW THE AUDIO-FREQUENCY AMPLIFIER WORKS

Figure A: This diagram shows the electrical action that takes place in a radio receiver from the time the current enters the antenna until it reaches a reproducing device after having passed through two stages of audio-frequency amplification.

shown at A. This is the voltage across the circuit designated as Circuit 1.

"The tube $V^1$ then acts as a relay and produces an amplified impulse in its plate circuit (Circuit 2), which has the same audio-frequency wave form as the original impulses in Circuit 1. These wave forms can be compared by referring to the dotted lines in curves A and B. The radio-frequency component of the current B is passed around the transformer winding P by means of the bypass condenser C, and only the audio-frequency component of the current B (which is shown by the dotted lines) passes through the winding P. This current, flowing through P, induces a similar impulse in the secondary winding S, except that the voltage of the impulses induced across the Circuit 3 is higher than the voltage in Circuit 2 on account of the step-up ratio used in the transformer windings.

"The voltage in Circuit 3 is shown at $A^1$. By comparing the voltages A and $A^1$ we readily see that in $A^1$ we have a much greater voltage impressed on tube $V^2$ than the A impressed on $V^1$. Therefore in the plate circuit of $V^2$ (Circuit 4) we have a greater current response than in $V^1$, Circuit 2. Compare the currents B and $B^1$.

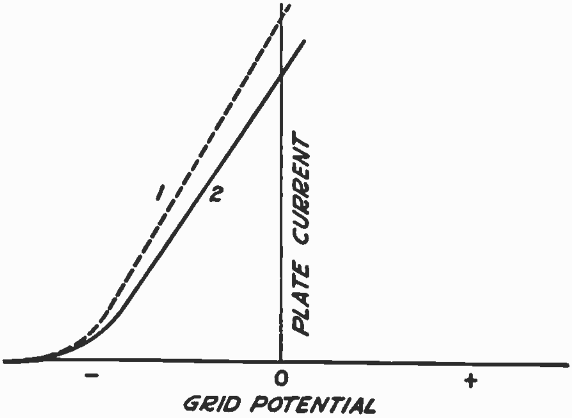
"It will be seen that the second tube amplifies the current flowing in the plate circuit of the first tube and supplies this amplified current to a second transformer, $T^2$, which also steps up the voltage of the impulse as shown in Circuit 5, supplying the grid of tube $V^3$ with a larger voltage than that applied to tube $V^2$. Compare $A^1$ and $A^{11}$. This in turn produces a still greater response in the plate circuit of tube $V^3$, Circuit 6, shown at $B^{11}$.

"Now, the problem before us is to get the plate current variations as large as possible; that is just what we have done, as is shown when we compare the currents B, $B^1$, $B^{11}$ in the plate circuits of the three tubes. They have been getting larger in each additional stage of amplification.

"A further analysis of this action should enable us to see clearly that the phenomena in a vacuum tube is purely a case of cause and effect. The cause is the voltage applied to the grid and the effects the corresponding current which flows in the plate circuit. In our diagram the causes are shown at A, $A^1$ and $A^{11}$ and the effects at B, $B^1$ and $B^{11}$. If we increase the cause as at $A^1$, we get a greater effect, $B^1$, and if we further increase the cause as at $A^{11}$, we get a still greater effect, $B^{11}$. The increase in the cause is accomplished by the transformers which step up the voltage of the succeeding impulses, and the effect is increased by the relay action of the vacuum tubes themselves.

"This amplification is done at an audio frequency, because the amplifying transformers pass the audio-frequency impulses with facility, but hold back the radio-frequency component of the current, not allowing it to flow through their windings."

We have really four distinct types of audio-frequency amplification. We have just completed our discussion of what is known as straight audio-frequency amplification. Then we have what has become known as push-pull amplification or power amplification (due to the great volume produced), resistance-coupled amplification and impedance-coupled amplification. Straight amplification and push-pull amplification are transformer-coupled systems. That is, one tube is coupled to the next magnetically by a very simple transformer involving a primary and secondary wind-



A SIMPLE CURVE

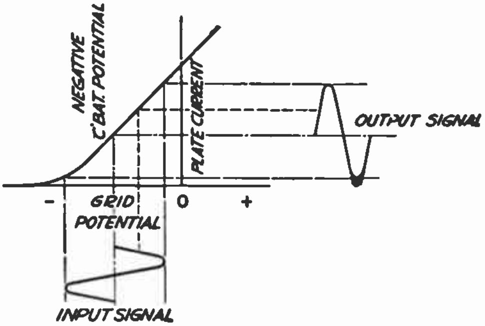
**Figure B: This simple curve shows the relationship between the grid voltage and the plate current of a standard three element vacuum tube.**

ing. We shall leave impedance-coupled amplification out of our discussion because it is as yet in its experimental form.

Push-pull amplification, which requires special transformers, is recommended in many cases where great volume is required because this volume may be produced with small distortion. If more than two stages of plain or straight transformer-coupled amplification are used, the duty imposed upon the third tube will be far beyond its electrical capacity and its output current will be badly twisted and distorted as a result. We may, however, attach to any two-stage audio-frequency system a push-pull unit and get as a result very sweet reproduction with high power volume.

It is the electrical characteristics of the vacuum tube that defeat attempts to employ more than two stages of audio-frequency amplification. To put it technically it is because the grid voltage when plotted graphically against the plate current is not in a straight line. While this phrase may sound terribly technical, it expresses nothing more than the electrical relationship between two values. It is the relationship between the grid voltage and the plate current of the tube and if we refer to Fig. B we shall see just what it means. The grid voltage is shown in the horizontal line and the plate current is shown along the vertical line. The reader will notice that the vertical line is marked zero and this means that it is the dividing line between positive and negative potentials. That is, everything above zero will be positive and everything below zero will be negative. When we start at the extreme left hand side it will be seen that as the grid voltage increases toward the vertical line the plate current also increases until we get to zero potential. The student will also note that the curve increases as the grid potential decreases.

When a B battery is connected to the plate of a tube through a transformer, the receiver offers a resistance to the passage of current from the battery so that the retarding increases as the cur-



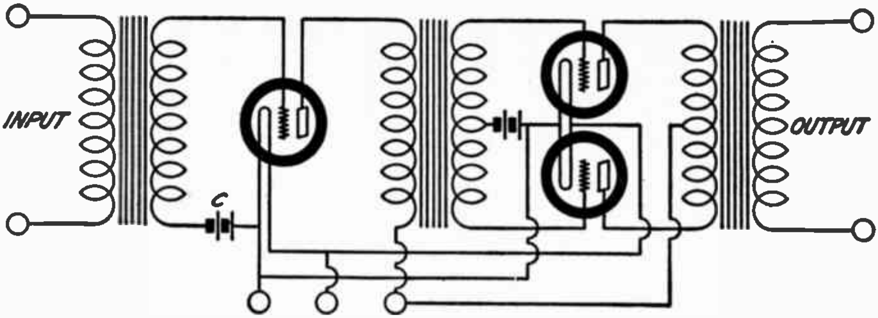
HOW DISTORTION IS PRODUCED

**Figure C:** If the reader will study this curve together with the text he will be made to understand the advantages of the push-pull system of audio-frequency amplification.

rent increases. This causes the current to drop back or to lag behind the values shown at B. It will be noticed if the sketch C is studied that the curve is straight for the grid voltages within certain limits. If the radio receiver could be operated so that only the straight portion of the line would be employed perfect reproduction would result. However, most receivers are operated so that the curved portion is involved.

When a negative potential is placed on the grid of a tube by inserting a C battery in the circuit, there is established a voltage as shown by the vertical line. This will be found marked. About these lines fluctuates the wave of the incoming signals and it is these that we desire to pass on to the loud speaker in the exact form in which they come in save for the fact that their energy content should be increased. Due to this small curve, the student will see that the lower side of the wave of the outgoing current is not of the same height as that of the upper side of the wave. This is indicated by the shaded area. This shaded area also indicates the amount of distortion that will be present in the loud speaker. We have a visual idea of the amount of unnecessary sound produced.

In Fig. D we will find a diagram of the standard two-stage push-pull amplifier. Each stage consists of no more than the standard vacuum tube and the special type of push-pull transformer. It will be noticed also that the secondary of the first transformer and the primary of the second or output transformer are tapped in the center. We can also see that the voltage impressed upon the primary of the transformer is the same as that which would be impressed upon an ordinary audio-frequency transformer. However, since the secondary of the transformer in the push-pull system is tapped in the center, the voltage impressed upon the grid of each of the two tubes used is only half of that which would be impressed upon a tube in an ordinary straight audio-frequency circuit. Consequently we may impress upon the primary just



A PUSH-PULL AMPLIFIER DIAGRAM

**Figure D:** This diagram shows all of the connections involved in a conventional two-stage amplifier of the push-pull type. The reader will notice the position of the C-battery between the first tube and the secondary of the first transformer. This is the correct position for all C-batteries for ordinary type of audio-amplification. The advantage of the push-pull amplifier lies in its high power amplification and small degree of distortion. So small is the distortion that such amplifiers may be employed after two stages of straight audio-amplification without danger of bad reproduction.

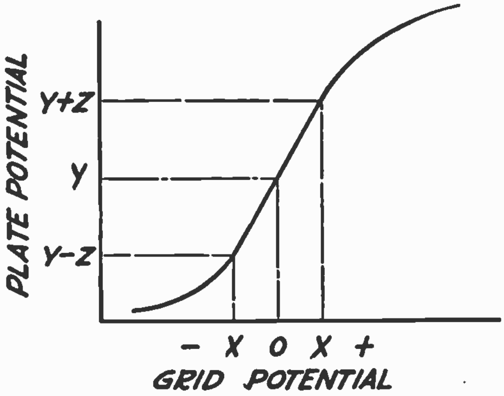
twice the voltage that we could impress upon another system. When this divided voltage is united in the primary of the output transformer we will have doubled the output energy.

Let us see if we cannot put this more simply. When two tubes are connected in a one-stage system (push-pull is really a divided or balanced one-stage system) there is a balancing effect between the tubes which will permit us to work each tube at a higher point than we could work the same tubes in a straight audio-frequency system. In a certain sense any distortion caused by one of the tubes up to a critical point will be balanced out by the other tube. By using this system we are able to get three times the volume that would be possible with a two-tube audio-frequency amplifier of the ordinary type.

Audio-frequency resistance-coupled amplification has, because of the splendid reproduction available from such sources, superseded most of the old types during the past few months. Resistance-coupled systems are both simple and inexpensive and unlike transformers, the resistance units employed for this purpose do not have critical characteristics. This means that with reasonable care the rankest novice may assemble an amplifier of this type and obtain from it very mellow and sweet reproduction.

To thoroughly understand resistance-coupled amplification we shall have to again go over the functioning of a vacuum tube, for it is upon the peculiar characteristics of vacuum tubes that resistance-coupled amplification is based.

In the accompanying curve (Fig. E) we see the graphic result obtained by plotting the plate current against the grid voltage. At another place (Fig. F) we see an oscillating circuit, one side of which is connected to the grid and the other side to the filament of a three element valve. We will assume that the normal current flowing in the plate circuit is represented by Y. It will also be noted that this Y line connects with the vertical line at a midway point. The characteristic line, that is the line which



VACUUM TUBE OPERATION

Figure E: The operation of a vacuum tube is explained by charting the relationship of the plate potential or voltage to the grid potential or voltage.

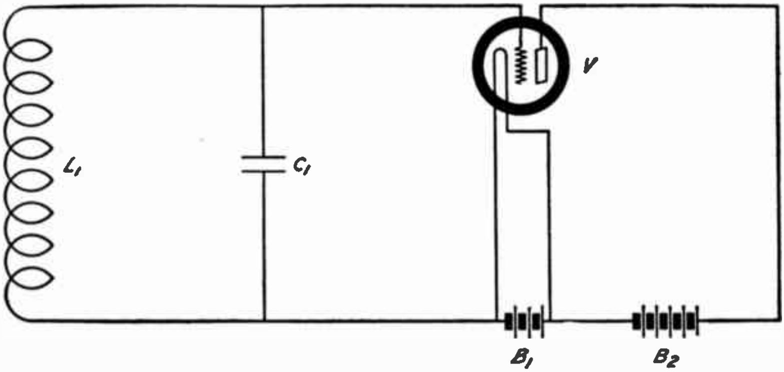
represents the characteristics of the tube, is the line which is partly curved and partly straight. Further examination will show that this Y line also connects to the midpoint of the straight part of the characteristic line.

We will assume that the normal current flowing in the plate circuit is represented by this Y line. It is desirable in practice that this should be the value of the plate current when the grid voltage is zero. In actual practice this condition can be arrived at by adjusting the voltage on the plate and to do this it is necessary to have a variable B battery and to also adjust the filament current.

Now let us assume that we have an oscillating current impressed upon the grid of the valve in Fig. F and that this current will place an alternating positive and negative charge on the grid. If we further assume that the potentials developed are created by an undamped oscillation of symmetrical wave form we shall see that the positive potential communicated to the grid will be numerically equal to the negative potential.

At this point it will be necessary to again refer to the sketch E showing the characteristic curve where we may examine the effect of this alternating potential on the current in the plate circuit of the tube.

We have previously assumed that the normal potential of the grid is zero and that the corresponding plate current is represented by Y. We will now assume that the potentials applied to the grid are positive X and negative X. Under such conditions we see that a potential of X positive on the grid causes the plate current to increase by a value Z. Further back we assumed that the positive potential was numerically equal to the negative potential and further that the portion of the curve upon which the tube operated is a straight line. It will now be seen that the negative X causes a decrease in the anode current of exactly Z. From this it will be seen that the theoretical variations of the plate current are exactly proportional to the oscillations in the circuit connected to the filament and grid of the tube. It is



THE VACUUM TUBE IN A STANDARD CIRCUIT

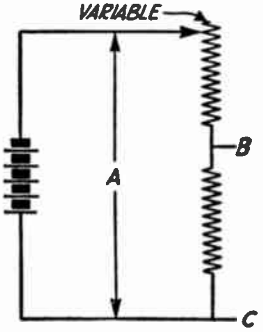
**Figure F:** The operation of a resistance-coupled audio-frequency amplifier will be better understood by first reviewing the action of a simple circuit like the above. A difference in potential is impressed across the grid and filament of the tube by the coil L. This is then rectified by the tube V aided by the A battery $B_1$ and the B battery $B_2$. As the text will explain, an oscillatory high-frequency current is impressed upon the coil $L_1$, carried to the vacuum tube and rectified in the usual manner. An understanding of this process will assist the student greatly in mastering the details of resistance-coupled amplification.

obvious that these variations may be made to control the grid potential of a second valve.

In resistance amplifiers a resistance is inserted in the plate circuit of the first tube and the variations of the plate current produce varying potentials increasing the resistance and these are applied to the grid and filament of the second vacuum tube.

If the plate potential to a tube is increased with respect to the filament, we find that the plate current gradually increases and similarly if we increase the grid potential the plate current increases. To put it differently, if the current through the same conductor varies it is equivalent to considering the conductor as a variable resistance. For our particular purpose we may consider the plate circuit of a tube in a resistance coupled amplifier to be composed of a fixed and variable resistance, the plate filament path constituting the variable element. The plate resistance constitutes the fixed component and it is the variable potentials produced across these which are applied to the filament and grid of the next tube. This will probably be better understood by referring to Fig. G. Here we have a battery connected across a variable resistance AB in series with a fixed resistance BC. For our purpose we will suppose that the resistance AB is equivalent to the resistance BC. If the potential of the battery should fall along the path AC the voltage would be distributed uniformly along both AB and BC and hence the voltage across BC would be exactly half of that across AB since both resistances are of the same value.

Let us suppose now that the resistance AB is lowered. The distribution of the potential along the path AC will then be altered for, since the value of AB has been increased, there will be less voltage drop along it. On the other hand the



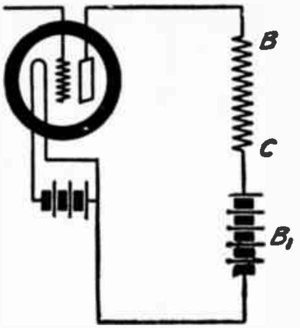
HOW A RESISTANCE ACTS ACROSS A BATTERY

Figure G: This simple circuit contains all of the elements involved in a single-stage resistance-coupled amplifier. The text will explain how the two systems are related.

total voltage drop along the path AC will increase. Similarly, if the resistance AB is increased the potential across BC will be decreased. It is this very principle that is taken advantage of in audio-frequency amplification of the resistance-coupled type.

If we will refer to the next diagram (Fig. H), which involves a vacuum tube and B battery and a resistance in series with the plate and filament of the vacuum tube, we shall find a condition existing analogous to that which we have just considered. The vacuum tube takes the place of the variable resistance AB in the previous diagram. Since the resistance of the space between the plate and the filament of the tube is varied according to the changes upon the grid, there will be a fluctuation in the voltage drop across BC providing, of course, that the filament and the grid of the tube are connected to a radio circuit.

In the next figure (Fig. I) we see a resistance-coupled amplifier. Radio-frequency currents are applied to the grid and the filament of the first tube through the medium of the resonant circuit containing the coil and the variable condenser. This causes the first tube to act as a variable resistance in series with the fixed resistance BC. The variations in the resistance of the tube cause a fluctuating voltage drop across the terminals of the resistance BC and these variations are carried on to the second tube. In normal practice, there would be a potential across BC, the fixed resistance, of something like 30 volts. This would be supplied by the B battery of the first tube. If a little fixed condenser in the grid circuit of the second tube is not used, the potential of the grid of the second tube would be in the neighborhood of 30 volts and the tube would be rendered inoperative. It is this little condenser that prevents the passage of anything but the small variations in the potential produced across the terminals BC. (It will be recalled that pure d.c. will not pass through a condenser.) In place of the fixed con-



THE OPERATION OF A RESISTANCE-COUPLED AMPLIFIER

Figure H: Here the vacuum tube takes the place of the variable resistance AB in Figure G. It will be seen that the space between the filament is made variable in resistance by the charges placed on the grid of the tube.

denser, a battery (which is shown) might be inserted which would oppose the current flow of the B battery of the first tube. This, however, is expensive practice and there are not enough advantages in the system to make it advisable to use it.

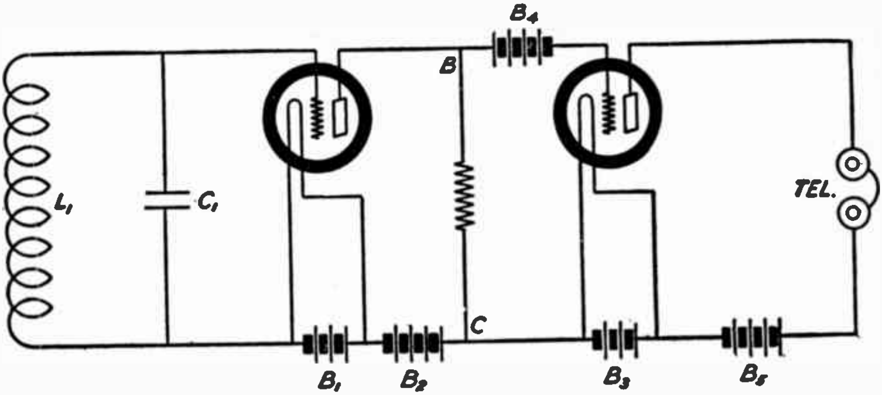
For best results, audio-frequency amplifiers of the resistance-coupled type usually require about 130 volts of B battery. The resistances used range from ¼ to ½ megohm. The usual form of grid leak is admirably suited to resistance-coupled amplification and standard fixed condensers of .01 mfd. capacity may be used to stop the flow of the B battery current. Although it is not advisable to use more than two stages of ordinary audio-frequency amplification employing the usual type of transformer, this rule does not have to be followed in the case of resistance coupling. Here three stages of amplification may be used with absolute safety. In practice, however, it has been found best to use one stage of audio-frequency amplification with the transformer and the two following stages with resistance coupling.

Resistance coupling affords faithful reproduction of music and is without question the best form of amplification that has thus far been developed.

In radio reception we do not only have the A and B battery, but we also have the C battery, which is perhaps less understood than either of the other two. A C battery, providing it is used correctly in audio-frequency circuits, will effectively overcome a great deal of needless distortion of the output current.

While C batteries are employed to prevent distortion, they can also create distortion. It is only by an understanding of their operation that such distortion may be prevented.

A C battery is usually made up of several cells of flashlight battery connected in series so that the total voltage of the battery will be the sum of voltages of the cells. Thus, a three-cell battery gives 4.5 volts. Such batteries are placed in a circuit so that their negative poles are connected with the grid and consequently their function is to place a negative charge of electricity upon the



A RESISTANCE-COUPLED AMPLIFIER

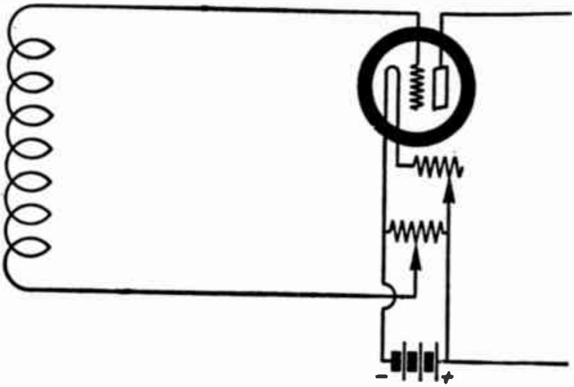
Figure I: Diagram of connections used in a simple two-stage resistance-coupled audio-frequency amplifier. The voltage drop occurs across the fixed resistance marked BC. This is the general principle employed in all resistance coupled audio-frequency amplifiers.

grid. The positive pole of the C battery finds its way to the filament and the negative pole of the B battery. This method of connection may be easily remembered by keeping in mind the fact that it is connected just the reverse of the B battery. The positive pole of the B battery is always connected to the plate while the negative pole of the C battery is always connected to the grid. It is to be remembered that this arrangement is not to be employed with detector tubes, but only with amplifiers.

The object is to place enough negative potential upon the grid so that its maximum positive point will still remain below zero. Since a negative grid cannot draw a current, no distortion will be produced.

A C battery of the wrong voltage, either too high or too low, will be worse than no C battery at all. The voltage must be controlled within rather narrow limits. If it is carried beyond a critical point and the grid is made highly negative, the plate current will be distorted. We will have as a result badly distorted music, because we cannot distort a current with sound superimposed upon it without at the same time distorting the sound. Indeed if we insist upon carrying the negative potential of the grid to a point where it is abnormally high, we would cut off the plate current entirely. We should choose a C battery of such voltage that when the grid is at its most positive point, it will still have an appreciable negative potential. This will prevent the plate current from being distorted and also keep the music sweet and melodious. A potentiometer shunted across the C battery so that its potential could be (Fig. J) varied from practically zero to full value is one means of getting the correct voltage. It will be found that the voltage should be somewhere between 3 and 9.

The amount of C battery on the first stage is not nearly as critical as that on the second stage. This is easy to understand if we know that the voltage of the incoming radio wave is weaker and therefore can be more readily accommodated to the straight part of the charac-



HOW TO USE A POTENTIOMETER

Figure J: The manner of employing a potentiometer to place a negative bias on the grid of the vacuum tube is illustrated.

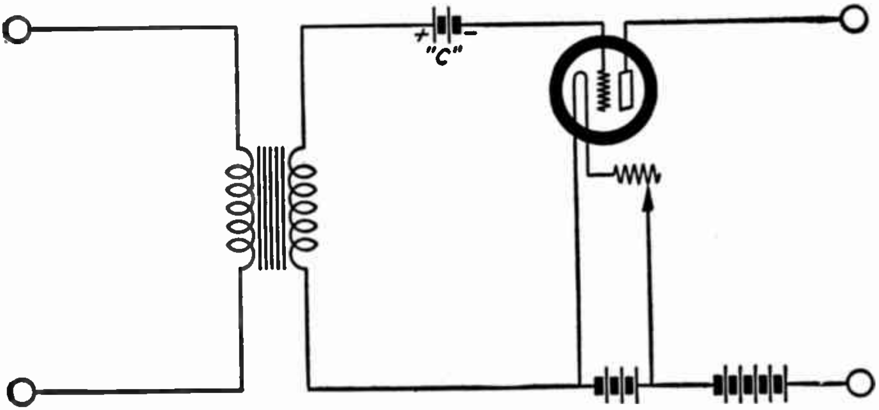
teristic curve. Since the voltage is boosted in each stage of amplification, in the second stage it has been built up to a higher point and the radio user will therefore find it more difficult to reach just the proper C battery potential.

Although the C battery is usually employed as shown in Fig. K, experience has proven that it is more practical to place it as shown in Fig. L where it may be used without adding a length to the grid lead, which, owing to its susceptibility to stray currents, it is best to keep as short as possible. A long grid lead is an invitation to stray currents and when they are induced in it, a feed-back condition is brought about which usually results in audio-frequency regeneration and consequent distortion. It is wise therefore to place the C battery between the filament and the secondary of the amplifying transformer. When in this position the impedance of the secondary winding acts in such a manner as to ward off any stray potentials that may reach the grid and bring about trouble.

It is always well to keep the C battery fresh, for when extreme chemical action sets in, which is usually denoted by swelling and the formation of blisters, the battery is apt to become noisy through a certain amount of current fluctuation to which the grid is somewhat sensitive, especially at the first stage. However, but a trifle of current is drawn from a C battery and it can be used for a long time before it will be necessary to replace it.

A technical understanding of audio-frequency amplification is impossible unless the reader becomes familiar with the true nature of the audio-frequency transformer. An acquaintance with this essential will not only arm him with knowledge that will permit him to operate radio sets most effectively but it will also permit him to buy transformers intelligently and to specify their characteristics.

The research work going on today is bound to upset a number of notions about audio-frequency transformers which have long been prevalent among radio fans. For example, people still buy transformers by specifying the turns ratio, although the turns ratio is no cri-



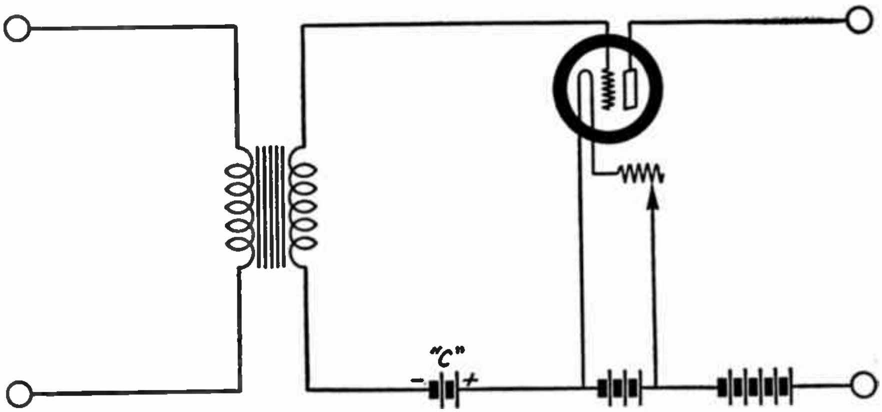
HOW NOT TO USE A C BATTERY

Figure K: Although the C battery will function when used as shown, it is not the correct position for it.

terion of the quality of a transformer. Others believe that it is necessary to use transformers having different turns ratios in the different stages of an amplifier, and manufacturers turn out different ratio transformers when such a procedure is only an attempt to rectify defects.

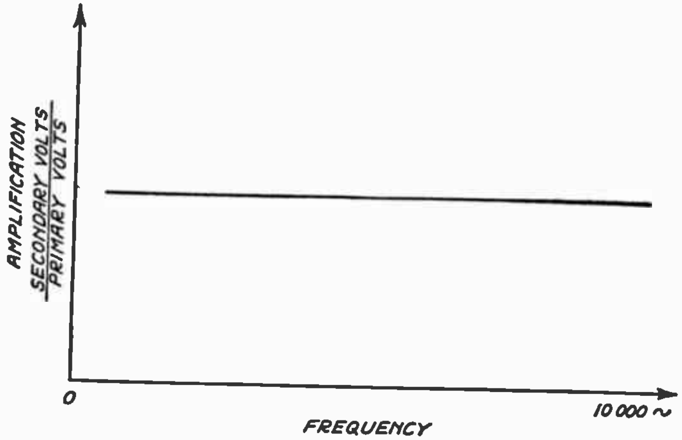
After all, the transformer must meet just one requirement to be classed as a high quality transformer: It must reproduce faithfully the sound currents which are supplied to the primary circuit.

Audible sound vibrations range in frequency from as low as 16 vibrations a second to as high as 30,000 a second. But for all practical purposes, such as the transmission of high quality speech and music, we are concerned, essentially, with the range between 30 and 10,000



HOW TO USE THE C BATTERY CORRECTLY

Figure L: The text will give the reason for connecting the C battery of a radio set in the position illustrated.



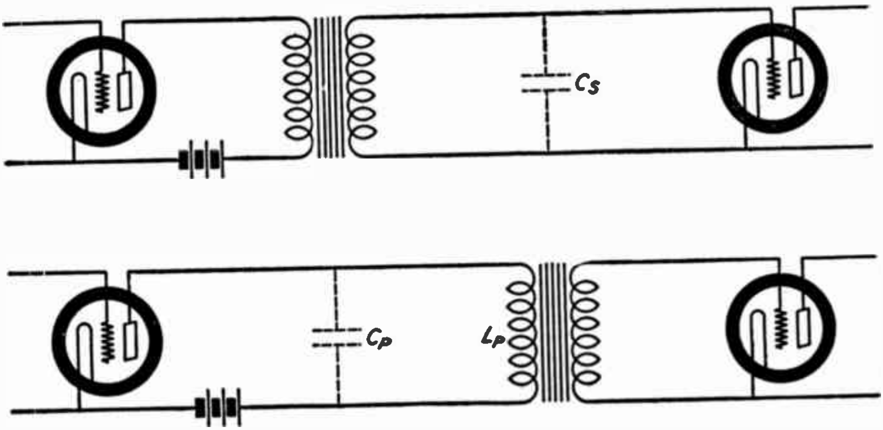
HOW AN IDEAL AUDIO-FREQUENCY TRANSFORMER SHOULD AMPLIFY

Figure M: The straight horizontal line shows what the amplification response should be for an ideal transformer with changes in frequency from 60 to 10,000 cycles; it would amplify all the audible frequencies with equal intensity.

cycles a second. The lowest notes on the piano keyboard and the beat of the kettledrum are in the neighborhood of 25 or 30 cycles while the piccolo and organ reed may go as high as 10,000 cycles. Between these two extremes we have every other possible intermediate frequency, and all possible combinations of frequencies such as might occur in the rendition of a selection by a symphony orchestra, a band or a chorus. Even when we are apparently concerned with only one frequency (as, for example, middle C, 256 vibrations a second, as played by a violin), other frequencies are involved; for harmonics (or overtones) are generated which are of several times the fundamental frequency, and the intensity of each of these overtones bears a certain quantitative relationship to the intensity of the fundamental. It is evident, then, that for any reproduction to sound natural, the transformer must be able to reproduce all frequencies from 30 to 10,000 cycles equally well over the entire range.

The difference between an audio-frequency transformer intended for use in radio-telegraph reception and one intended for radio-telephone or broadcast reception will at once be readily appreciated. In the case of telegraph reception we are concerned with one audio frequency which may be 500 cycles or 1,000 cycles or some other frequency of that order. The transformer may be designed to give its maximum amplification at the signal frequency, and no particular thought need be given to what happens at the other frequencies. Also the transformer can be given a high step-up ratio so that the transformer itself amplifies the signal voltage as much as possible. Ratios as high as 10 to 1 have been used without detracting from the efficiency of the transformer at the particular signal frequency used. Radio-telephone reception obviously presents a much more difficult problem and introduces considerations which are vital to good results.

As a measure of the quality of an



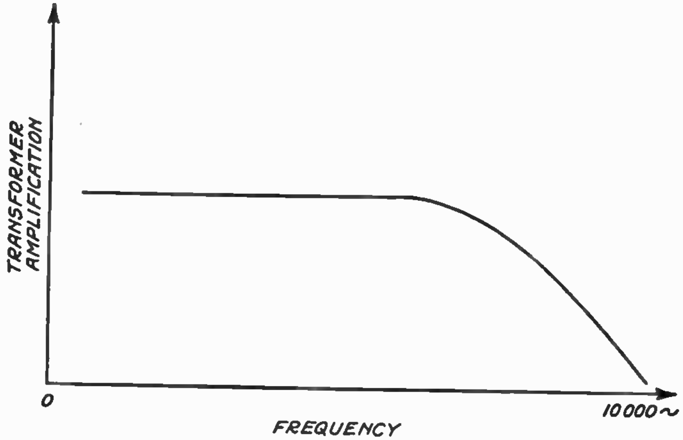
HOW DISTRIBUTED CAPACITY AFFECTS THE HIGH TONES

Figure O: In the top figure the capacity of the secondary windings has the same effect as though a condenser Cs were connected across the terminals. The high turns-ratio multiplies this capacity effect so that we have the effect of a condenser Cp as shown in the bottom figure. The result is that the higher audible frequencies are by-passed around the primary winding and do not reach the grid of the following tube.

amplifying transformer we may take its "frequency characteristic" which shows the relative performance of the transformer at different frequencies. Suppose we apply a given constant voltage at different frequencies to the primary of the transformer and then measure the voltage across the secondary of the transformer at these different frequencies. An ideal transformer would have frequency characteristics as shown at M. This curve shows that the transformer reproduces in the secondary all the frequencies between 30 and 10,000 cycles equally well. This is the ideal which audio-frequency transformer design should approach. The greater the departure of actual transformers from this ideal the less desirable the instruments would be for broadcast reception.

The ratio of the number of secondary turns to the number of primary turns is called the "turns ratio." When a transformer is designed for a particular frequency, the voltage across the secondary is equal to the voltage impressed on the primary times the turns ratio, provided the coupling coefficient is unity, which is very nearly the case in most closed-core transformers. But at other frequencies this is not necessarily so. One of the factors which is instrumental in producing this effect is the distributed capacity of the transformer secondary winding.

If, with a given number of turns on the primary winding, the turns ratio is increased, the secondary turns increase correspondingly. The greater the number of turns on the secondary the greater is the distributed capacity of the secondary winding. This distributed capacity behaves, in effect, as a shunt across the secondary of the transformer. Furthermore, transformer theory and practice show that this secondary distributed capacity is equivalent in its effect to a certain capacity in the primary circuit, and this equivalent primary capacity is equal to the actual secondary capacity multiplied by the



WHY SPEECH IS MUFFLED

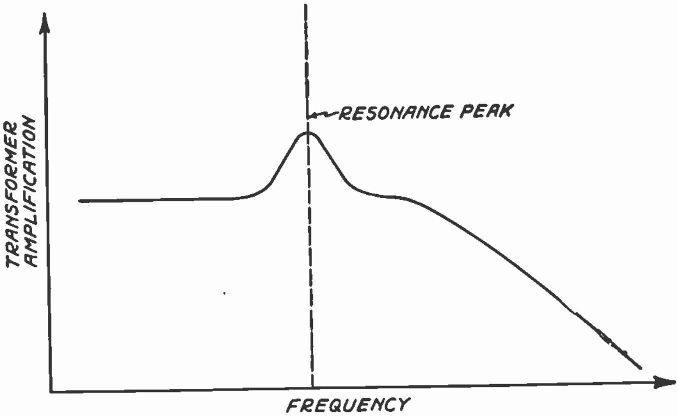
Figure N: This curve shows a falling off in amplification as the frequency is increased. The high tones are lost and the result is a muffled, drummy quality to both speech and music. This undesirable but frequent action is the most common cause of poor reproduction in home-made audio-frequency amplifiers using poorly designed audio transformers.

square of the ratio. Thus, if a given transformer that has a turns ratio of 7 has a distributed secondary capacity of C microfarads, then it behaves as though we had a capacity of $(7)^2C$, or 49C microfarads capacity in the primary. In other words, the capacity effect of the secondary is multiplied about 50 times in the primary circuit, and it behaves, in effect, as though it were shunted across the primary. This increased primary capacity produces a great departure from the ideal flat frequency characteristic, and introduces considerable distortion.

A transformer for interstage coupling is generally used in connection with vacuum tubes as in Fig. N (top) where Cs represents the distributed capacity of the secondary.

Fig. N (bottom) represents the same circuit, except that the secondary distributed capacity is replaced by its equivalent primary capacity. We thus have two reactances in parallel, the primary inductance of the transformer and the effective primary capacity. If there were no capacity, all the audio-frequency current in the plate circuit would flow through the primary inductance and would thus be effective in producing secondary voltage. The presence of the capacity, however, has the effect of shunting some of this audio current, and, as the reactance of a capacity decreases with increase of frequency, it will shunt *more of the high-frequency currents* than the low. Also, since this shunt current flows through the capacity rather than through the primary of the transformer, it can have *no effect in producing induced voltage* across the transformer secondary. As a result we have progressive falling off of secondary voltage as the frequency is increased, and the ideal frequency characteristic of Fig. N begins to look somewhat like that of Fig. P.

The first effect of a high turns ratio, which means high distributed capacity in interstage coupling transformers, is to



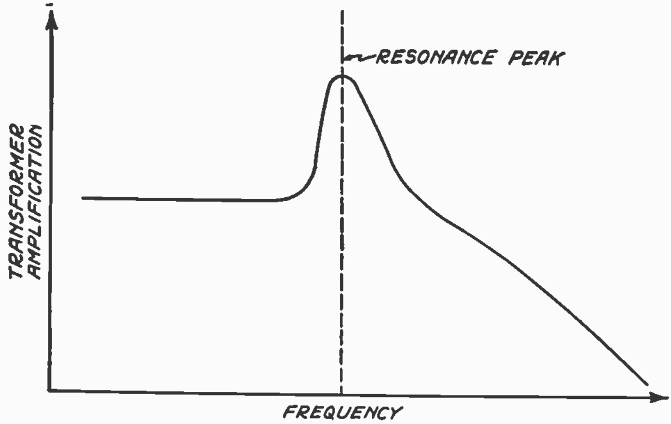
HIGH CAPACITY ALSO PRODUCES RESONANCE EFFECTS

Figure P: The capacity and the inductance of the transformer form a tuned circuit and when the distributed capacity is high, the resonance point falls within the audible frequencies and excessive amplification of a particular tone is the result. This is also a common fault of many amplifiers of the audio-frequency type.

produce decreased amplification at the high frequencies. The distortion characterized by the absence of the high frequencies is a muffled, drummy quality in both speech and music, and the absence of sibilants and consonants in speech.

The high distributed capacity that results from a high turns ratio produces still another undesirable effect in audio-amplifying transformers—a resonance phenomenon at the particular frequency to which the circuit $L_p$ $C_p$ in Fig. O (bottom) tunes. This is a tuned parallel circuit whose impedance at resonance is a maximum. The voltage developed across it is, therefore, a maximum at resonance. Hence there will be a peak in the amplification at this frequency, and there will be another departure from the ideal transformer characteristics of Fig. M which now begins to look like Fig. N. The distortion introduced by such a transformer is obviously an exaggeration of the particular frequency to which the transformer constants tune, and this is often the explanation of why certain musical tones stand out prominently and conspicuously over all others in a particular receiver. If such a transformer is used in both first and second stages of an audio amplifier it will be evident that this resonance effect will be multiplied in the second stage, and the amplification characteristics will look like Fig. Q.

To avoid over-exaggeration of this resonance effect, therefore, many manufacturers recommend the use of a transformer having a different turns ratio in each stage. This mitigates the evil of an over-exaggerated single frequency, but introduces instead *two* resonant periods. For, when each transformer has a different turns ratio the constants will be different, and $L_p$ $C_p$ (Fig. O), will tune to a different frequency. The combined frequency characteristics of both transformers will, therefore, be of the nature of Fig. R where two moder-



WHAT HAPPENS WHEN THE SAME TURNS RATIO IS USED FOR TWO STAGES

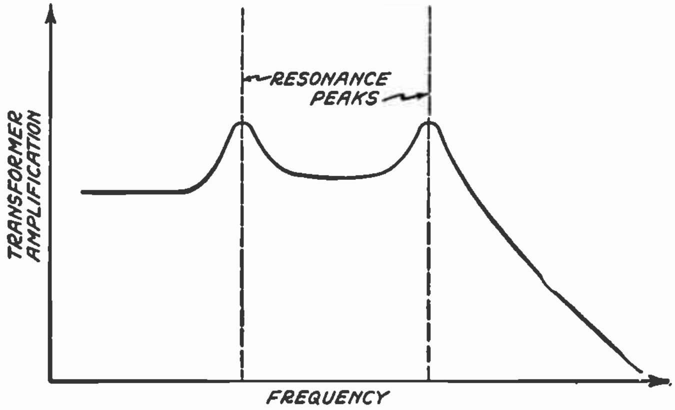
**Figure Q:** If a transformer which has a bad resonance point is used in each of the two stages, the distortion will be multiplied and an exaggerated resonance peak is the result. It is very difficult to design a transformer to overcome this defect.

ately sized resonance peaks are produced as against one over-emphasized peak in Fig. Q. This procedure is obviously no solution to the problem of securing uniform amplification at all frequencies. The solution is, rather, to make transformers which amplify all frequencies uniformly, and the first step is to *avoid* high turns ratio which produces two irregularities in the ideal flat frequency characteristic. There is poor amplification at the higher frequencies and resonance peaks.

The high-ratio transformer will in general give greater volume than the low-ratio transformer, though this may not always be the case, as it is possible that the loss in amplification at the high frequencies will neutralize the gain obtained at the low frequencies. In electro-acoustic converters it is almost invariably true that high quality of signal is inconsistent with quantity of signal. In the case of microphones, high quality of reproduction is accompanied by *diminished* output. Similarly, in the case of transformers, high quality can only be secured *at the expense of quantity of signal*, which means that high ratios *must be* dispensed with so long as the usual grade of transformer steel is used.

The next important consideration which emphasizes the necessity of low ratios is the primary impedance (A.C. resistance) of the transformer. Transformers are connected as shown in Fig. O with primary in the plate circuit and secondary across filament and grid. But, as the grid is at a negative potential, the secondary may be considered as though on open circuit. Therefore, the total amplified voltage produced is directly proportional to the voltage available across the primary inductance $L_p$, and for purposes of discussion we may regard the circuit as a reactance-coupled amplifier.

In a reactance-coupled (plain coil



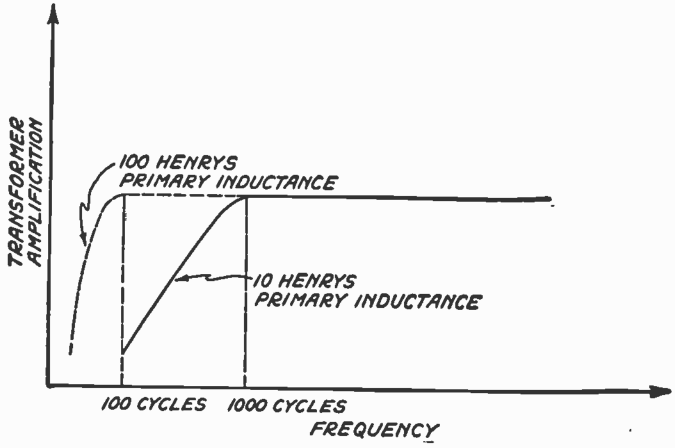
WHAT TWO DISSIMILAR TRANSFORMERS MAY DO

**Figure R:** The curve shown is the combined effect of using a transformer which has one resonance point in the first stage, and a transformer with a different resonance point in the second stage.

coupled) amplifier the voltage developed across the reactance depends upon the ratio of the plate reactance to the internal resistance of the tube. The greater the reactance the greater the voltage across it. But, when the reactance reaches a value of about three times that of the valve resistance, almost maximum voltage is developed across it. Theoretically, maximum voltage is developed across the reactance when it is infinite, but for all practical purposes we may consider that maximum voltage is developed across a plate reactance when its value is three times that of the tube resistance. For any values of the reactance below this, the voltage developed across it will be less than the maximum.

Inasmuch as the reactance of a coil is directly proportional to the frequency, maximum voltage amplification will not be secured unless the above condition is met at all frequencies. To illustrate with an actual problem, consider the case of a transformer whose primary has an inductance of 10 henrys (the henry is the unit of inductance) connected in the plate circuit of a tube with plate impedance of 20,000 ohms. The reactance of the primary is given by 6fL, where f is the frequency and L the inductance. At 1,000 cycles the reactance is equal to 60,000 ohms, which is three times the plate impedance of the tube. Above 1,000 cycles the reactance becomes greater but the voltage developed across it is practically constant. Thus, full maximum amplification is secured above 1,000 cycles with this transformer. Below 1,000 cycles, however, the reactance is less than that required for maximum voltage, and the amplification is correspondingly decreased.

The characteristics of such a transformer are shown in Fig. S and it is seen that the low frequencies are not reproduced properly. In order that the low frequencies be taken in by the transformer, its primary inductance must be considerably greater than 10 henrys.



**WHAT HAPPENS WHEN THE PRIMARY INDUCTANCE IS LOW**

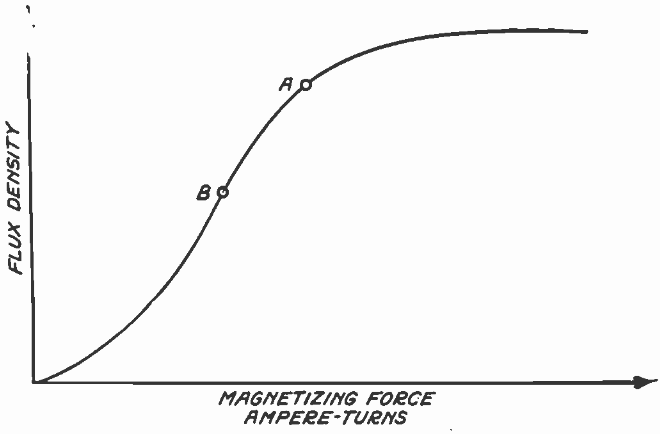
Figure S: If the inductance of the primary winding of the transformer is too low, the low notes are lost because they are not properly amplified. Speech or music will then have a shrill, tinny sound.

If the primary inductance were 100 henrys, maximum amplification would be secured at 100 cycles and over, but frequencies below 100 would be dropped out. The condition, therefore, for securing the very low frequencies is that the primary inductance must be very great, in fact high enough so that its reactance at the lowest required frequency is three times the tube impedance.

But high inductances cannot be secured unless a great number of turns are used on the iron core, and for a given transformer ratio the secondary turns go up proportionally with the primary turns, which produces an increase in the distributed capacity, and a loss of high frequencies. Thus, the conditions for securing the low frequencies conflict with that for securing the high frequencies. As a result, unless radical changes are made in the weight and dimensions of an audio transformer, a compromise must be struck between the conditions for securing both low and high frequencies. Constants must be chosen which will not make the low frequency cut-off point too high.

The above limitations to securing a flat top characteristic for an audio-frequency transformer are, in the final analysis, the result of restricting the weight and dimensions of the transformer. It is desirable to economize both in space and weight, and as a result, transformers are generally made small with not much iron. This introduces the various distortions which are present.

The relationship between the various factors involved in the magnetic circuit of an iron core is shown in Fig. T. This curve shows the flux density (flux density is the number of magnetic lines of force in a sq. cm.), or number of lines of magnetic force for a unit cross-section of the core, produced by any magnetizing force, which is proportional to the product of the current and the number of



THE SIZE OF THE TRANSFORMER CORE IS IMPORTANT

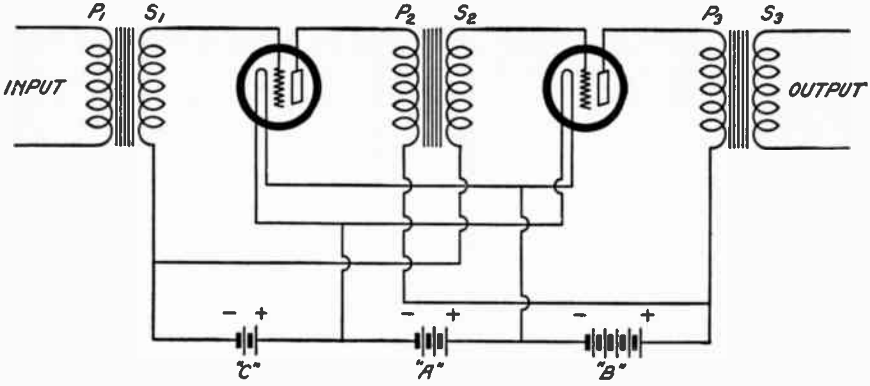
**Figure T:** Small audio-frequency transformers often distort because the iron core is so small that it is magnetized to the point A on the curve where variations of the plate current above and below this point do not produce equal voltage variations on the grid of the next tube. The flux density should be such that the magnetization of the core will lie at point B on the curve. Thus it is seen that the volume of iron in a core is important.

turns of wire through which it flows.

The inductance of any winding on a closed iron core, as, for example, the primary of an audio frequency transformer, depends on the number of turns and the total flux threading the core (not allowing for leakage which is small for a closed core). For a given flux density, the total flux threading the core is proportional to the cross-section of the core. When the cross-section of core is small, as is the case in the average amplifying transformer, the flux density must be high in order that a given flux be produced. From Fig. T it is seen that a high flux density can only be secured by a correspondingly high magnetizing force. As the d.c. plate current is fixed for any given tube and operating conditions, the number of turns must be high to secure the necessary magnetizing force. The smaller the cross-section the greater must be the number of turns. For any given transformer ratio this results in a correspondingly higher number of secondary turns, with resultant increase in distributed capacity. The consequence is that high-frequency distortion is produced, as explained under the discussion of distributed capacity.

If the size of the transformer core were increased, a given flux could be produced by a smaller flux density. For a given tube and plate current this would be secured with a smaller number of turns which, in the case of a transformer of given ratio, would result in lower distributed capacity and less high-frequency distortion. The larger the transformer the less the high-frequency distortion.

It can likewise be shown that the low-frequency distortion decreases as the size of the transformer increases. For a given flux density and number of turns the total flux threading the larger



THE TRANSFORMER-COUPLED AUDIO-FREQUENCY AMPLIFIER

**Figure U:** This is a standard amplifying circuit with the exception that there is included, in the grid circuits, a grid-biasing battery called a "C" battery. This will often help to reduce distortion in a circuit of this kind. C batteries also greatly aid in cutting down distortion in plain audio-frequency amplifiers of conventional design. However, they are practically necessary with push-pull systems.

cored transformer is greater. Therefore, the inductance will be greater, and it will take in more of the low-frequency range than a smaller transformer for reasons explained in the discussion on primary impedance. The distortions thus produced are a dropping out of the lower and upper range of frequencies.

There is another type of distortion introduced different from those mentioned above—the introduction of new frequencies. This is due to saturation of the iron core and is most likely to occur in small transformers. The current flowing through the primary of the transformer may be resolved into two components; first, the direct current of the tube, and second, the audio-frequency alternating current. The direct current is the larger of the two, and produces a certain magnetizing force and flux density which are constant. Suppose that these values are such that the transformer operates about point A of Fig. T. Then the audio-frequency current produces variations in the flux density which produce corresponding variations in voltage.

However, equal variations of the magnetizing force above and below point A of Fig. T do not produce equal variations of flux density, due to the shape of the curve. In other words, the wave form of the secondary voltage is different from that in the primary of the transformer, which means that distortions have occurred in the original sound. An alteration of the wave form of voltage is equivalent to the introduction of frequencies other than those originally present. If the transformer were large enough to permit the direct current of the tube to magnetize the core to the extent indicated by point B of Fig. T, this distortion would not occur, for equal variations in the audio-frequency current above and below point B would produce equal variations in flux density above and below B, because the transformer is now being worked on the straight-line portion of its magnetizing curve. This effect is similar to the working of a vacuum-tube amplifier on the straight-line portion of its characteristic rather than at the saturation point where distortions enter.

The conclusion to be drawn is that the quality of an audio-frequency transformer improves with increase in its size and the amount of active iron in it. Very small transformers are bound to give poor quality. In the past, manufacturers have been guided more by considerations of space and weight economy than by considerations of quality. This policy must now be reversed if high quality standards are to be maintained. By proper design of the transformer, by proper choice of turns ratio and transformer constants, and by a careful selection of materials, distortionless transformers *may* be made.

The ideal audio-frequency amplifier should operate without distortion, have a uniform amplification factor for all frequencies and intensities within the predetermined range, and at the same time deliver the maximum power obtainable from the tube used at the predetermined maximum intensity of input.

The amplification curve of the amplifier, plotted against frequency with constant input e.m.f., must be flat, within the range of frequencies predetermined. If this is not the case, certain notes will be heard louder than the rest, or certain harmonics will be disproportionately loud, and the effect will be distorted reproduction.

In order that these requirements may be fulfilled, it is often necessary to sacrifice efficiency in intensity and amplification to obtain quality. Usually it is possible to amplify *perfectly*, with two stages, to the same intensity as could be done *imperfectly*, in one stage.

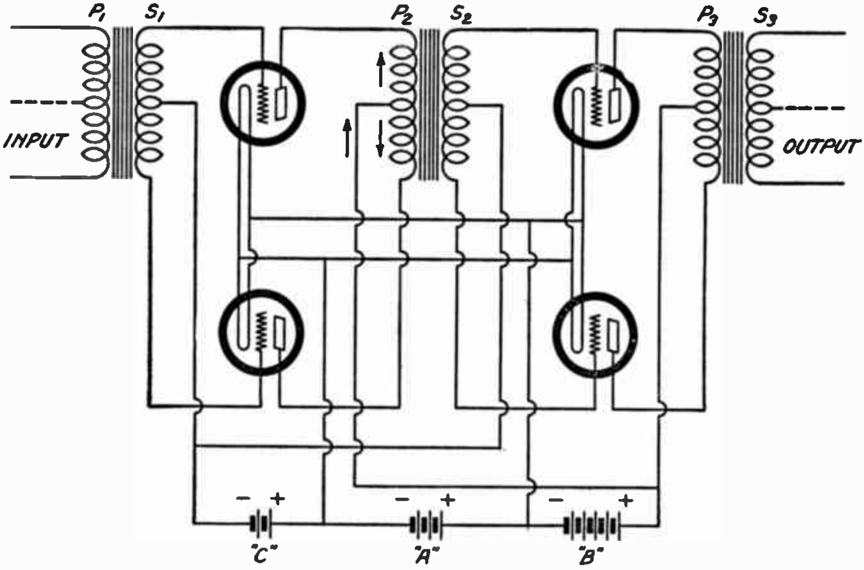
The most commonly used audio-frequency amplifier is the transformer-coupled type. It will be seen from the diagram in Fig. U that the first tube is coupled to the input circuit through a transformer, the primary of which, P1, is suited to the impedance of that circuit. In receiving equipment, the detector tube characteristics determine this impedance and in broadcasting equipment, it is the microphone. Any variation in primary current will produce a corresponding alternating electro motive-force (e.m.f.) across the secondary coil, S1, which e.m.f. is impressed on the grid circuit of the first tube. A corresponding change in plate current of this tube occurs, along the characteristic of the tube, which current flowing through winding, P2, of the second transformer produces an alternating e.m.f. or voltage across winding, S2. The plate current flowing through winding, P3, produces an alternating e.m.f. at secondary winding, S3, in the same manner as outlined above for the previous stage. The winding, P3, is determined by the second tube's plate impedance and S3 depends on the output-circuit impedance. The output circuit, in the case of a receiving outfit, is a loud-speaker or headset. Quite often, the third transformer is omitted and the headset or loudspeaker is placed directly in the plate circuit of the last tube. For a transmitter, the output circuit may be a larger amplifier tube or a modulation system.

The transformer-coupled amplifier is the *most efficient* type of audio-frequency amplifier but, in most cases, the *poorest* from the point of view of quality of reproduction. It takes advantage of the amplification constant of the tube and, in addition, by means of a step-up ratio of the transformers, the secondary voltages are raised so that with the present receiving tubes having a voltage-amplification constant of about 6, it is possible to obtain amplification as high as 20 or higher. However, distortion is introduced mainly because iron-core transformers must be used. There is a steady value of plate current flowing through the primaries, and when variation takes place, the operation is not within the straight line portion of the B-H curve of the laminations. In addition, a minute hysteresis loop is traced, introducing distorting harmonics. The frequency range of the transformers is also usually limited, the best of transformers showing good behavior only over a range of up to 2,000 or 3,000 cycles.

As was already mentioned, the chief difficulty with the transformer-coupled amplifier lies in the fact that the cores of the transformers are *saturated* by the plate current of the tube, flowing through the primary winding. By use of a larger core this may be partially overcome but, at the same time, the core losses will be increased, causing a lessening in the efficiency of the transformer so far as intensity is concerned.

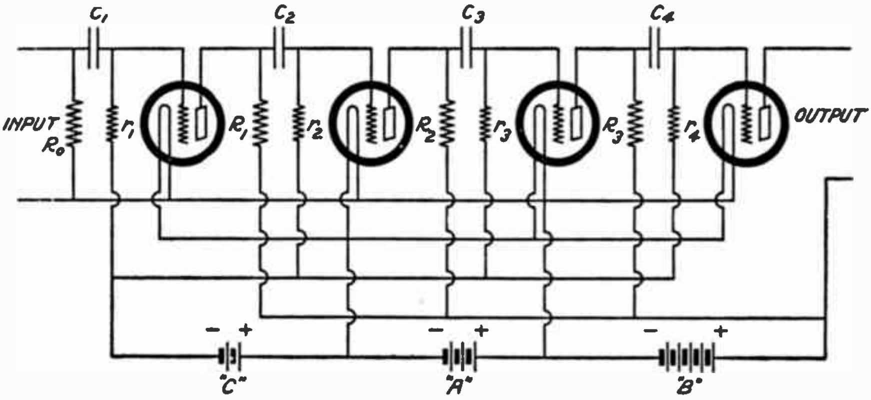
It is possible to avoid this difficulty and yet to get the same or a greater amount of amplification by making use of a back-to-back or push-pull connection thus eliminating the constant value of flux in the cores.

The connection for two stages is shown in Fig. V. The operation of the input transformer is the same as in the first-mentioned type except that there is a mid-tap on the secondary connected through a negative-grid-bias battery to the filaments. At a given instant, the outer terminals of S1 will be positive and



THE PUSH-AND-PULL AUDIO-FREQUENCY AMPLIFICATION CIRCUIT

Figure V: By means of split-winding transformers and the use of two tubes per stage, the distortion due to the permanent magnetization of the iron cores is eliminated. This type of amplification gives exceptionally good reproduction



THE RESISTANCE AND CONDENSER-COUPLED AMPLIFIER

**Figure W:** If properly designed this type of amplifier will give better reproduction than either of the other two types of transformer-coupled amplifiers. This scheme is almost universally used in broadcasting for amplifying voice-currents before impressing them upon the transmitter. Slightly modified, this system also lends itself to amplification in reception.

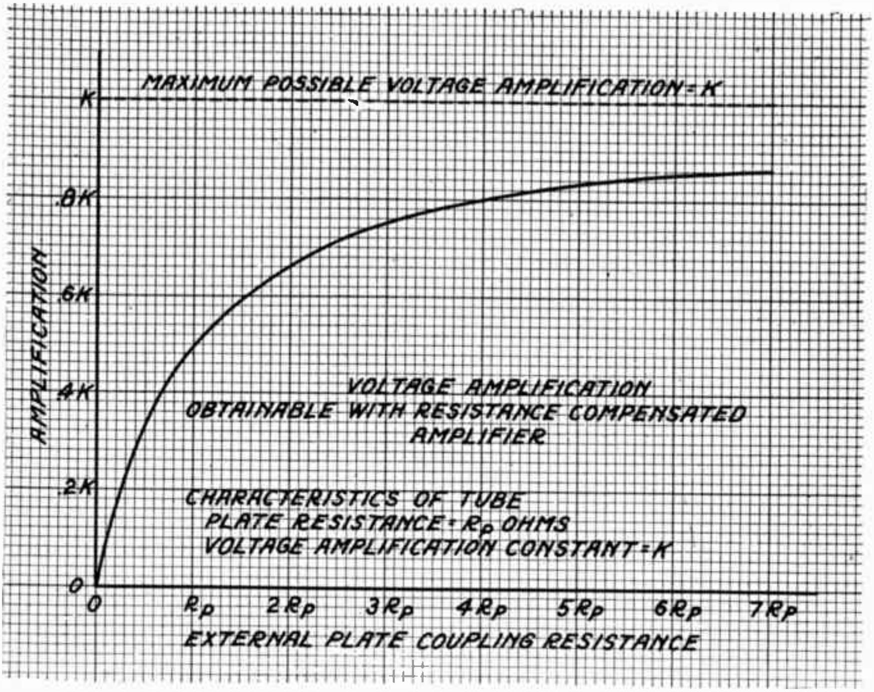
negative respectively so that the grids of the tubes in the first step are 180 degrees out of phase. The corresponding plate currents will be increasing and decreasing, respectively. Before any disturbance is made, the plate battery currents will be as indicated by the arrows and since the tubes are identical and have the same grid potential, the plate currents will be equal and flow in opposite directions in the transformer winding, P2. At equilibrium, therefore, *there will be no flux in the core of the transformer*, but when an alternating e.m.f. is impressed on the grids of the tubes, as described above, there will be a resultant flux in the core which will induce an alternating e.m.f. in winding, S2. The action is the same in the second step through the output transformer as described in the first case. The dotted mid-tap shown on the input transformer is necessary if a double button microphone had been used or if the previous steps had been from a similar amplifier. If the back-to-back principle is followed through further amplification, the output transformer must also be tapped as indicated by the dotted line,

It would appear that the amplifier just described would be only fifty percent as efficient as the standard transformer-coupled type, but when it is remembered that for the same total output, tubes of only one-half the output rating may be used in the push-pull amplifier, it is understood that the two *are equally efficient*. In addition, the push-pull amplification transformers *have no steady flux in their cores so that the quality of reproduction as well as the range of frequencies is bettered*. There remains, however, the distortion due to operation over the hysteresis loop which is always present in an iron-core device.

Transformer-coupled amplifiers of either type are decidedly limited as to frequency and are not, unless carefully designed, faithful in their reproduction due to the introduction of harmonics from iron cores. The resistance and condenser-coupled amplifier shown in Fig.

W is decidedly better from these points of view. It is, at once, obvious, however, that it is impossible to get an amount of amplification from each tube greater than that determined by its own amplification factor. Even this condition is *never reached*, as will be explained later. The input may be through a transformer as before or it may be through a coupling resistance and condenser from a smaller tube as shown. The condensers C1, C2 and C3 are identical for the same type and size of tubes as well as the grid resistances, r1, r2 and r3 and the plate resistances R1, R2 and R3.

In addition to the grid leaks, it is often advisable to use a grid battery to establish the proper operating grid potential. The battery is shown at C. When an alternating e.m.f. is impressed across the input terminals, that same e.m.f. will operate on the grid of the first tube, with the exception of the small drop in the condenser C1. By making the condenser large, the maximum possible impressed voltage is assured. If this impressed voltage is increasing in a positive direction, the plate current of the first tube will increase, causing the drop across R1 to increase. As the battery voltage sup-



**THE MAXIMUM AMPLIFICATION THAT CAN BE OBTAINED WITH THE RESISTANCE-COUPLED AMPLIFIER**

Figure X: It will be noticed that, as the value of the plate resistance is increased, the amplification obtainable is also increased up to a certain point, where it remains constant.

plying the plates is constant and the battery resistance is small in comparison to that of the remainder of the plate circuit, the plate voltage of the first tube will be decreased correspondingly. This decreasing voltage is impressed across the grid and filament of the second tube where the same process is repeated and so on throughout the other stages of the amplifier,

Assuming the drop in the coupling condensers to be negligible (this will be treated in detail later), it is possible to express the amplification per tube as follows.

Let,

$I_p$=effective value of the a.c. component of the plate current of tube No. 1.

$k$=voltage amplification constant of the tube.

$E_{g1}$=effective value of a.c. voltage impressed upon the grid of tube No. 1.

$R_p$=a.c. plate-to-filament resistance of the tube.

$R_1$=external plate coupling-resistance, as shown.

then $I_p = \dfrac{k\,E_{g1}}{R_p\,R_1}$

$E_{g2}$ the effective value of a.c. voltage impressed upon the grid of the second tube, will be

$$I_p\,R_1 = \frac{R_1\,k\,E_{g1}}{R_p\,R_1} = E_{g2}$$

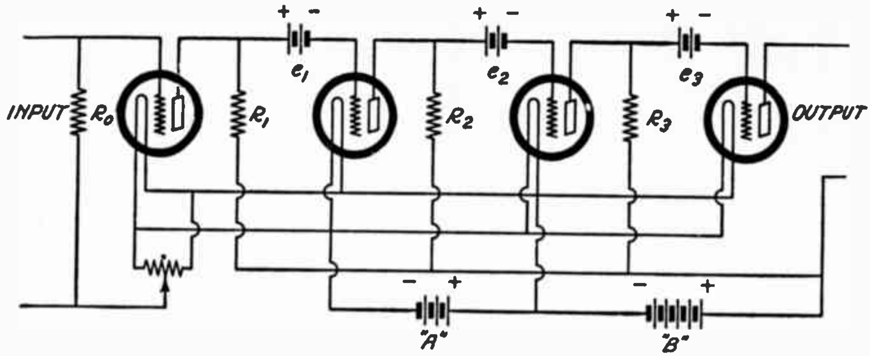
and the ratio $\dfrac{E_{g2}}{E_{g1}} = \dfrac{k\,R_1}{R_p\,R_1}$

which is the voltage amplification obtained per stage of tube.

It is thus seen that as $R_1$ is made large, the maximum amplification obtainable is of the value, K. The accompanying curve shows this action graphically. It must be remembered, however, that as $R_1$ is increased, it is necessary to increase the voltage of the plate battery accordingly, or the normal voltage on the plate of the tube is so decreased that its amplification constant is decreased.

The drop across the grid-coupling condensers, as has been mentioned before, must be small in comparison to the total value, $I\,R_1$. In other words, the reactance of the grid condenser must be small in comparison to the resistance of the parallel circuit, composed of the grid-leak resistance and the internal grid-to-filament resistance of the tube. Here again, the wide range of frequencies, to be accounted for, establishes a weakness. Since 25 cycles was taken as the minimum frequency. the condensers must have a comparatively large capacity. But when the condensers are made large, another consideration enters. If the grids of the tubes were operated free, that is, with no grid leaks, which corresponds to an infinite leak resistance, the action would be erratic.

In the above condition, a sudden stray negative voltage on the grid of a tube might cause the plate current of that tube to drop to zero. Due to the insulation of the grid through the condenser, the plate voltage would not appear until the charge was removed from the grid. This action is commonly termed "blocking" of the tube, and it is for this reason that the leaks are used. Now if a condenser, C, and a leak, R, are used on a tube, the time for the grid to resume its operating potential is defined by the time constant, RC seconds. If, therefore, the capacity of the condensers is increased, the amplifier will tend to distort so that to bring the time constant back to the proper value defined by the frequency of the highest note, the resistance of the grid leaks must be decreased. In so doing, the drop $I_c r_g$ which is the actual voltage affecting the grid will be reduced. It is therefore seen that the proportioning of leak resistance and condenser capacity is a compromise. A further



THE APERIODIC RESISTANCE-COUPLED AUDIO-FREQUENCY AMPLIFIER

Figure Y: This is at the same time the purest reproducer and simplest of the resistance type of amplifiers. Although its over-all amplification is by no means as great as in the case of the transformer-coupled type, nevertheless it has its peculiar advantage, because all possibility of distortion is eliminated.

effect in this amplifier enters when the leak voltage drop is made to compare with the condenser drop. In this case, the amplifier will operate with greater intensity on notes of higher frequencies because the ratio of leak voltage to the voltage drop across the condenser changes appreciably.

From the above discussion, it is obvious that the plate coupling-resistances may be displaced by high-inductance chokes of comparatively low resistance. In this way, greater amplification may be obtained from a plate battery of the same voltage. However, the element of iron losses and distortion due to the iron core enters to counterbalance the increased amplification.

Due to the more faithful reproduction obtained, the resistance and condenser-coupled amplifier described above has been adopted to considerable extent for the speech input amplifiers on broadcast transmitters. The practice has been to use more tubes and get good quality rather than to use transformer-coupling with its high amplification and possible introduction of distortion. The resistance and condenser-coupled amplifier, however, is limited to the upper frequencies, but since most musical and speech reproduction is above 200 cycles, satisfactory operation is obtained.

There is an amplifier that is simpler than the ones described above which responds uniformly to all frequencies from zero, or d.c., to about 100,000 cycles, at which frequency the internal capacity-coupling in the tube limits the operation. In other words, it is an *aperiodic* amplifier. Its circuit for four stages is shown in Fig. Y. The plate coupling-resistances, $R_1$, $R_2$, $R_3$, are designed in the same manner as in the case of the resistance and condenser-coupled amplifier. The grids are coupled *conductively* to the plate of the preceding tube through a small battery. It is the purpose of these batteries to neutralize the plate voltage and thereby to establish the proper potential on the grid. Since there are no condensers or inductances in the circuit, all possibility of distortion is minimized. Further, it will be seen that there is a through conductive path, making d.c. amplification possible. It is a simple matter to positively adjust this amplifier.

The apparatus required for a four-stage unit is as follows:

4 Western Electric 216-A vacuum tubes or equivalent;
4 sockets for above tubes;
6 Western Electric 38-A, 48,000-ohm resistance units (or equivalent) 96,000 ohms per plate;
1 "A" battery potentiometer, 200 to 400 ohms;
1 D. C. milliameter, 0-25 milliamperes;
1 input discharge resistance, 50,000 to 100,000 ohms;
1 storage "A" battery, 6 volts;
1 "B" battery, 120 volts, capable of delivering 50 milliamperes;
3 "C" batteries, 45 volts each, adjustable, current practically nil.

Be sure that all connections are as illustrated in Fig. Y in the section explaining the theory of the amplifier. Obtain the static characteristic curves for the tubes used, so that the value of plate current for proper operation may be determined. For the 216-A tubes, this is about 9 to 15 milliamperes, and is obtained for the last tube when the grid is connected directly to the negative filament lead. When these tubes are used, disconnect the grid of the last tube from the negative of $e_3$, and connect it temporarily to the negative filament terminal. Note the plate current as read for the last tube on the milliameter, say 11 milliamperes. Now disconnect the grid of the third tube (from the left on diagram) from the battery, and connect it to the negative filament, at the same time connect the grid of the fourth tube to its battery. Adjust the connection of $e_3$ until the original normal plate current is restored to the last tube, 11 milliamperes in this example. Connect the grid of the second tube to negative filament, and adjust $e_3$ to give normal plate current in the last tube. Finally connect the grid of the first tube to negative filament and adjust $l_2$ for normal plate current in the fourth tube. The complete amplifier, excepting the first stage, is now correctly adjusted to give maximum amplification with minimum distortion. The critical adjustment on the first tube is made when the input transformer has been connected. Under this condition, the potentiometer is regulated until the plate current of the last tube is once again restored to normal value.

The amplifier is simple and easy to operate, once the initial adjustments have been made. One point must be continually observed; *the plate current of the last tube should not be allowed to change or "dance."*

Any movement of the needle on the meter indicates the presence of distortion. It is best to provide a means for controlling the input to the amplifier, and, by means of this control, the current must be kept steady and fixed.

The introduction of the dry-cell vacuum tubes with their very special characteristics, has confused many radio experimenters who have attempted to employ these devices in amplifying systems. For the benefit of these workers there is appended a comprehensive accumulation of data along these special lines. The material, as presented, was prepared by Frank A. Hinners, R.E., after a long series of exhaustive experiments:

"Many laymen who are thinking about joining the ranks of broadcast listeners, and even large numbers of broadcast listeners of experience, find it difficult to decide when to use, and when not to use the dry-cell tubes.

"When portability is required above all else, the dry-cell tubes obviously recommend themselves. Even when portability is not a factor but the consideration of small first cost and low upkeep is important, the dry-cell tubes have much to recommend them. The cost of a storage battery and the charging appliance represents a considerable sum, which is, of course, unnecessary with dry-cell tubes.

"The dry-cell tube used for some purposes performs quite as well as the larger storage-battery tubes, yet for other purposes it cannot equal the large tube.

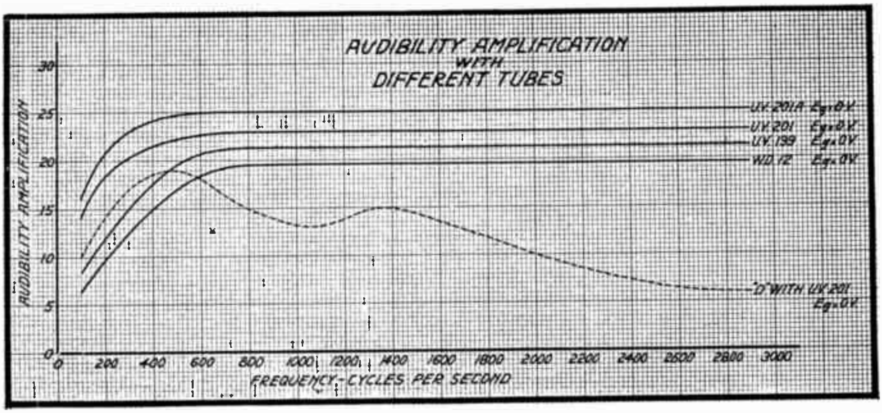
"To mention some examples, the dry-cell tube fitted with the proper grid leak when used as the detector in regenerative receivers, produces results closely approaching the larger tube, if not in signal volume, certainly from the DX standpoint. Used with the proper grid leak in non-regenerative receivers in which radio-frequency amplification is *not* incorporated, results equalling but not excelling the crystal detector are the rule. Reference is made to the WD-12 tube operated from a single dry cell. Operated in this type of receiver, *without* proper grid leak, results are inferior to a crystal detector. Since we are considering the amplifying properties of the dry-cell tube here, its detector action cannot be described at length; sufficient to say that the dry-cell tubes, which are of the hard, highly exhausted type, are not especially sensitive detectors.

"In choosing between the two general types of tubes now in use, storage and dry-cell operated, the public finds itself confused by much conflicting information. Many, attracted by the lower first cost of the dry-cell tubes, buy them with expectations of a performance equal to the larger tubes. Frequently, disappointment is a result, because the listener expects too much from this type of tube—due to no fault of the tube. Were the information regarding the dry-cell tube available in quantitative form, instead of the prevalent terms such as 'good,' 'fair' and 'poor,' the truly remarkable merit of this form of tube would become known and needless disappointments, therefore, avoided.

"In order to supply this quantitative information, a series of observations were conducted in the laboratory under conditions practically duplicating actual service.

"An audio-frequency amplifying transformer of exceptionally good electrical design, with a four-to-one turn ratio, was used. The results obtained apply strictly to this particular make of audio-frequency transformer and therefore would not be found correct for all makes of such transformer. In general, however, the differences between the amplification obtained from the various tubes hold approximately true for other transformers of similar design and of the same general characteristics.

"In Fig. Z a family of curves is shown. The vertical axis shows the audibility or current amplification. The horizontal axis shows the audio frequencies of the alternating-current voltages applied to the vacuum tubes and the audio-frequency amplifying transformer. In the test, the amplification and the frequency of the a.c. voltage applied to the grids of the amplifier were noted. The amplification, together with the particular frequency of the input current were plotted as the observation was made. A curve drawn through the points plotted indicates how the amount of amplification obtained is influenced by the varying frequencies applied to the grids of the various vacuum tubes indicated in combination with the audio-frequency amplifying transformer. The frequencies used in the experiments correspond to the basic range of frequencies produced in music and human speech.



A GROUP OF FREQUENCY-AUDIBILITY CURVES FOR AMPLIFYING TRANSFORMERS

**Figure Z: The four top curves in heavy black lines show the audibility record of one transformer used in connection with four different types of vacuum tubes. Notice that the amplification is constant over a wide range of audio frequencies. This is a good transformer; it does not distórt but it amplifies with equality all the frequencies within the range shown. The lower dotted curve shows the audibility of a poor transformer. Notice how the amplification falls off at the higher frequencies. This transformer would produce distortion. It is unusual to find vacuum tubes of different manufacture that will give the same curve with the same transformer. Oftentimes tubes of the same manufacturer will not do this.**

"At points where curvature appears the change in amplification noted is the direct result of the particular frequencies applied to the grids of the vacuum tubes. At these frequencies, tones emitted from loudspeakers and headphones operated by the transformer and vacuum tubes cannot correspond, in point of volume, to the original tone acting upon the microphone in a broadcasting station. This effect is known as 'distortion,' and appears wherever the output does not reproduce the input with fidelity.

"To illustrate to what an extent an audio-frequency transformer of poor design may be held accountable for distortion, the characteristic curve of another transformer has been added, which appears as curve 'D.' Obviously a transformer that produces such an erratic characteristic would be unsuited to broadcast reception. Yet, a considerable number of such transformers are being offered to the public and enjoy a wide sale.

"The ideal transformer would produce a straight line parallel to the frequency scale. Although the transformer used in these tests has a sloping characteristic below 600 cycles a second, at higher frequencies it produces practically uniform amplification. For this reason it is well suited to these measurements, as we are in quest of information on vacuum-tube performance.

"In these measurements the amplification is expressed as 'times audibility' and represents the number of times the telephone current has been multiplied in passing through the particular vacuum-tube and transformer-combination used.

"In all curves shown in Fig. Z, the voltage applied to the plates of the various vacuum tubes used was 67.5, a voltage most frequently specified by transformer manufacturers. The grids of all tubes tested were connected to the

Dry Cell Tube Data

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|
| | | ONE STAGE | | | | TWO STAGES | | |
| Tube | Current Ampli. | Energy Ampli. | % Output | % Diff. | Current Ampli. | Energy Ampli. | % Output | % Diff. |
| 201-a | 25 | 625 | 100 | 0 | 625 | 390,000 | 100 | 0 |
| 201 | 23.5 | 550 | 88 | 12 | 550 | 300,000 | 77 | 23 |
| 199 | 21.5 | 460 | 73 | 27 | 460 | 210,000 | 54 | 46 |
| WD-12 | 19.5 | 380 | 61 | 39 | 380 | 144,000 | 37 | 63 |

negative-filament terminal. This connection is standard with most amplifier and receiving-set manufacturers.

"In the table on this page the results obtained from the curves in Fig. Z have been entered, together with some further information obtained by calculation. The theoretical energy amplification obtained with UV-201-a tubes has been made the standard of comparison, its value being expressed as 100 percent.

"The sound volume delivered by headphones and loudspeakers is governed by the electric energy supplied to them. The current increase due to amplification, in itself is not a direct indication of the comparative sound output that either the headphone or the loudspeaker may be expected to produce. To determine the comparative sound volumes that may be produced by headphones or loudspeakers operated by various tube combinations, it is necessary to express the measured current or audibility increase as energy amplification, inasmuch as such devices are energy-operated.

"The energy amplification may be assumed to vary as the square of the current amplification because the impedance of the load circuit was maintained constant as well as larger than the internal plate impedance of the vacuum tube. This assumption is quite correct, as the relative amplification values noted in the above table are taken along the flat portion of the characteristic and thus free from the influence of frequency changes.

"The energy amplification computed in this manner is noted in column 3.

"Column 4 shows the percentage output produced by the various tubes specified in terms of 201-a output. Column 5 shows the percent difference in output of such tubes in terms of the 201-a output.

"From the observations noted in columns 3, 4 and 5, it will be seen that the WD-12 tube used as a single-stage audio-frequency amplifier delivers an energy output, equivalent, in round numbers, to 60 percent of the 201-a tube output, representing a 40 percent sacrifice in result. In the case of the 199, these figures become 73 and 27 respectively, representing a smaller sacrifice in result, namely, 27 percent.

"Instead of using the percentages of column 4, let us refer to the energy amplifications listed in column 3.

"Suppose we consider the electric energy fed to the amplifier by the detector as the energy unit. One stage of audio-frequency amplification would produce a sound volume 625 times larger than this unit with the 201a tube; 550 times with the tube 201;* 460 times with tube 199 and 380 times with tube WD-12. These values differ considerably numerically on paper, yet the differences seem less impressive to the ears of the listener.

"Two stages of audio-frequency amplification are more widely used by the listener and for this reason an appraisal of the dry-cell tube's performance in this field will perhaps prove of even greater interest. To carry these observations this further step forward, calculations are again necessary.

"Amplifiers arranged in cascade amplify in geometric progression if the voltage applied to each of the grids falls within the straight portion of their grid-plate characteristic; that is, voltages whose values are below the bend in this characteristic. When so operated, the result produced by two stages of amplification 'A' becomes the product 'A x A.' This relation applies to the amplification whether expressed as current or energy amplification. In either case the amplification for two stages is the product of the amplification of the individual stages, however expressed, and if each stage produces the same amplification 'A' the result of two stages is '$A^2$.' In the case of three stages of audio-frequency amplification, were there are no very serious practical limitations, the over-all amplification produced would correspond to the third power of the amplification of the individual stage, equal amplification, of course, being obtained from each of the stages.

"This geometric relation which governs the operation of the cascade amplifier is of the greatest significance, and yet it is little known to the radio listener.

"Vacuum tubes are rated in terms of their individual performance, but their operation in the cascade arrangement leads to results of a different order. Differences noted in their individual performance, which may be quite small, assume astonishing proportions in the cascade arrangement.

"It may be of some interest to note how the action of the cascade arrangement would differ if it obeyed arithmetical instead of geometrical law. The case, it should be remembered, is purely hypothetical and except for purposes of illustration, it has no value whatever. Were the amplification arithmetical, two such stages of amplification would equal the sum of the individual amplification of the two stages. The values of columns 6 and 7 would be only twice as large as the values of columns 2 and 3. A far greater number of tubes would be required to produce the amplification values noted in columns 6 and 7. The percentages noted in columns 8 and 9 would not, however, differ from those of columns 4 and 5.

"Take the 199 tube as an example: This tube was 73 percent as effective as the 201-a tube. It produced 165 less energy units than the 201-a tube. Two such stages of amplification obeying arithmetical law would lack another 165 energy units, reaching a total of 330 units. This would, however, still be equal to 73 percent of the amplification produced by two 201-a tubes.

"Actually, however, because the over-all amplification is the product and not

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*The improvements in storage-battery-operated tubes are also clearly indicated. It is to be observed that tube 201-a produced a trifle less than 14 percent more energy amplification than the older 201 tube. This by itself is a considerable improvement but, when accomplished with one-fourth of the filament current formerly needed, represents a decided advance in the art of vacuum-tube manufacture.

the sum of the individual amplification of each tube, the resultant amplification becomes .73 x .73, or 54 percent.

"Referring to the table we find two stages of 199 and WD-12 are, respectively, 54 percent and 37 percent as effective as two stages of 201-a amplification. The comparative loss or sacrifice in volume for two stages of 199 and WD-12 becomes 46 percent and 63 percent, respectively. Differences in performance of this order, which are enormous indeed, account in large measure for whatever disappointments listeners experience in their use of the dry-cell tubes.

"These differences may be more strikingly illustrated by referring to column 7 of Table 2. Here the over-all, calculated energy amplification has been entered. Also in this case consider the energy fed to the first amplifier tube as the unit. We find that if two 201 tubes replace 201-a tubes of like number, the energy is increased 300,000 fold. For two 199 tubes, 210,000 fold, and WD-12 tubes, 144,000 fold.

"Now with two 201-a tubes an amplification of 390,000 fold was noted. If we consider the loss of energy units, it is to be noted 90,000 units less are obtained with 201 tubes;* 180,000 less with 199 tubes, and 246,000 less with WD-12 tubes.

"From the data obtained it must be apparent that when cost is weighed against results, the use of the dry-cell tube as a single-stage, audio-frequency amplifier *is* wise economy.

"However, weighing cost against results, the dry-cell tubes used in the amplifier of two stages do not, in the opinion of many, represent real economy. Considering the investment represented by the receiving set, two-stage amplifier, vacuum tubes, loudspeaker and sundry accessories, the added storage-battery and charger cost is not prohibitive, particularly as each of these units is so much less effective when dry-cell tubes are used.

"It should be noted, however, that the two-stage amplifier that uses dry-cell tubes produces an amplification many times greater than the amplification of the single-stage amplifier using the larger tubes. When it is considered that the two-stage amplifier fitted with dry-cell tubes costs less than a single-stage amplifier that uses the larger tube provided with its complement of storage battery and charger, the former has much in its favor. Do not, however, look for performance approaching the two-stage amplifier fitted with storage battery tubes."

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*Here it is to be observed that the two-stage audio-frequency amplifier using 201-a tubes produces 30 percent more energy amplification than the older 201 tubes.

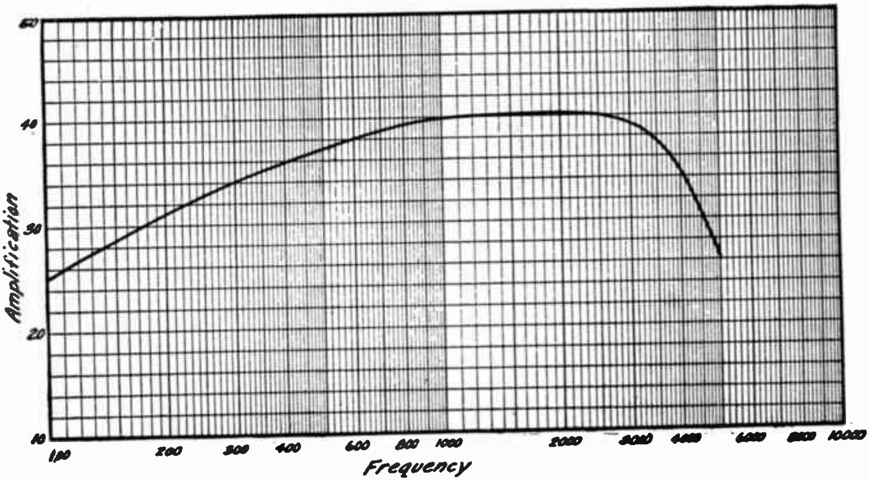
## Acme Transformer

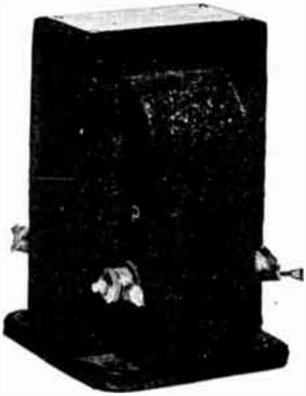
### Specifications

Dimensions; 3½ x 3 x 2 in.
Case; sheel metal
Insulation; Bakelite
Connectors; binding posts

Mounting; for panel or base
Ratio; 3½ : 1
Finish; black enamel
Type; MA-2

## Acme Amplification Curve





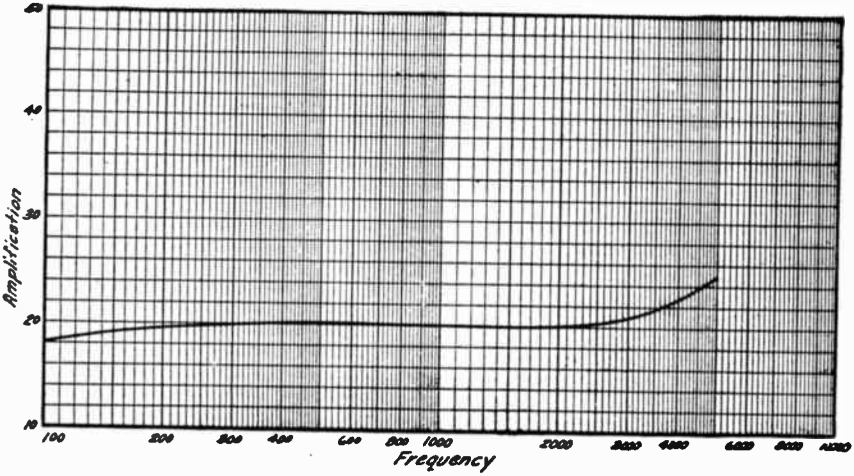
## All-American Transformer

### Specifications

Dimensions; 2½ x 2 x 2½ in.
Case; sheet brass
Connectors; binding posts and lugs
Insulation; Bakelite

Mounting; for panel or base
Ratio 3 to 1
Finish; crystalline black
Type; lyric

## All-American Amplification Curve



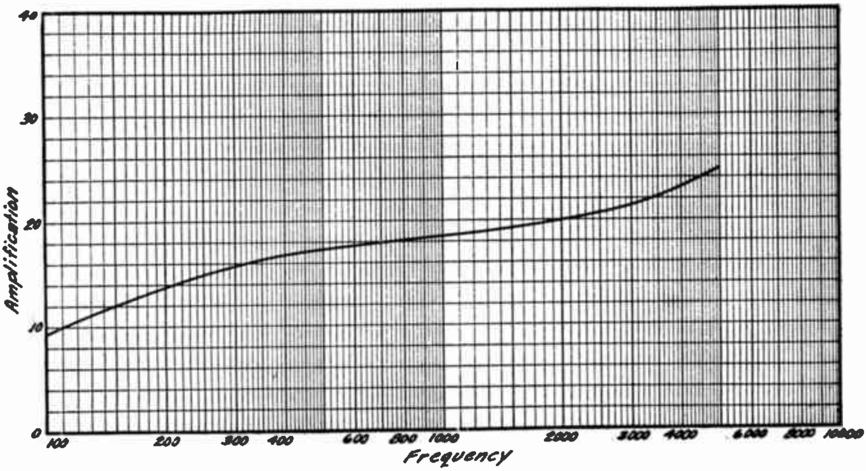
All-American Transformer

## Specifications

Dimensions; 2½ x 2¾ x 2 in.
Case; sheet metal
Connectors; lugs
Insulation; Bakelite

Mounting; for base or sub-panel
Ratio; 4 to 1 and 5 to 1
Finish; black enamel
Type; de luxe

## All-American Amplification Curve



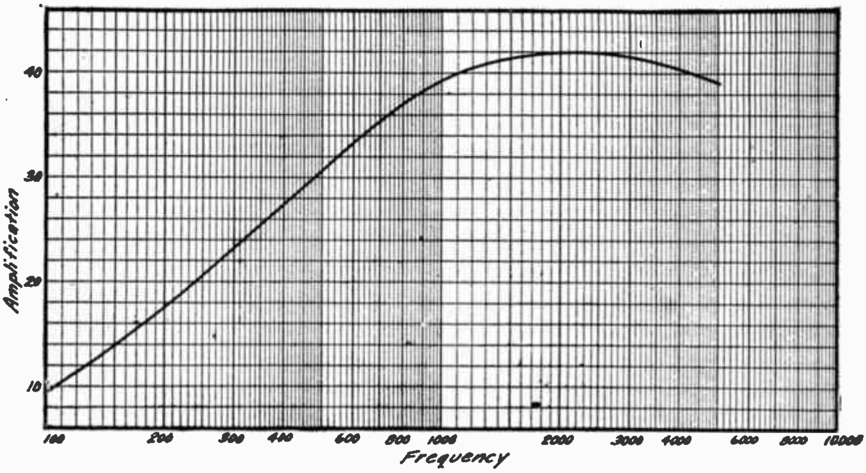
## All-American Transformers

### Specifications

Dimensions; 2½ x 2 x 2½ ins.
Case; sheet metal
Connectors; bindings posts and lugs
Insulation; Bakelite

Mounting; for sub-panel or base
Ratio; 5 to 1
Finish; black enamel
Type; R12

## All-American Amplification Curve



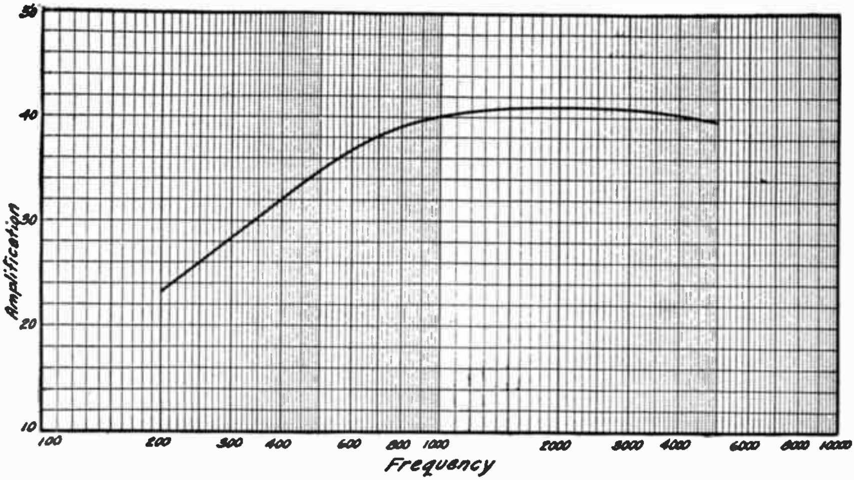
## Amertran Transformer

### Specifications

Dimensions; 1¾ x 2¾ x 2 in.
Case; semi-full, sheet brass
Insulation; fibre
Connectors; binding posts and lugs

Mounting; for panel or base
Ratio; 3½:1 and 5:1
Finish; black
Type; AF-7 and AF6

## Amertran Amplification Curve



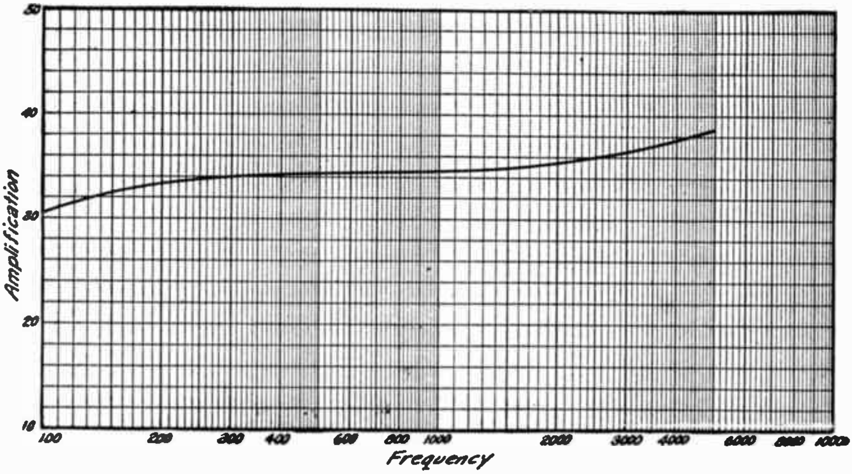
## Amertran Transformer

### Specifications

Size; 2¾ x 2¾ x 2¼ ins.
Container; pressed metal
Insulation; Bakelite
Connectors; soldering lugs

Ratio; 3½:1
Finish; brown enamel
Mounting; for base

## Amertran Amplification Curve

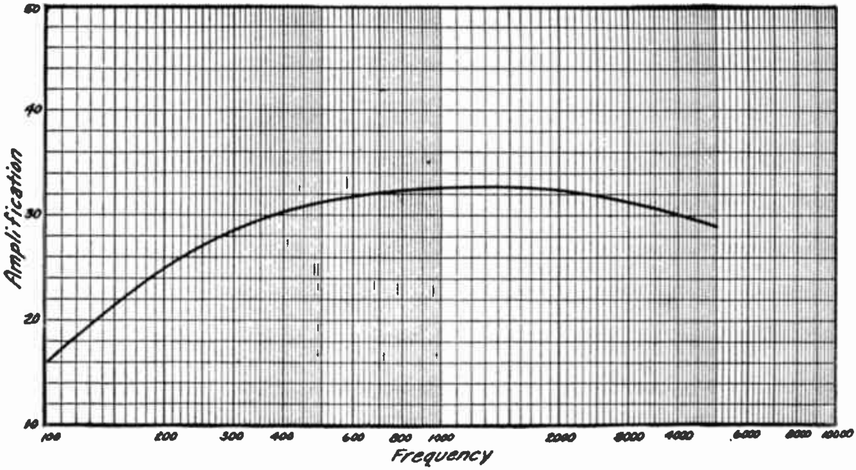


## Brandes Transformer

### Specifications

Dimensions; 3 x 2⅛ x 1¾ in.
Case; sheet metal
Connectors; lugs
Insulation; Bakelite
Inductance (800 cycles); primary open, 30-35 henries
Mounting; for base or sub-panel
Finish; black enamel
Ratio; 1 to 5
Primary resistance; 1400 ohms
Secondary resistance; 14,000 (at 800 cycles)

## Brandes Amplification Curve



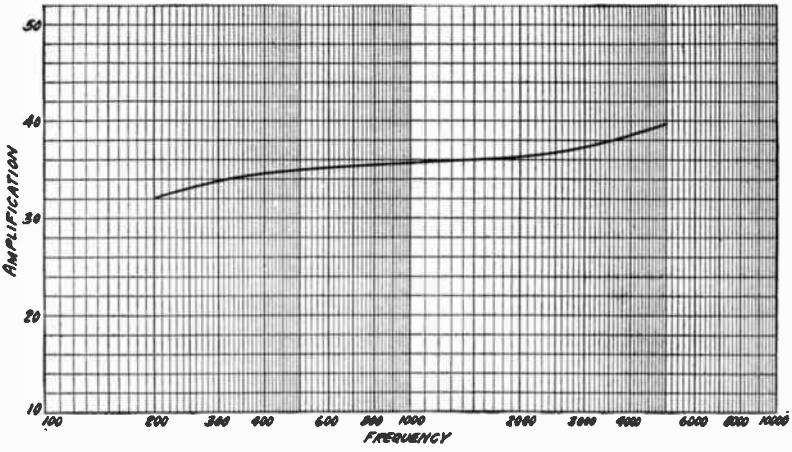
## Branston Transformer

### Specifications

Dimensions; 3 x 1 ½ x 2 ins.
Case; sheet metal
Insulation; Bakelite
Connectors; binding posts and lugs

Mounting; for base or sub-panel
Ratio; 3½:1
Finish; brass and black enamel
Impedance;

### Branston Amplification Curve



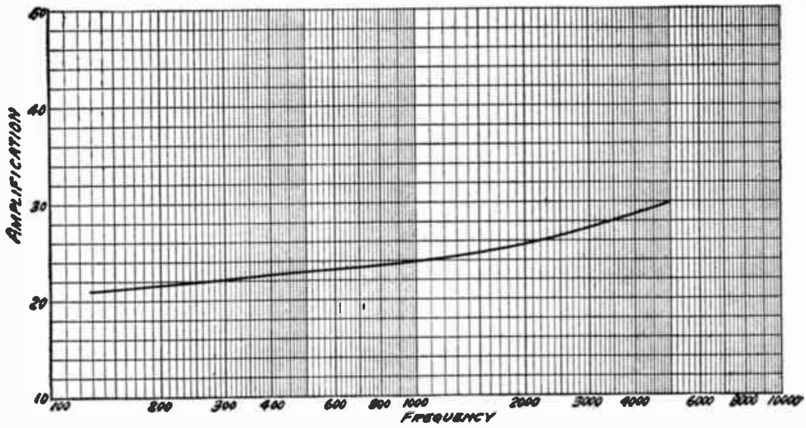
## Erla Transformer

### Specifications

Dimensions; 3½ x 3½ x 2⅞ in.
Case; sheet steel
Connectors; binding posts
Insulation; Bakelite

Mounting; for base or sub-panel
Ratio; 3½:1
Finish; crystalline black
Core; cruciform type

### Erla Amplification Curve



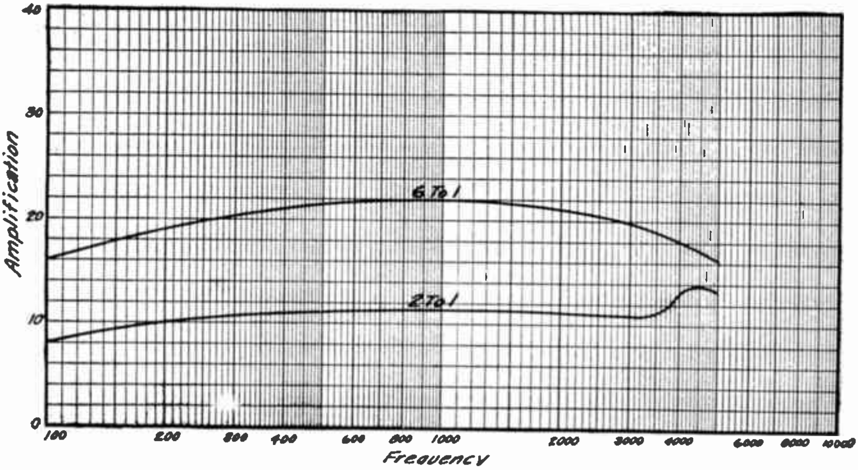
## General Radio Transformer

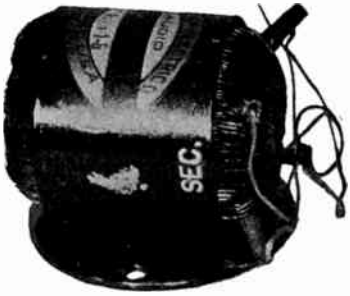
### Specifications

Dimensions; 3½ x 2¼ x 2 in.
Case; drawn sheet metal
Insulation; Bakelite
Terminals; lugs and screws
Finish; black enamel

Mounting; for base and sub-panel
Ratio; 5.95 to 1 (also made in 1 to 2.1)
D.C. resistance; pri. 1300 ohms, sec. 15,000
Impedance at 1000 cycles; pri. 155,000 ohms, sec. 5,500,000 ohms
Type: 285

## General Radio Amplification Curve





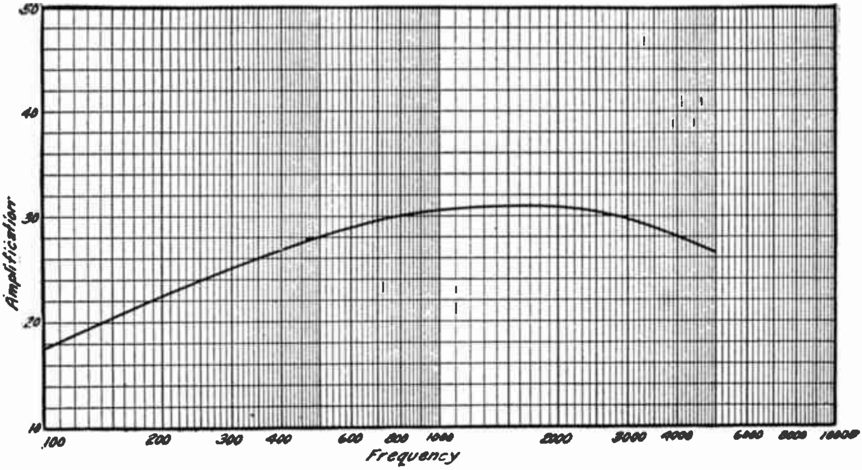
## Hedgehog Transformer

### Specifications

Dimensions; 1¾ x 1½ x 1½ in.
Case; metal tube
Connectors; pigtails
Insulation; Bakelite

Mounting; for base
Ratio; 5:1
Finish; black enamel
Core; iron wire

### Hedgehog Amplification Curve



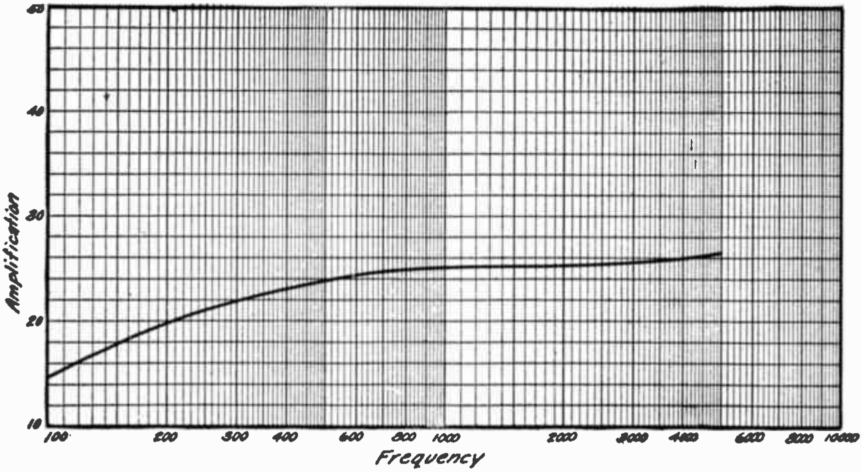
## Jefferson Transformer

### Specifications

Dimensions; 1½ x 1¾ x 2 in
Case; sheet metal
Connectors; lugs
Insulation; Bakelite

Mounting; for panel or base
Ratio; various ratios
Finish; black enamel

## Jefferson Amplification Curve

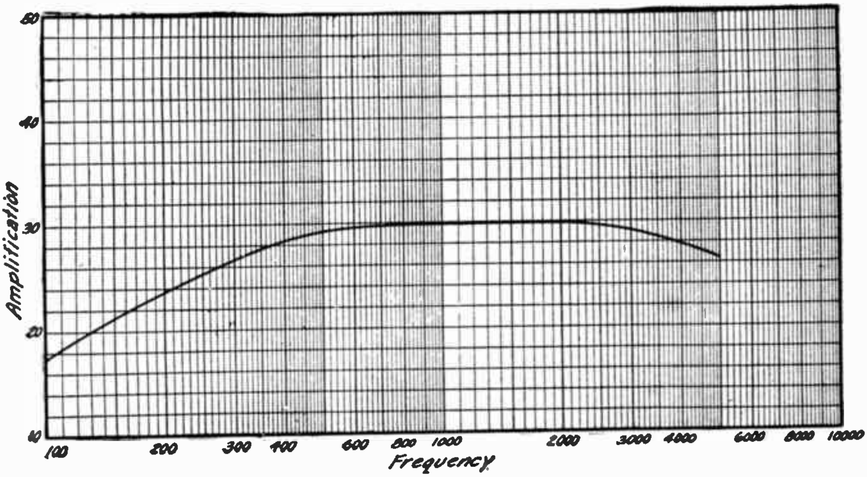


## Karas Transformer

### Specifications

Dimensions; 2¾ x 2½ x 2¾ in.
Case; sheet metal
Connectors; binding posts and lugs
Insulation; Bakelite
A.C. resistance Sec. pri. open, 7,600,000 ohms
Mounting; for base or sub-panel
Finish; black enamel
Turns ratio; 1 to 5
Amplification ratio; 3.7 to 1
Sec. reactance with primary open; 550,000 ohms

## Karas Amplification Curve



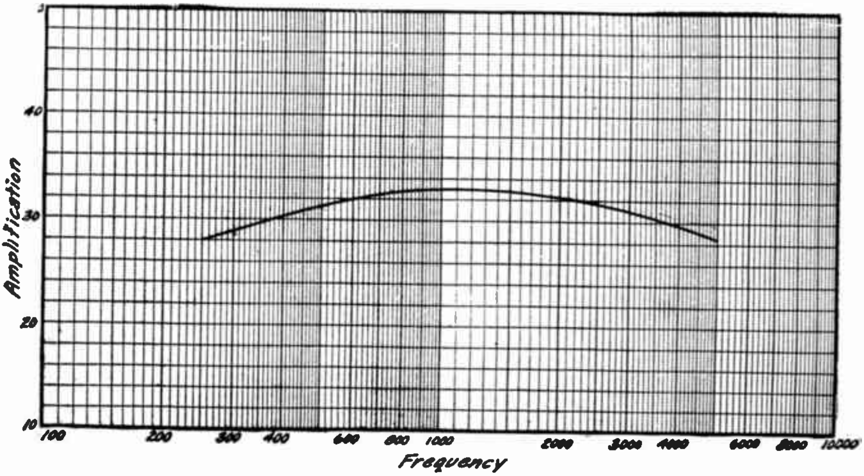
Kellogg Transformer

## Specifications

Size; 2¾ x 2¼ x 2¼ ins.
Insulation; Bakelite
Container; metal

Connectors; binding posts and lugs
Ratio; 3:1.
Finish; black enamel

## Kellogg Amplification Curve



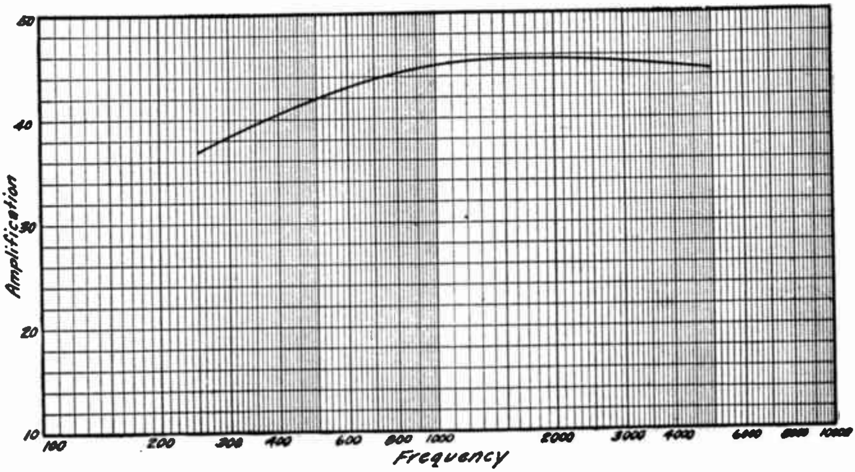
## Kellogg Transformer

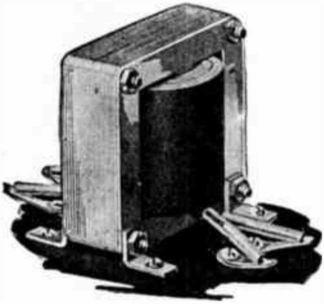
### Specifications

Dimensions; 2¾ x 2¼ x 2¼ ins
Case; sheet metal
Insulation; moulded Bakelite
Connectors; binding posts and lugs

Ratio; 4½ to 1 and 3 to 1
Mounting; for base or sub-panel
Finish; black enamel
Shielded

## Kellogg Amplification Curve





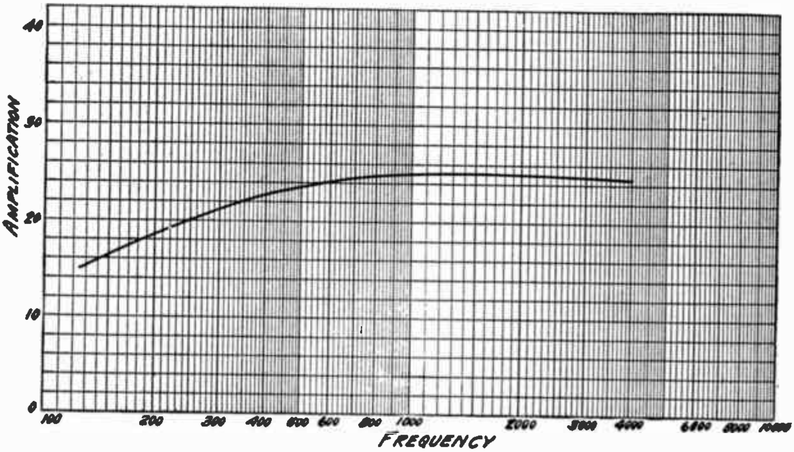
## Liberty Transformer

### Specifications

**Dimensions**; 2¼ in. high
**Case**; covered or uncovered types
**Connectors**; binding posts or unmounted type
**Insulation**; Bakelite

**Core**; clamped between stamped frames
**Finish**; nickel
**Mounting**; base or sub-panel
**Type**; H

## Liberty Amplification Curve



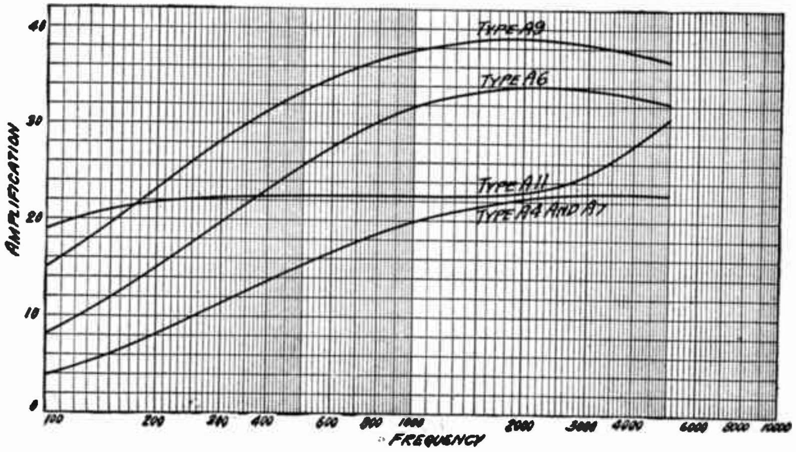
## Marle Transformer

### Specifications

Size; 2⅝ x 2¼ x 4½ in.
Container; moulded Bakelite
Connectors; binding posts

Ratio; 5 to 1
Primary resistances D.C.; 1000
Secondary resistances D.C.; 5700

## Marle Amplification Curves



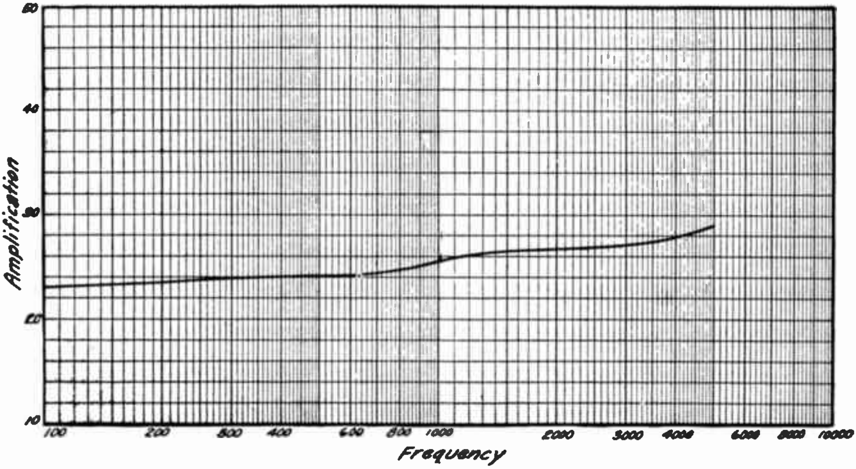
## Pacent Transformer

### Specifications

Dimensions; 3½ x 2½ x 2 in.
Case; sheet brass
Connectors; binding posts and lugs
Insulation; Bakelite

Mounting; for sub-panel or base
Ratio; 3:1
Finish; nickeled and polished
Type: 27-A and 27-B

## Pacent Amplification Curve



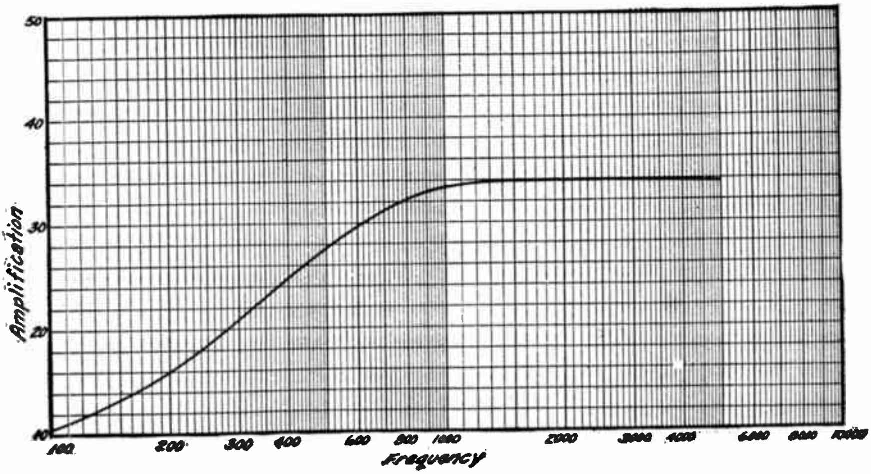
## Precise Transformer

### Specifications

Dimensions: 3¼ x 2¼ x 2¼ in.
Case; sheet brass
Insulation; fibre
Connectors; binding posts

Mounting; for base or sub-panel
Ratio; 1:4½
Finish; crystalline black
Type; 285

## Precise Amplification Curve



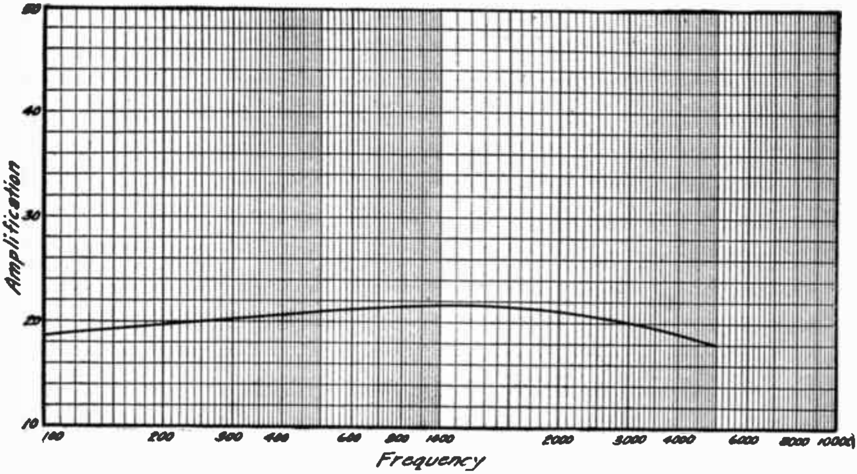
Precise Transformer

## Specifications

**Dimensions**; 2 x 2¼ x 2¾ in.
**Case**; sheet brass
**Insulation**; Bakelite
**Connectors**; binding posts

**Mounting**; for base or sub-panel
**Finish**; crystalline black
**Ratio**; 5:1 and 2½:1
**Type**: 285

## Precise Amplification Curve



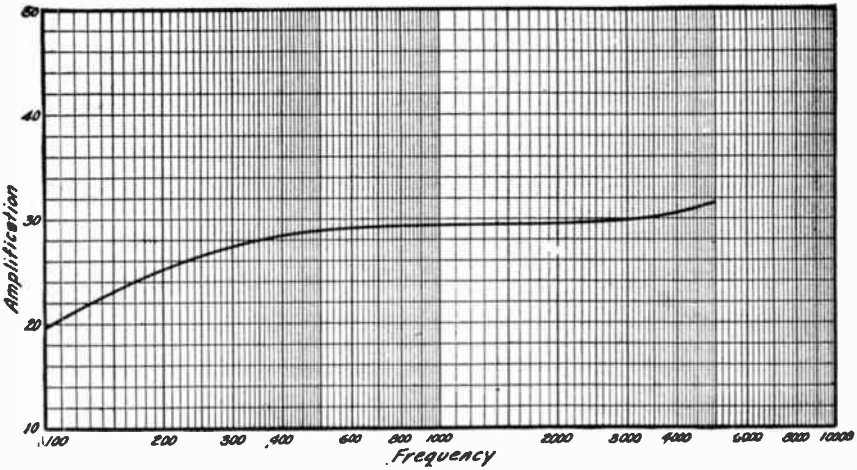
Samson Transformer

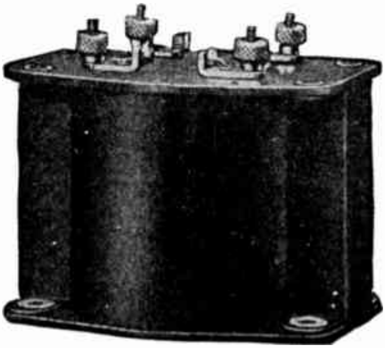
## Specifications

Dimensions; 2¾ x 2 x 3 in.
Case; sheet metal
Connectors; binding posts and lugs
Insulation; moulded bakelite

Mounting; for sub-panel or base
Ratio; 3:1
Finish; black enamel
Type; HWAS

Samson Amplification Curve



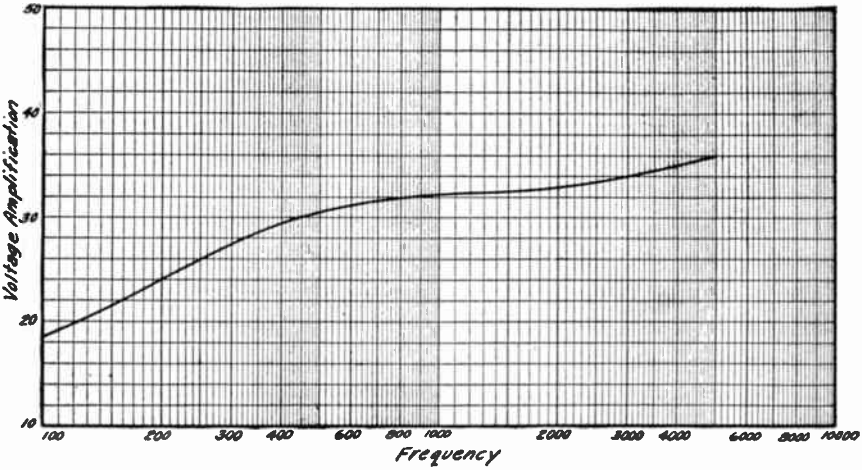


## Stromberg-Carlson Transformer

### Specifications

Dimensions; $2\frac{3}{4}$ long, $1\frac{15}{16}$ths wide and $2\frac{3}{16}$ths high
Case; sheet metal
Connectors; binding posts and lugs
Insulation; Bakelite
Mounting; for base or sub-panel
Finish; black enamel
Ratio; 4 to 1
Primary reactance; 125,600 at 1000 cycles

### Stromberg Amplification Curve



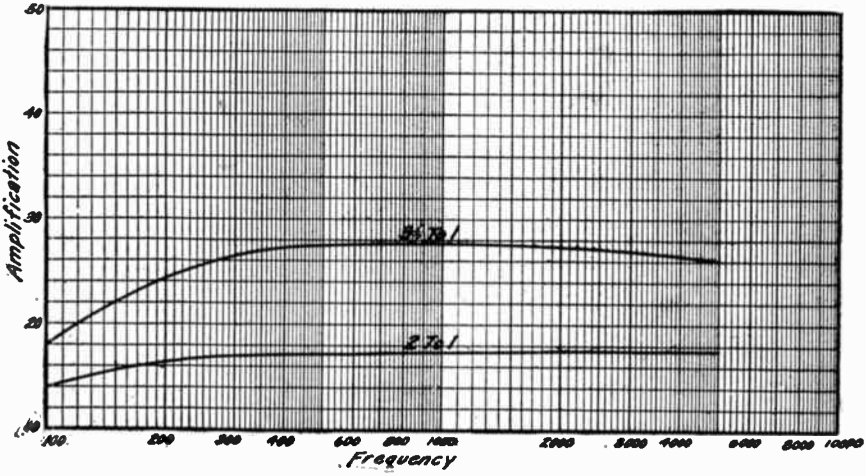
## Thordorson Transformers

### Specifications

Dimensions; 2 x 1¾ x 2½ in.
Case; sheet brass
Connectors; binding posts with lugs
Insulation; Bakelite

Mounting; for base or sub-panel
Ratio; 6:1, 3½:1 and 2:1
Finish; black enamel

## Thordorson Amplification Curves



Como Output Transformer

## Specifications

Dimensions; 3¼ x 1¾ x 2¼ in.
Case; sheet metal
Connections; binding posts
Insulation; Bakelite

Mounting; for sub-panel or base
Ratio; low ratio
Push-pull type
Finish: crystalline black

Como Input Transformer

## Specifications

Dimensions; 3¼ x 1¾ x 2¼ in.
Case; sheet metal
Connections; binding posts
Insulation; Bakelite

Mounting; for sub-panel or base
Ratio; low ratio
Push-pull type
Finish; crystalline black

Dongan Transformers

Specifications

| | |
|---|---|
| Dimensions; 2¾ ins. high | Mounting; for sub-panel or base |
| Case; sheet brass | Ratio; 2 to 1, 3¾ to 1 and 6 to 1 |
| Insulation; Bakelite | Finish; black enamel |
| Connectors; binding posts and lugs | Also made unmounted |

Erla Transformer

Specifications

| | |
|---|---|
| Dimensions; 2½ x 2¾ x 1¾ ins. | Mounting; for sub-panel or base |
| Case; sheet metal | Ratio; 6:1 |
| Connectors; binding posts | Shielded |
| Insulation; Bakelite | Finish; black enamel |

## Fada Transformer

### Specifications

Dimensions; 3½ x 2¼ x 1⅞ in.
Case; moulded Bakelite
Connectors; binding posts and lugs

Mounting; for sub-panel or base
Ratio; 4 to 1
Finish; black Bakelite
Current carry cap. 15 milliamperes

## General Radio Transformer

### Specifications

Dimensions; 2½ x 2½ x 2¼ in.
Case; none
Insulation; Bakelite
Connectors; binding posts

Mounting; for sub-panel or base
Finish; black enamel
Ratio; 6:1 and 2:1

Jefferson Transformer

Specifications

Dimensions; 2¼ x 2¼ x 2½ in.
Case; sheet metal
Connectors; binding posts
Insulation; Bakelite

Mounting; for sub-panel or base
Ratio; 3:1
Finish; black enamel
Type; Star

Kellogg Transformer

Specifications

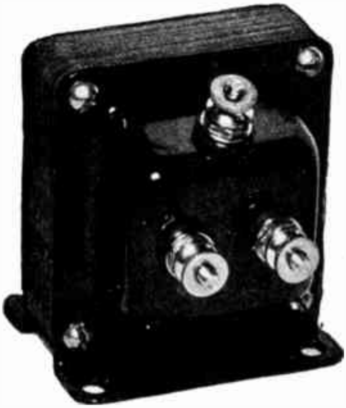
Dimensions; 2½ x 2 x 2½ ins.
Case; uncovered
Connectors; binding posts
Insulating; Bakelite

Mounting; for base
Ratio; 3:1
Finish; black enamel

Martin-Copeland Transformer

Specifications

Dimensions; 2½ x 1¾ x 1¾ ins.
Case; uncovered
Connectors; binding posts
Insulation; Bakelite
Mounting; for panel or base
Ratio; 3½:1
Finish; nickeled



Modern Transformer

Specifications

Dimensions; 2½ x 2⅛ x 2¼ ins.
Case; sheet metal
Connectors; binding posts
Insulation; Bakelite
Mounting; for base or sub-panel
Ratio; 10:5-3
Push-pull type
Finish; black enamel

New York Coil Transformer

Specifications

Dimensions; 2⅜ x 2¼ x 2¾ ins.
Case; not enclosed
Insulation; Bakelite
Connectors; binding screws

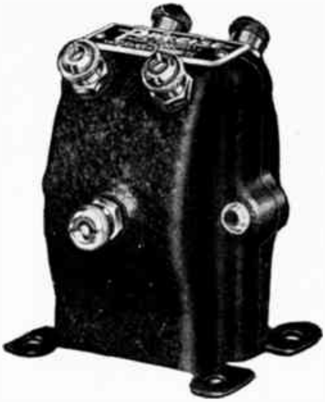
Ratio; 4½:1
Mounting; for sub-panel or base
Finish; nickel and black

Perry Transformer

Specifications

Dimensions; 3 x 2¼ x 2 ins.
Case; drawn brass
Insulation; Bakelite
Connectors; binding posts

Mounting; for panel or base
Ratio; 3½:1
Finish; crystalline black



## Precise Transformer

### Specifications

Dimensions; 2 x 2¾ x 2½ ins.
Case; sheet brass
Connectors; binding posts
Insulation; Bakelite

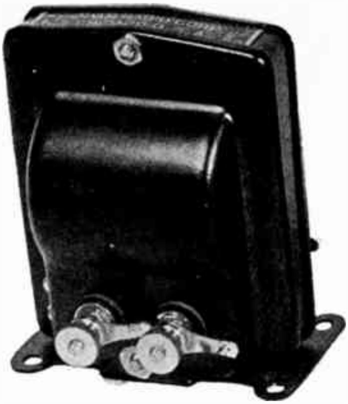
Mounting; for base or sub-panel
Finish; crystalline black
Ratio; 3:1
Push-pull type

### Specifications

## Precise Transformers

Dimensions; 2½ x 1¾ x 1½ ins.
Case; sheet brass
Insulation; Bakelite
Connection; binding posts

Mounting for panel or sub-base
Ratio; 4½:1
Finish; black enamel

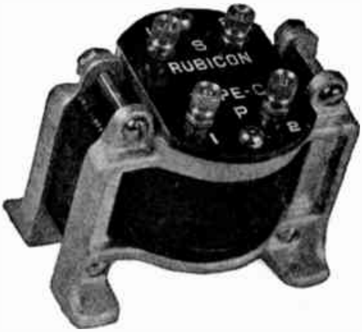


Quam Transformer

Specifications

Dimensions; 2⅞ x 1½ x 2 ins.
Case; sheet metal
Connectors; binding posts and soldering lugs
Insulation; Bakelite

Mounting; for base
Finish; black enamel
Ratio; 3:1

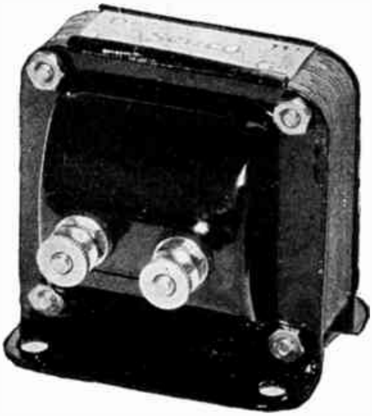


Rubicon Transformer

Specifications

Dimensions; 2½ x 1⅞ x 2 ins.
Case; uncovered; aluminum frame
Connectors; binding posts
Insulation; hard rubber
Core; clamped between aluminum frames

Mounting; for sub-panel or base
Finish; aluminum frame
Ratio; 3½ to 1 and 5 to 1
Primary resistance; 1000 ohms
Secondary resistance; 6500 ohms (resistance for 5 to 1 ratio)
Type; D



Serco Transformer

Specifications

Dimensions; 2¼ x 2 x 3 ins.
Case; sheet metal
Insulation; Bakelite
Connectors; binding posts

Mounting; for base or sub-panel
Ratio; 3½:1
Finish; black enamel

Shermatran Transformer

Specifications

Dimensions; 2 x 2 x 3 ins.
Case; semi-enclosed
Insulation; Bakelite
Connectors; lugs

Mounting; for panel or base
Ratio; 5:1
Finish; black enamel

Sterling Transformer

Specifications

Dimensions; 1¾ x 2¼ x 2¾ ins.
Case; sheet metal
Connectors; lugs and screws
Insulation; Bakelite
Finish; black enamel
Net weight; 12 ounces

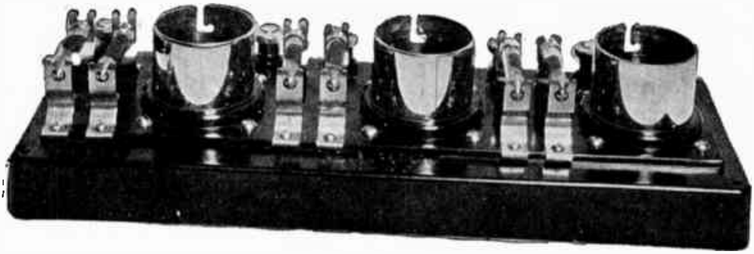
Mounting; for base or sub-panel
Ratio; 4 to 1
Primary resistance; 1100 ohms
Secondary resistance; 16,000 ohms
Impedance 800 cycles; primary with
Sec. open, 112,000 ohms

Thordorson Transformer

Specifications

Dimensions; 1¾ x 2½ x 2 ins.
Case; sheet brass
Connectors; binding posts and lugs
Insulation; Bakelite

Mounting; for sub-panel or base
Ratio; 6 to 1, 3¼ to 1 and 2 to 1
Finish; nickel

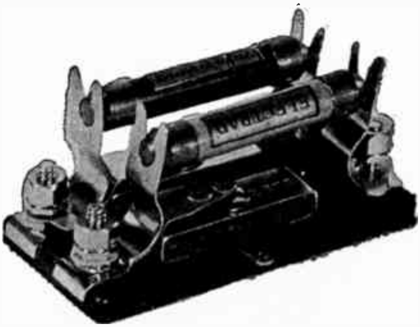


## Daven Resistance-Coupled Amplifier

### Specifications

Type; 3 stages
Tubes; 6 volt standard, best with high MU tubes
B-battery; 90 to 135 volts

Base; moulded Bakelite
Connectors; nickeled binding posts
Resistances; made to take standard grid leaks
Condensers; mica

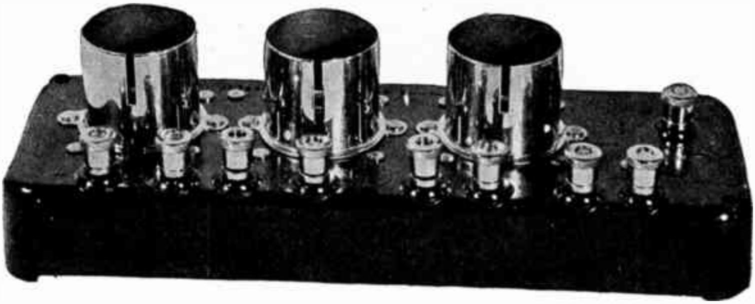


## Electrad Resistance Unit

### Specifications

Base; moulded Bakelite
Condensers; mica (interchangeable)
Resistance; clips made for standard grid leak units

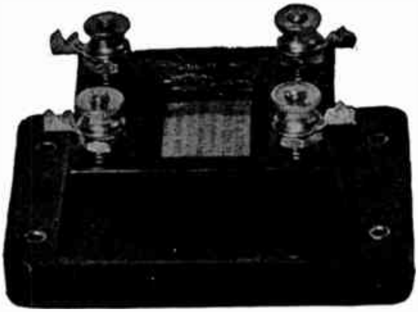
Connectors; binding posts with soldering lugs
Finish; nickel
B-battery; 90 to 135 volts



## Allen-Bradley Resistance-Coupled Amplifier

### Specifications

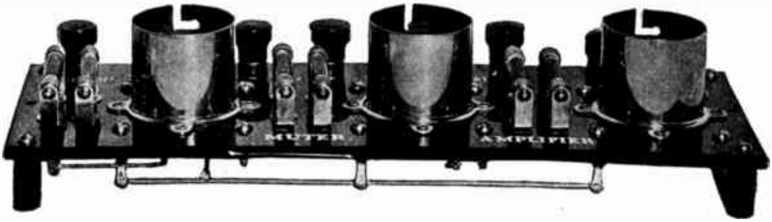
Type; 3 stages amplification
Resistances; standard grid leaks mounted under base
Condensers; Dubilier mica condensers
Base; moulded Bakelite
Connectors; binding posts
Finish; polished nickel
Use; any standard tuner
B-battery voltage; 90 to 135



## Brach Resistance Unit

### Specifications

Container; moulded Bakelite
Condensers; mica (not interchangeable)
Resistance units; not interchangeable
Connectors; nickel binding posts with soldering lugs
Mounting; base
Voltage; 90 to 135



## Muter Resistance Coupled Amplifier

### Specifications

Type; 3 stage
Tubes; standard 6-volt type
Base; sheet Bakelite
Resistances; standard grid leak units
Use; any standard tuner
Condensers; mica
B-battery voltage; 90 to 135

## Polymet Resistance Unit

### Specifications

Base; Bakelite
Condensers; mica (interchangeable)
Connectors; binding nuts with soldering lugs
Resistance unit; standard grid leaks (interchangeable)
B-battery voltage; 90 to 135

## SECTION VIII

# Radio-Frequency Amplification

THE engineering sages have it that radio-frequency amplification with unit controlled tuning mechanism, represents the Philosopher's Stone of wireless communication. It seems, too, that manufacturers are aiming more and more toward receivers of this type because of their great sensitivity and the possibility of using them without a system of clumsy wires outside the house.

Mr. L. M. Cockaday contributes in the following pages, a very agreeable treatise on the subject of radio-frequency amplification:

"Radio-frequency amplification is amplification of the current impulses received from the antenna circuit of a receiver *before* they have been rectified by the detector tube. The successive stages are coupled together with *radio*-frequency transformers.

"Before we take up the subject of how the radio-frequency amplifier works, however, let us learn of one of the disadvantages of audio-frequency amplification. That will help us to better understand the aim and purpose of amplification before detection.

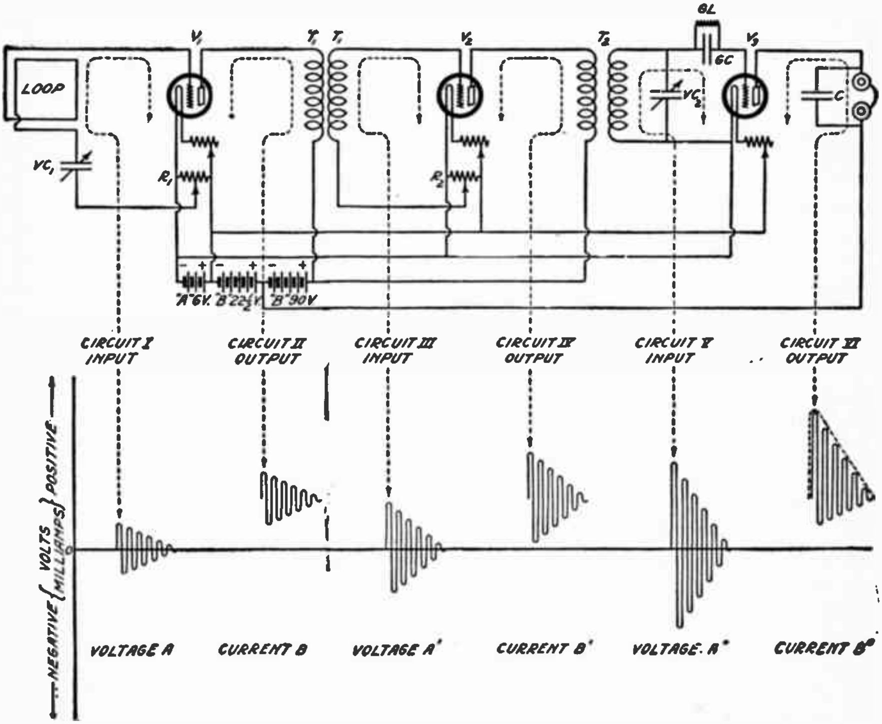
"The detector tube receives radio-frequency oscillations and turns them into impulses of direct current. *But the impulses must be of a certain strength before the detector will respond to them.*

"Let us consider the case of a receiving set that employs a vacuum tube detector and two stages of audio-frequency amplification. The set is installed in a city. Signals from stations located in the city may be detected and received with such volume as to be unbearable. This happens because the detector delivers a fairly large impulse to the amplifiers and they further strengthen them to an enormous value. Signals from stations, say 500 miles away, are only just audible with the detector alone, but when the amplifiers are used they are comfortably audible; the amplifiers take the feeble current from the detector and nourish it. Signals from across the other side of the country, however, may be too weak to be detected by the detector tube and so the amplifiers are supplied with no current and no signal is heard.

"This difficulty of the audio amplifier may be summed up in the following statement. The audio-frequency amplifier will not function on a signal unless the signal is of sufficient strength to operate the detector tube and thus supply an audio impulse to the amplifier. This is true no matter how many stages of amplification are used. Audio-frequency amplification has its use, however, as it is the most efficient method used in getting a loud signal when the initial signal is strong enough to operate the detector tube.

"Radio frequency, on the other hand, has just the opposite characteristics; by its use, weak distant signals are amplified, but they cannot be increased by this method to a value high enough to operate a loud speaker satisfactorily. Radio-frequency amplification strengthens the feeble oscillations received from the antenna circuit until they are strong enough to be detected by the vacuum-tube detector. In other words radio-frequency amplification takes place before the signals are rectified by the detector and audio-frequency amplification takes place after they are so rectified.

"So much for the general explanation. Let us now see how the radio amplifier works. In the diagram we show a conventional circuit with two stages of radio-frequency amplification, and a vacuum-tube detector, that employs a loop antenna. The tuning elements consist of the loop inductance and the variable condenser VC. The first stage of amplification consists of the tube V1; this is coupled to the second stage tube V2 by means of the radio-frequency amplifying transformer T1. The second stage is coupled to the detector tube V3 by means of a second transformer T2, which is started by a condenser VC2, and which supplies the amplified radio-



RADIO FREQUENCY ANALYZED

**Figure A:** The lower chart shows exactly what current changes take place in a radio-frequency amplifying circuit.

frequency impulses to the detector tube for rectification.

"A weak impulse (much too feeble to operate a detector tube, let us say) is received by the loop and tuned by the condenser VC1. This high-frequency impulse flows through the input circuit I and impresses a tiny voltage wave (A) on the grid of the amplifier tube V1. The relay action of the tube reproduces this wave form in its plate circuit II and causes a current (B) to flow through the primary winding of the transformer T1. The voltage of the impulses is stepped up by the transformer T1, and supplied by its secondary winding to the grid of the V2 in circuit No. III. This voltage is shown at A; by comparison with A it will be seen that it has been increased considerably. The tube V2 then responds to this voltage $A^1$ and the current wave $B^1$ flows in its plate circuit IV, through the primary winding of the transformer T2. Comparison of B and B1 will show a great increase in the current value. The transformer T2 then steps up the voltage of the impulses and impresses a voltage $A^{11}$ on the grid condenser (GC), which passes it to the grid of the detector tube V3 in circuit No. V. Compare voltages A and $A^{11}$. $A^{11}$ is very much stronger than A.

"If A had been supplied to the detector tube direct, it would have been too weak to be detected by the tube V3 and there would have been no response in the plate circuit VI. However, the weak impulses shown at A have been amplified by the radio-frequency amplifier until they are strengthened as shown at $A^{11}$, when the tube V3 is able to detect them, or in other words, rectify them as shown at $B^{11}$ in circuit VI. This current $B^{11}$ flows through the bypass (see Part 9, Condensers) condenser C and the voltages on the condenser cause a low-frequency current, as indicated by the dotted lines in $B^{11}$, to flow through the telephones T thus producing audible sounds.

"It must be borne in mind that the impulses on the grid of each tube oscillate about its free grid potential, and to secure maximum results the potentiometers R1 and R2 are provided as means for adjusting this free grid potential with respect to the filament.

"This same sensitivity of the radio-frequency amplifier makes it suitable for use with the loop antenna, which collects only an extremely small amount of energy, where the audio-frequency amplifier alone would fail.

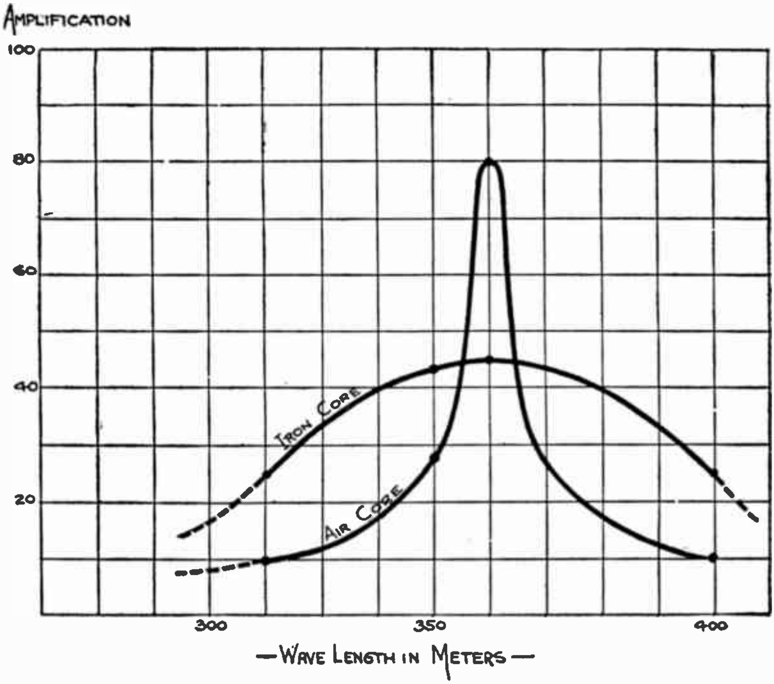
"The use of radio-frequency amplification with a loop antenna for building up the strength of the feeble impulses so that the detector tubes can detect them, combined with the use of the audio-frequency amplifier to increase these audible impulses to sufficient strength to operate a loudspeaker, makes an ideal set for listening to broadcasting. And not the least of its virtues is the fact that it may be assembled complete in a case similar to that of a phonograph, with batteries, tubes, loop and all; no outside connections are necessary.

"The use of audio-frequency amplification is limited to signals which are strong enough to be detected and this method will increase the volume tremendously. The use of radio-frequency amplification is for increasing the strength of feeble impulses that are not strong enough for a detector to pick up alone.

Our discussion of radio-frequency amplification must have impressed us with the fact that the transformers used between the tubes are most important parts of the amplifying equipment. After all is said and done, successful radio-frequency amplification is a mere matter of transformer design; the transformer, as simple as it is, has been the engineering stumbling block. We are fortunate in having this side of the question discussed for us by Mr. George Lewis, an engineer of splendid standing in the art. Mr. Lewis' work follows:

"Radio-frequency amplification has been used for a number of years in the design of radio receivers for commercial communication purposes wherein the wavelengths range from 600 to 25,000 meters. At the longer wavelengths, corresponding to those used in trans-Atlantic communication, little difficulty is experienced in obtaining good results.

"The advent of radio broadcasting at wavelengths between 360 and 500 meters, however, introduced so many new problems in transformer design, that the manufacturers of radio-broadcasting receivers seemed to favor the use of a detector and several stages of audio-frequency amplification. The operation of the vacuum tube as a radio-frequency amplifier offers far greater application than any other service at the present time. And while it is true that the vacuum tube may be utilized effectively as an audio-frequency amplifier and as a detector in receiving circuits, yet signals



A COMPARISON OF SELECTIVITY FROM IRON-CORE AND AIR-CORE TRANSFORMERS

Figure B: These two resonance curves show the relative selectivity obtained with an air-core transformer and an iron-core transformer for radio-frequency amplification. Notice how much greater amplification is obtained on 360 meters with the air-core transformer. On wavelengths other than this, however, the iron-core transformer gives the greater amplification.

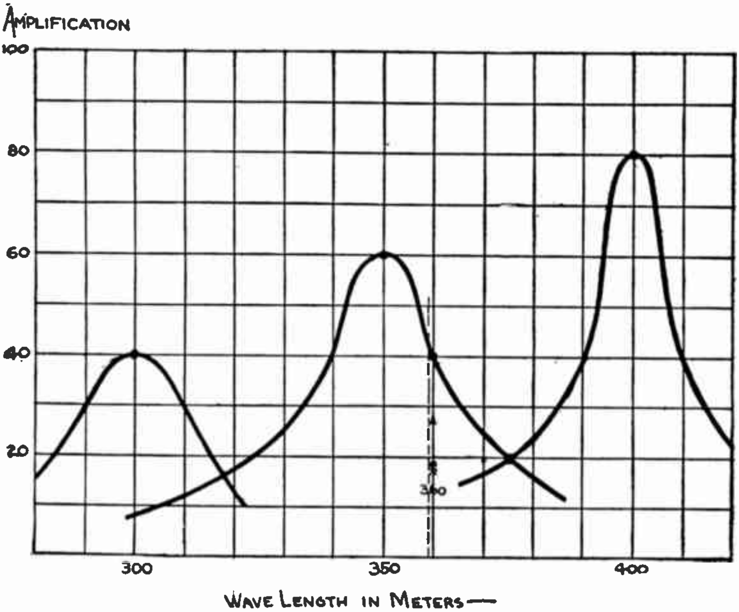
cannot possibly be received unless their strength is sufficient to operate the detector.

"In the early days of radio, communication over a certain distance was looked upon as a problem of transmitter power, as it was considered that a certain energy would be required to operate a detector and unless the transmitting station was capable of delivering this energy at the receiving point, communication could not be established. Today the problem has been altered from *transmitter power* to *receiver sensitivity*—a much less expensive proposition, brought into effect by radio-frequency amplification.

"In other words, the more modern receiving equipment brings about the same effect as moving the transmitter up toward the receiver.

"It is an accepted fact that the output of a detector does not vary in direct proportion to the input voltage applied to the grid, but as the grid potential is lowered a certain (cut-off grid voltage) is reached below which no response is registered in the plate circuit and the electron tube ceases to function as a detector.

"This means, that signals from radio stations located at a distance so far from the receiver as to prevent potentials greater than the cut-off grid voltage to be applied to the detector tube of the receiver, cannot be recorded, even though a number of stages of audio-frequency amplification are employed.



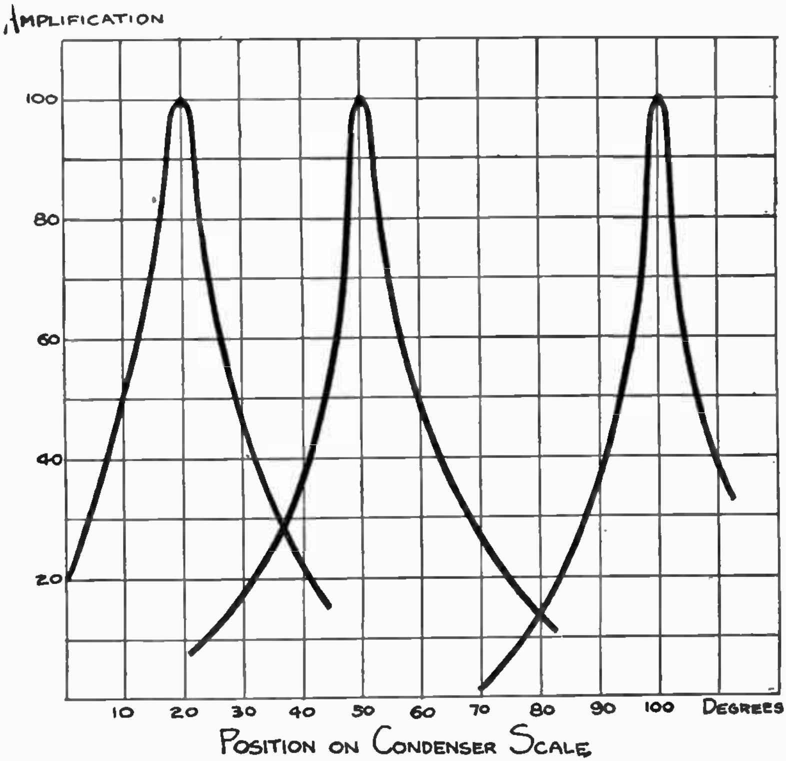
A RESONANCE CURVE FOR A RADIO-FREQUENCY TRANSFORMER

Figure C: In this case the transformer has a winding tapped in three places. The highest amplification is obtained on 400 meters. The next highest peak would be at approximately 350 meters and the lowest tap would give a peak at 300 meters. At wavelengths between these taps, however, the amplification would drop off quite severely.

"At applied potentials greater than this (cut-off grid voltage) value the output or response in the plate circuit of the detector increases more rapidly than the square of the input potential. Therefore, any arrangement that tends to increase the potential delivered to the detector will not only greatly increase the volume of detected signals, but make it possible to receive stations which would be inaudible otherwise, due to the inherent (cut-off) factor of the detector tube. This condition immediately recommends the use of radio-frequency amplification.

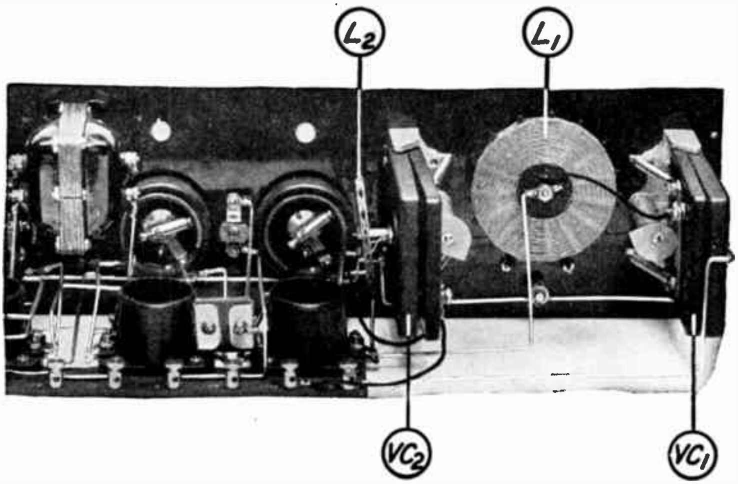
"Radio-frequency amplification, in general, may be grouped in the following classes:

1: *inductive coupled*
   Air-core transformers (aperiodic)
   Air-core transformers (tuned)
   Iron-core transformers (aperiodic)
   Iron-core transformers (tuned)



A RESONANCE CURVE FOR A TUNED TRANSFORMER

Figure D: This device would be used with a variable condenser. The condenser settings are shown along the bottom edge of the chart. These settings correspond to the wavelength ranges shown in the charts in Figures C and D. Using this method of amplification, the resonance peak could be shifted along over the entire range with higher constant amplification at the various wavelengths. For instance, at a setting of 20 on the condenser, corresponding to a wavelength of about 300 meters, the amplification could be considered as 100. By simply varying the condenser throughout the entire scale, the peak can be shifted to cover all wavelengths (within a certain range) with equal efficiency. This is shown on the graph, by the two additional curves for a condenser setting of 50 and 100 respectively.



A RECEIVER EMPLOYING TUNED RADIO-FREQUENCY AMPLIFICATION

Figure E: The antenna circuit is tuned with a coil, L1 used in connection with a variable condenser, VC1, or "book" type. The plate circuit of the radio-frequency tube is tuned by a similar coil and condenser, L2 and VC2 respectively.

2: *direct coupled*
- Tuned impedance
- Choke-coil arrangement
- Resistance coupled
- Electrostatically coupled

"Practically all of the systems of radio-frequency amplification have been used from time to time with some degree of success, either in this country or in Europe. However, the particular construction of the American vacuum tube, together with the shortness of the waves utilized for broadcasting, has tended until recently to confine the practice in this country to inductive-coupled transformer arrangements.

"During the past few years, however, a number of manufacturers have developed and marketed receivers in which the radio-frequency amplification was accomplished by a fixed ratio. Transformers of the direct-coupled type are composed of two inductive windings which, when operated in connection with the grid-to-plate capacity of the vacuum tube, bring about resonance of the desired frequency. This arrangement for transformation is limited by the extremely narrow wavelength band over which the transformer will efficiently operate. A fixed-ratio transformer with an air core is remarkably efficient in its operation. However, the sharp resonance curve confines all practical operations to wavelengths quite close to its resonance period.

"This limitation is shown by the sharp-peaked resonance curve at A.

"Here it is evident that the receiver operated with this transformer will receive radio concerts at a wavelength of 360 meters with a signal intensity or volume of 80. Other stations broadcasting on a wavelength of 400 meters will be received with a volume of 10.

"The air-core transformer has been utilized with a fair degree of success when the windings are provided with a switching arrangement wherein the turn ratio and the resonance period can be set for several separate wave zones.

"For instance, a transformer may be constructed with three taps so connected to the windings that a resonance is obtained at 300, 350 and 400 meters. An amplification curve for a transformer of this class is shown at C.

"It will be noted that the highest amplification point is at 400 meters, and that all of the other resonance points are lower. This is due to the resistance introduced when the coils are tapped. The 400-meter position utilizes the whole coil. The other positions do not, but have (dead ends) or inactive sections, which absorb a part of the energy.

"While the amplification obtained at 360 meters is only 40, as compared to the 80 listed for the transformer in Fig. B, this tapped transformer can be used more efficiently at *all* wavelengths between 275 and 425. It is readily appreciated that the strength of received signals is not uniform between the wavelengths here listed, but stations transmitting at wavelengths of 300, 350 and 400 meters are received with a maximum signal strength, and those at 275, 320 and 370 meters are received with reduced volume.

"A great majority of the radio-frequency transformers in use at the present time, instead of using tapped windings so as to obtain tuning peaks or high-amplification points as described, introduce a magnetic core which tends to broaden the useful wavelength band. The construction of this transformer is exactly the same as the air-core transformer except for the introduction of the magnetic core. The influence of the magnetic circuit in broadening the resonance curve is shown by the low, broad curve of Fig. B, wherein the sharp resonance period of 360 meters is not obtained, as is the case when the core is removed. While the volume of the received signal is reduced to 45 in comparison with the 80 obtained when the core is removed, the signal volume at 300 and 400 meters *is increased.*

"Receivers that embody transformers of the types described above have been operated with a certain degree of success during past years where all of the radio broadcasting stations of this country were licensed to operate on wavelengths of 360 or 400 meters. Stations transmitting at wavelengths greater or lower than these values are what may be termed beyond the useful amplification wavelength zone of these transformers.

"The sharp resonance curve shown in Fig. B represents the amplification at various wavelengths on each side of the resonance point with a transformer composed of two coupled windings having a definite value of self inductance. As the windings are composed of a great number of closely associated turns, they bring about a high value of distributed capacity between the various turns of the windings. The effect of this combination can be represented by a condenser having the same value as the distributed capacity and connected between the terminals of the coil.

"In the particular instance of the transformer of Fig. B the inductance and capacity of the windings are purposely proportioned in the design of the transformer to be resonant at 360 meters, thereby enabling the radio concerts to be received with the greatest intensity at this broadcasting wave.

"Windings designed to have an appreciable value of distributed capacity cannot be included in the class of efficient inductances as the condensers formed between the windings are notoriously inefficient, due to the poor dielectric properties of the insulation covering the wire. A more efficient design may be arranged by altering the construction of the inductance so as to reduce the internal or distributed capacity as far as possible and then bring about the resonant condition at 360 meters by tuning the circuit by means of an efficient variable condenser. An arrangement of this class is termed tuned-radio-frequency amplification, and represents the most efficient form of radio-frequency amplification available at the present time. Not only is the amplitude of the received signal increased from 80 to 100 by the introduction of an efficient inductance and condenser, but the wavelength range of the system can be greatly increased.

"As an example, assume that the condenser and coils were selected so that resonance was obtained at 600 meters when the condenser was set at 100 degrees, corresponding to its full scale, or maximum capacity, position.

"The resonance curve obtained at this setting is shown by the right-hand curve of Fig. D. This arrangement would bring about resonance at 400 meters when the condenser was set at 50 degrees, as shown by the middle curve of Fig. D. The 300-meter resonance curve is shown at 20 degrees. If resonant at 360 meters, the condenser would be adjusted to a position between 30 and 40 degrees where the 360-meter signals would be received with the same intensity as the three waves already shown. Here we have a radio-frequency amplifier of practically uniform amplitude, that is, amplification with equal intensity at any wavelength over the range of the instrument. The simplicity of construction and the ease with which the tuned-radio-frequency amplifier is operated cannot be overestimated.

"Fig. E illustrates a receiver of this class wherein the inductance consists of a special form of basket-woven coil of an extremely efficient type used in combination with a tuning condenser.

"In this type of amplifier the condenser plays an important part. Experimenters and investigators have appreciated the technical advantages embodied in this principle of amplification. However, the popularity of this system has been retarded by the discouraging reports circulated by those constructing such an amplifier with condensers having high dielectric losses or strong external or stray electric fields. The condenser having the high loss reduces the over-all efficiency of the device to that of the ordinary transformer and the stray field prevents the proper wavelength adjustment.

"It is claimed at times that there is little difference between radio-frequency amplification and audio or voice-frequency amplification except a slight increase in the range of the receiver.

"It may be stated that radio-frequency amplification will not materially increase the power or volume of strong signals, and that *all* magnification of power *must be accomplished* by radio-frequency amplification. However, the following inherent advantages found in radio-frequency amplification are most important in the design of an efficient radio receiver:

1—An increase in the receiving range of a receiver;
2—Amplification without distortion of signals;
3—Possibilities of employing loop or frame-type antennas;
4—Reduction of the possibilities of interference caused by re-radiation when used with regenerative receivers."

## Aero Radio-frequency Transformer

### Specifications

Use; tuned radio-frequency
Wire; cotton covered, no dope
Frame; bakelite
Mounting; brackets, panel or base
Connectors; binding posts

## Bremer-Tully Radio-frequency Transformer

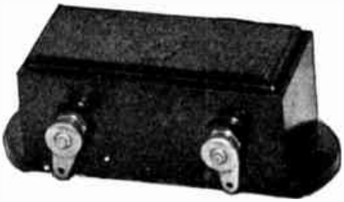
### Specifications

Type; toroid
Frame; moulded Bakelite
Wire; green silk covered
Mounting; for base or panel
Connectors; binding posts
Winding; air spaced
Use; radio frequency transformer coupling

## All-American Radio-frequency Transformer

### Specifications

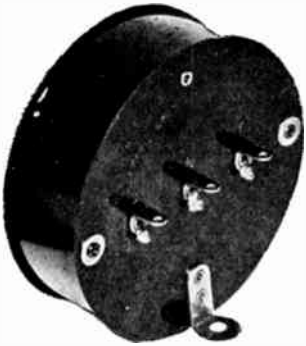
Use; radio-frequency coupling
Wavelength; 150 to 650 meters
Container; moulded Bakelite
Connectors; binding posts and soldering lugs
Mounting; for base or panel



## All-American Radio-frequency Transformer

### Specifications

Use; radio-frequency coupling
Wavelength; broadcasting range
Container; moulded Bakelite
Mounting; for base
Connectors; binding posts and soldering lugs



## Celco Radio-frequency Transformer

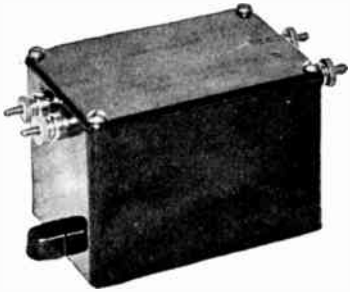
### Specifications

Use; intermediate frequency
Container; sheet Bakelite
Connectors; soldering lugs
Mounting; for base
Wavelength; for broadcasting range
Type; D coil, air core

## Harper Radio-frequency Transformer

### Specifications

Type; radio-frequency coupling
Coil; solenoid, space wound
Base; Bakelite 3½ x 4½ inches
Container; sheet copper shielding, crystalline black finish
Connectors; binding posts and soldering lugs



## Como Radio-frequency Transformer

### Specifications

Use; superheterodyne
Wavelength; for broadcast range
Container; moulded Bakelite
Mounting; for base
Size;
Connectors; binding posts

## Dubilier Radio-frequency Transformer

### Specifications

Use; radio-frequency coupling
Type; iron core
Ratio; 1.26
Wavelength; 225 to 550 meters
Container; moulded Bakelite
Mounting; for base
Connectors; binding posts

## Eastern Coil Radio-frequency Transformer

### Specifications

Type; octagonal
Wire; silk covered copper
Mounting; for condenser or base
Supports; Bakelite strips
Connectors; binding screws.

## Erla Radio-frequency Transformer

### Specifications

Use; radio-frequency coupling
Type; toroid
Wire; green silk covered
Insulation; Bakelite
Connectors; binding posts
Mounting; panel or base

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## General Radio Radio-frequency Transformer

### Specifications

Use; superheterodyne circuits
Wavelength; 7000 to 12,000
Container; metal
Insulation; Bakelite
Connectors; soldering lugs
Mounting; base
Size; 2½ x 2¼ x 1½ ins.

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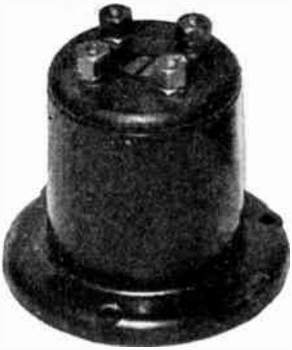
## General Winding Radio-frequency Transformer

### Specifications

Use; radio-frequency coupling
Winding; green silk covered copper
Type; solenoid
Form; Bakelite tube
Mounting; base
Wavelength;
Connectors; binding posts



## Haynes-Griffin Radio-frequency Transformer

### Specifications

Use; radio-frequency coupling
Wavelength; broadcast range
Container; moulded Bakelite
Mounting; base
Connectors; binding posts

## Heliotor Radio-frequency Transformer

### Specifications

Use; radio-frequency coupling
Type; toroid
Frame; pressed Bakelite
Winding; silk covered copper
Wavelength; broadcasting range
Connectors; binding posts
Mounting; base

## Hilco Radio-frequency Transformer

### Specifications

Use; superheterodyne
Wavelength; for broadcast work
Container; metal, crystalline finish
Mounting; base
Connectors; binding posts with soldering lugs

## Hilco Radio-frequency Transformer

### Specifications

Use; radio-frequency coupling
Wavelength; broadcasting range
Winding; honeycomb
Mounting; base
Connectors; binding posts

## Kellogg Radio-frequency Transformer

### Specifications

Use; radio-frequency coupling
Wavelength; broadcasting range
Insulation; hard rubber
Winding; honeycomb silk covered
Mounting; base
Connectors; soldering lugs

## Naxon Radio-frequency Transformers

### Specifications

Use; radio-frequency coupling
Wavelength; broadcasting range
Type; toroid with silver plated primary
Frame; sheet Bakelite
Mounting; base
Connectors; binding posts

## Power-Plus Radio-frequency Transformer

### Specifications

Use; radio-frequency coupling
Type; D-coil
Frame; moulded Bakelite
Mounting; for condenser or base
Connectors; binding posts

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## Premier Radio-frequency Transformer

### Specifications

Use; radio-frequency coupling
Wavelength; broadcasting range
Container; metal
Mounting; base
Connectors; soldering lugs

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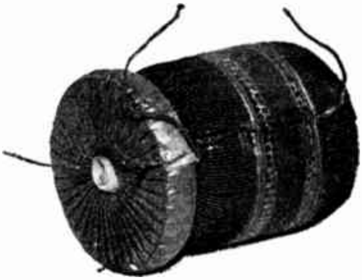
## Precision Radio-frequency Transformer

### Specifications

Use; radio-frequency coupling
Type; octagon
Frame; moulded hard rubber
Wire; silk covered
Wavelength; broadcasting range
Mounting; base
Connectors; soldering lugs



## Radio Foundation Radio-frequency Transformers

### Specifications

Use; radio-frequency coupling
Type; double toroid
Wavelength; broadcasting range
Mounting; base
Connectors; pigtails

## Samson Radio-frequency Transformers

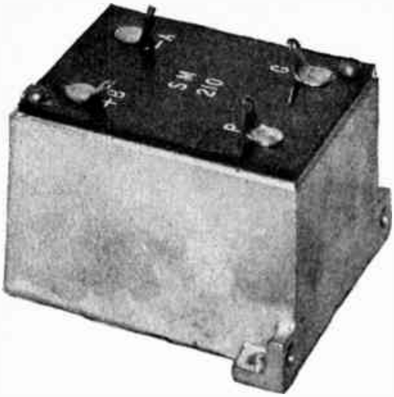
### Specifications

Use; superheterodyne
Wavelength; 3000 to 10,000 meters
Container; moulded Bakelite
Mounting; base
Connectors; binding posts and soldering lugs

## Sickles Radio-frequency Transformers

### Specifications

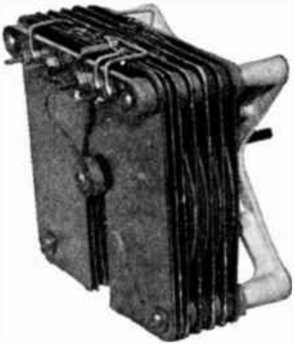
Use; radio-frequency coupling
Wavelength; broadcasting range
Container; metal case
Mounting; base
Connectors; binding posts



## Silver-Marshall Radio-frequency Transformers

### Specifications

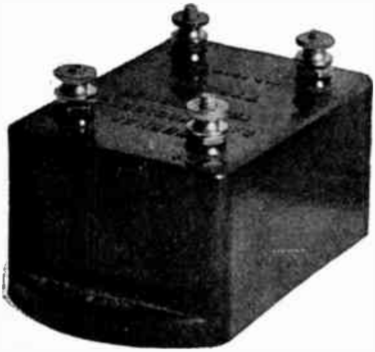
Use; superheterodyne
Container; cast aluminum
Insulation; Bakelite
Connectors; soldering lugs
Mounting; base or panel, vertical or horizontal
Wavelength; for broadcast work



## Telos Radio-frequency Transformer

### Specifications

Use; radio-frequency coupling
Type; variometer
Supports; coil supports, heavy cardboard
Insulation; Bakelite
Connectors; binding nuts
Wavelength; broadcasting range



## Werner Radio-frequency Transformer

### Specifications

Use; radio-frequency coupling
Case; moulded Bakelite
Wavelength; broadcasting range
Mounting; base
Connectors; binding posts

## SECTION IX

# Fixed and Variable Condensers

In the last part on coils it was said that a radio set consists principally of three vital devices, coils, condensers and vacuum tubes. These, with perhaps the 'phones thrown in, are indispensable elements. The condensers and coils are used for tuning to the waves and the vacuum tube is used to detect and amplify the signals. It is in recognition of the importance of this third element, the condenser, that this treatment has been included concerning fixed and variable condensers.

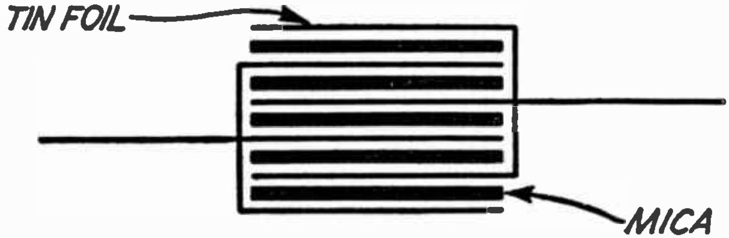
It would perhaps be wise to briefly review what has previously been said about electrostatic current storing devices. When a condenser is mentioned there should immediately crop up in the mind of the reader a mental picture of two or more metallic plates separated by a non-conducting substance such as air, glass, mica, or quartz. We may recall that only alternating current may pass through condensers because they continuously cause the plates to be charged and discharged and direct currents have the power to charge the plates only once.

We were also told that a condenser is something like a milk bottle or other liquid receptacle. It will discharge (overflow) only after it has become filled (charged). The time required for its becoming charged depends entirely upon its electrical capacity and this in turn depends upon the quality of the materials used in the condenser and their arrangement. A condenser as big as a piano box may be made that will not have the capacity of a condenser small enough to be placed in the palm of the hand so that we see the size of a condenser is deceiving when taken as an index of its capacity.

Before passing on to the more intricate electrical features of variable condensers let us devote a few moments to a brief outline of the mechanical side of condenser construction. After all, the mechanics of every electrical device must be understood before one can pass on and intelligently consider the electrical side of the subject.

In our sketch (Fig. A) we see the general scheme used in the manufacture of fixed condensers, that is, condensers with fixed capacities. Looking at it carefully we see that it is nothing more or less than a series of electrical sandwiches, the "bread" being little slabs of insulation while the filling is a conductor. It will be noted that there are two groups of fillings and that they are separated from each other by the blocks of insulation. The pieces of conducting material are usually referred to as plates. The plates in each group are connected together (soldered) and a wire lead brought out to the terminal.

Since it is desired to obtain a large electrical capacity in a small space, tinfoil is used for the plate material and mica in very thin sheets for the insulating material in most cases. Mica is



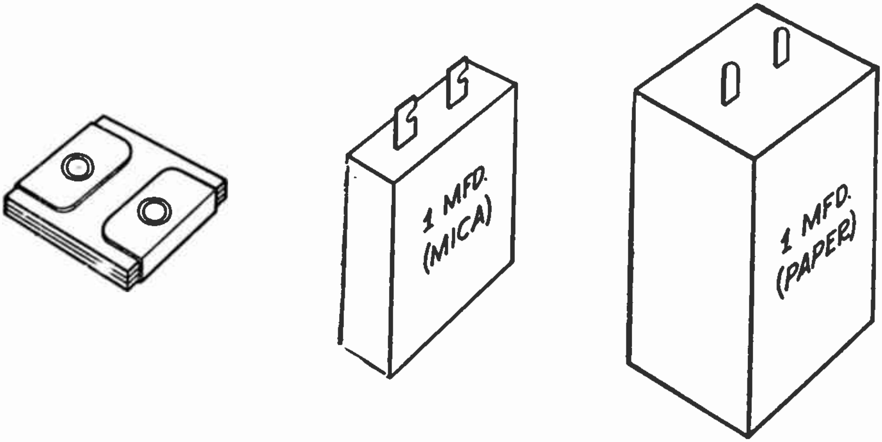
HOW A CONDENSER IS ASSEMBLED

Figure A: This illustrates the scheme used to make fixed condensers. The insulating material, which is usually mica, is sandwiched in between the metal plates. These plates, in the case of fixed condensers, are of copper foil or tin foil. In the construction of condensers of this type, it is essential that the plates (both insulation and conductor) are pressed together tightly. Otherwise heavy losses will be introduced and the quality of reception will be brought down to a low level. Some special mechanical means is usually employed to keep the plate together.

exceptionally efficient for this purpose because it has a high insulating value and very thin sheets of it may be used to produce high capacities. Exceptionally thin sheets may be used in radio receiving because we are not dealing in any case with exceptionally high voltages and there is no danger of the insulation being punctured. If a small receiving condenser should be placed across a 3000-volt line, the insulation would, no doubt, break down under the terrific pressure and the condenser would become short circuited. Under these conditions it is usually said that the condenser has become punctured.

If we examine the second sketch (Fig. B) we will see the common forms taken by fixed condensers. The first form is of the mica type with the elements squeezed between two bakelite end plates, eyelets being used not only to hold the end plates in position, but to also form the terminals of the condensers. The largest condenser is of the paper type. That is, paper is used as the insulator and condensers of this type have a capacity in the neighborhood of ¼ to 2 mfds. However, such devices are more often employed in continuous wave radio transmitting sets.

While on the subject of small fixed condensers it will perhaps be well to warn the reader against the use of paper condensers in reception. Paper condensers are not usually produced with end plates and the elements are very loosely assembled. When such a condenser is placed in an alternating current circuit, the rapidly changing charges on the surface of the plates exerts an actual mechanical force and the condenser will give out a humming noise corresponding to the frequency of the current in the circuit. It is natural to assume that a condenser acting in this manner is not performing its service efficiently and that it is not the best thing to use. Paper condensers should never be employed in radio receivers and especially in audio-frequency circuits. In the audio-frequency circuit the current is vibrating at a comparatively low rate and the inertia of the plates of such condensers is small enough so that they respond readily to these currents. If an exceptionally poor paper condenser is used in the audio-frequency side of a receiver one may readily hear the music or voices coming over it by simply placing the ear close to the condenser. Some physicists, taking advantage of this prin-



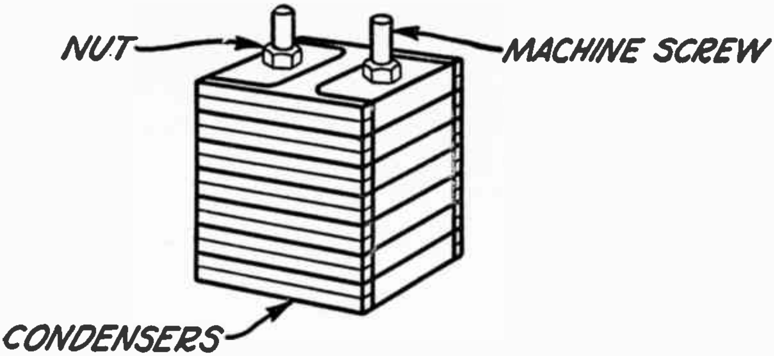
DIFFERENT TYPES OF FIXED CONDENSERS

**Figure B:** The small condenser at the left is mica insulated and it is available in the smaller capacities. The condenser in the middle may have a capacity anywhere from .25 mfd. to 1 mfd. At the right is illustrated the form taken by paper or telephone condensers. The larger type of paper condensers are employed in systems to "iron" out the ripples in a pulsating direct current. This principal is employed in the construction of "B" battery eliminators so that the current or voltage put on the plate of the vacuum tube will be of a uniform nature.

ciple, have reproduced the human voice with an electrostatic loud speaking device.

Coming back to our little fixed condenser with the eyelets, we will see that it is very convenient to increase capacity by using more than one condenser and slipping each condenser over two machine screws as illustrated in Fig. C. Such an arrangement really amounts to an adjustable fixed condenser and since these small mica condensers may be purchased in capacities running all the way from .0025 to .01 mfds. practically any capacity may be arrived at.

These little fixed condensers have a multitude of uses in radio reception. In the most simple type of a crystal receiving set they are used to bridge across the 'phones as in Fig. D. In such a position they help to increase the signal strength and clarify reception. Such condensers are also used a great deal in performing what is known as a bypass function. We know that alternating current will pass through condensers and that direct current will not. Therefore, by properly using a condenser we can choke off direct current and permit alternating current to pass. The two circuits may be simply separated by a condenser. Thus, in reflex work radio-frequency current is made to pass over audio-frequency circuits although the current flowing in the audio-frequency circuit cannot reach the current flowing in the radio-frequency circuit due to its direct pulsating nature. Sometimes small fixed mica condensers are bridged across audio transformers so that the radio-frequency current in the circuit will be able to avoid the windings of the transformer because the resistance of the condenser is lower than the windings. The term resistance, by the way, when used in connection with alternating current is more often referred to as impedance. The reader should remember this to



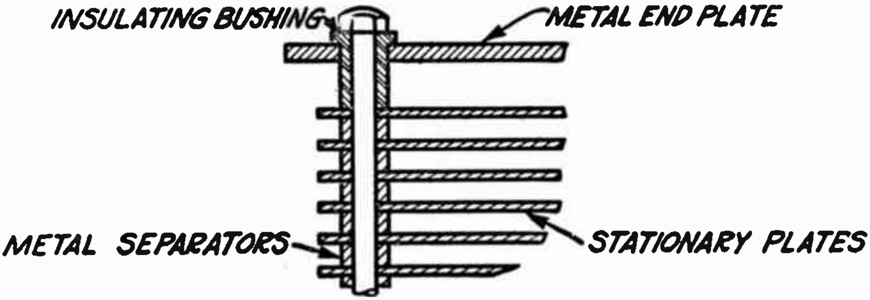
BUILDING UP CONDENSER CAPACITY

Figure C: By slipping a number of small mica condensers over two machine screws, the capacities will be added. This is so because the condensers are connected in multiple. The capacity of condensers connected in this fashion are always added. Two .025 mfd. condensers, for instance, would give a combined capacity of .050 mfd. This is a convenient system for use in building up correct capacities with the condensers on hand.

avoid confusion in digesting radio literature.

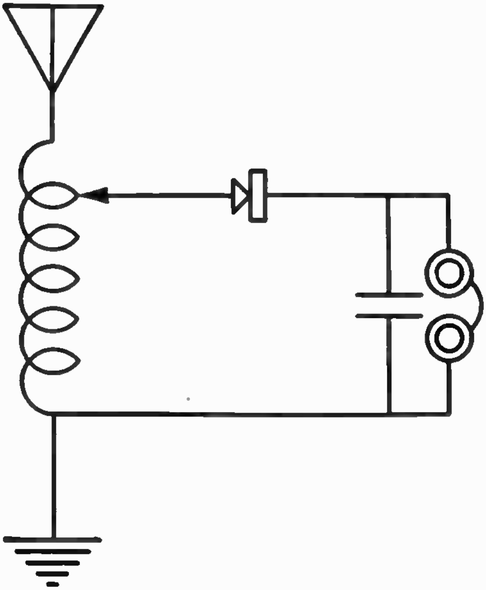
The subject of the variable condenser will be best introduced by carefully analyzing the general mechanical features of this type of instrument. Electrically it is the same as the fixed condenser; we have a number of electrical sandwiches consisting of insulation with metallic filling. The insulation in this case, however, is invisible because ordinary air performs the function. The group of stationary plates which are all connected together are sandwiched in between the movable plates which are also connected together. The separate groups of plates must not touch each other for the condenser immediately becomes short circuited and a direct conducting path is formed through it. Incidentally the plates in the stationary group are called the stator plates and the plates in the movable group are called the rotor plates.

We will obtain a very good idea of the practice followed in condenser construction by considering the attached sketch Fig. E. The condenser plates are made semi-circular and either aluminum or brass is the metal used. The plates may be soldered together but more often they are held in a slotted metallic member. The end plates, that is the plates at each end, should not function electrically but should be used merely as mechanical supports for the stationary and movable plates. Sometimes these end plates are made of an insulating material, but modern practice seems to be in favor of metallic plates. When metallic plates are used some effective means must be employed to prevent a flow of current between the movable and stationary plates. The stator plates must be insulated from the rotor plates. It is very important too that this insulation is of the very best kind and that it should be placed in a certain definite position for we must remember our definition of a condenser; it is made by separating two conductors by an insulator. Unless the solid insulation used to separate the rotor and stator plates is placed correctly there



BAD PRACTICE IN VARIABLE CONDENSERS

Figure E: Condensers assembled with fibre bushings in the manner shown are very inefficient devices and will greatly impair the efficiency of any radio receiver with which they are used. Fibre should never be employed as an insulator for condensers because of its property of absorbing moisture.



WHERE SMALL CONDENSERS ARE USED

Figure D: This diagram shows one of the methods usedi n employing small fixed condensers in crystal receivers. This condenser could be given several other positions in such a circuit but the one illustrated is most effective. Such condensers find a multitude of uses in vacuum tube circuits.

will be a damaging *capacity effect* which will interfere with the capacity obtained between the sandwiched plates. We shall consider this matter more in detail later on in this Section.

We will understand that the bearings of a variable condenser are important when we think of the changes in capacity that would result if the rotor plates were wobbly. This would cause a difference in the distance existing between the rotor and stator plates when the rotor was moved and our condenser would not give a uniform change in capacity; there would be little jumps in it that would greatly affect tuning. Small brass bushings are always employed in good condensers and they should be machined very accurately so that the shaft of the rotor will revolve without changing its vertical position.

In tuning a radio set it is often desirable to turn the rotor shaft of a condenser an almost microscopic distance. This is difficult to do with the unaided fingers and for this reason condensers are nearly always provided with vernier attachments. That is, attachments that may be used in causing the rotor to turn only a small fraction of an inch. These verniers take various forms. Gears are sometimes used and in every case the knob employed on the shaft of the condenser is in two parts. One part of the knob makes a direct connection to the rotor shaft and the other part works through a train of gears or by friction on a large disc connected to the shaft. If gear operated verniers are purchased the reader should carefully check the instrument for lost motion. This is ordinarily referred to as "play" and it is the result of mechanical imperfections between the gear teeth or the gear train. It is most difficult to tune accurately with a condenser having this lost motion.

Insulation takes an important part in condenser design and it might be well for us to go into this angle of the subject a little more thoroughly before we tackle the phases of the subject that are more difficult to understand than those just treated.

Although Professor Einstein did not specifically say so, insulation is a relative term. A substance that will effectively insulate at one voltage will pass current under another as freely as water passes through a sieve. Indeed, there is *nothing* that will not pass a certain quantity of electricity. Therefore, we insulate to *minimize* the leakage of currents.

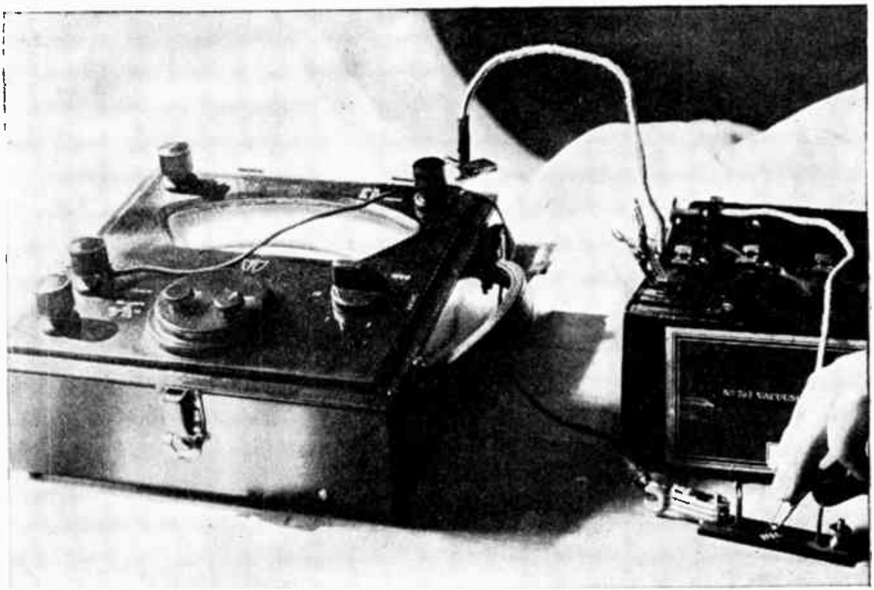
Electric leakage is an insidious thing from the viewpoint of the radio fan. When a water pipe, boat or air tank leaks it is a simple matter to find the outlet and to apply the needed remedy, but in a radio set we can have a leak as big as all outdoors and still we cannot see the invisible fluid that manages to escape. If there is anything that will quickly reduce the efficiency of a radio set, it is poor insulation. This is doubly true about transmitters, and even in receivers it is an important factor.

The degree of insulation necessary depends upon the voltage used. A water pipe that carries ten gallons of water per minute at a pressure of 60 pounds to the square inch would probably burst if the pressure in pounds to the square inch were suddenly multiplied by five. The same might hold true of a wire carrying electric current; if the voltage were suddenly multiplied by five or even by two, the insulation would become ineffective and we would experience heavy leakage. Although insulation cannot burst, it can break down electrically and burn up when the voltage reaches the rupture point where it can puncture things in its path that offer resistance.

There are two things that are most important in considering the subject of insulation: One is *voltage*, as we have already seen. The higher the voltage the greater the resistance of the insulation must be, to effectively keep it in its path of virtue, so to speak. The other factor would probably be little suspected by the average experimenter. It is *frequency*.

The way in which frequency affects an insulating substance may be a bit obscure, but nevertheless this fact is as true as the law of gravity. Some notion of the importance of frequency and its effect upon dielectric strength (insulating strength) may be gained from the fact that an insulator that will stand up under an application of 100,000 volts at a frequency of 60 cycles per second may break down and become totally ineffective under a voltage of 20,000 at 150,000 cycles per second. From this we learn that radio-frequency currents are much more difficult to handle and insulate. They are the wilder and more unruly members of the electric-current family.

It is usual to measure resistance of insulating materials in ohms just as the degree of resistivity offered by a copper wire is measured in ohms (or fractions of an ohm). In measuring resistance of real insulators we have such "gobs and gobs" of ohms that we use a more convenient term, the megohm (1,000,-



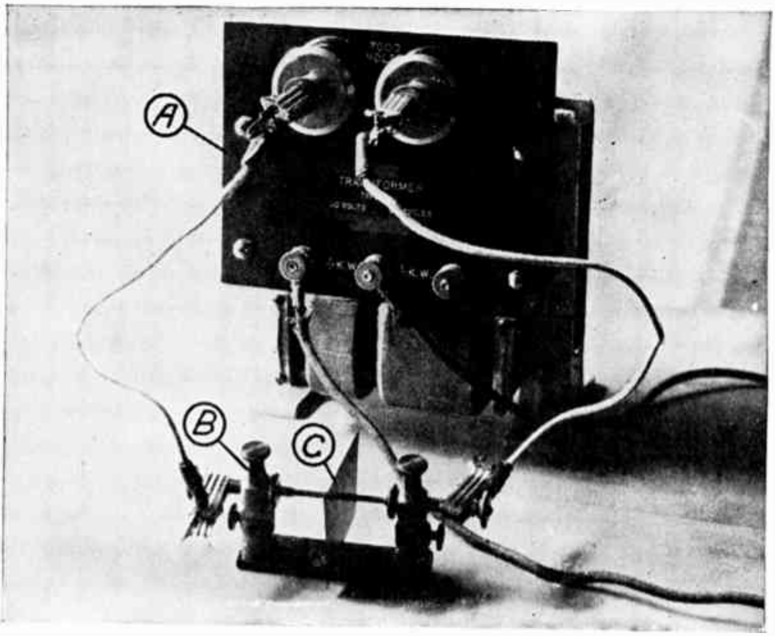
AN ELEMENTARY TEST OF INSULATION

Figure F: With a regular "B" battery and an extremely sensitive microammeter connected in series with a piece of insulating material, it is sometimes possible to get a current of 15 microamperes to flow through the insulation. This test is a crude test, however, and would only serve to show up a very poor piece of insulating material.

000 ohms). That this term is more convenient will be appreciated when it is understood that a unit cube of a good insulating material might have a resistance of 100,000,000,000,000,000 ohms.

The dielectric strength of any substance (and by this we mean its ability to resist a voltage that would tend to break it down) can be likened to the mechanical strength of the metal in a high-pressure tank. Any dielectric or insulating substance has a critical voltage point at which it will rupture or break down and allow current to pass through it freely. If it is a good insulator the amount of voltage that must be applied to do this is necessarily high, ranging from 1,000 to 500,000 volts for the different thicknesses of insulation.

Dielectric strength is measured in terms of the number of volts required to puncture any definite thickness of the material. It is a sort of indefinite quantity, since it is difficult to measure with any degree of accuracy. In the accompanying illustration we see a small high-potential transformer of 7,000 volts potential, set up to puncture a small thickness of insulation of the much-used "mud" variety, which is usually a combination of lampblack and shellac. The voltage at which puncturing takes place, depends upon the *frequency* of the current, the *time* during



A TEST OF THE DIELECTRIC STRENGTH OF AN INSULATING SHEET

Figure G: A high-potential transformer A is connected across the terminals of a spark gap B. The sheet of insulation of known thickness is then fastened between the electrodes of the spark gap and then the voltage of the transformer is raised until the dielectric strength of the sheet is overcome and a spark passes through the insulation. The voltage at which this electric breakdown occurs is the dielectric strength of the material, and it is measured in volts per mil.

which the voltage is applied and the *size* and *shape* of the electrodes and their *distance* apart.

For instance, the use of needle points will often cause a breakdown at voltages where flat surfaces will not. This, of course, can be understood since what we might call the voltage gradient in the insulator is larger in the case of the needle points and a smaller area of the insulator is called upon to withstand the entire strain. If the same load were distributed over a larger area the insulator might successfully withhold it.

The insulating materials that we use in our radio sets should be of the best variety. The "mud" referred to should be used only where it is not called upon to resist the passage of radio-frequency currents, no matter what their voltage value may be. The contributor has made a number of tests on the insulating strength of some of the lower grades of this substance and he finds that at radio frequencies they pass a considerable amount of current even when the voltage is seemingly insignificant. Some of this material makes beautiful-looking grid leaks and it is only necessary to mount the binding posts *in* it at a definite distance apart to obtain any number of megohms or fractions of a megohm as a grid leak! Even with a direct voltage, this material shows the passage of dangerous amounts of current. A simple experiment with a microammeter, similar to that shown in the photograph gives indisputable proof of this statement. If a small piece of the stuff is connected up in series with a 100-volt "B" battery, appreciable quantities of current will be allowed to pass, even when the electrode separation is comparatively large! With a separation of ½ inch the contributor has had an ammeter reading as high as 15 microamperes. According to Ohm's Law $R = \frac{E}{I}$. If we have a current of .00000025 amperes and a voltage of 100, it is evident that the insulation is only 4 megohms which is disgustingly low for anything that is dignified by the name of insulation. This material is probably all right to use for knobs, dials and the like, but its performance as a restrainer of electric pressure is not sufficiently noteworthy to warrant its use in radio equipment.

Any of the synthetic-resinous products are well suited to radio use whether in transmitters or receivers. They offer a fairly substantial resistance to moisture, their dielectric strength is high and their mechanical strength is enormous. The contributor can say little in favor of vulcanized fibre as far as its use for radio insulation is concerned. Its use for panels is to be discouraged since it has a terrific appetite for water and sucks in atmospheric moisture with sponge-like efficiency. Fibre has a dielectric strength of 330 volts per mil, or 13,000 volts per millimeter with a thickness of 1/32 of an inch. This, of course, is in the perfectly dry state (which is unusual and which can be maintained only in the laboratory under experimental conditions). Compared with this, the resinous materials show a dielectric strength of 1,000 volts per mil or 39,400 volts per millimeter in a thickness of 1/32 of an inch. A good piece of this material has a volume resistivity of about 1,000,000 megohms ($10^{12}$ ohms) per centimeter cube. The surface resistivity may be anywhere from 100 megohms to 10,000,000 megohms. These figures show us that any of these products can be used with perfect safety as panels and for other insulating purposes in a radio set.

There are numerous grades of this type of material. One is formed by allowing sheets of paper, white duck, or cloth to soak in raw resinous liquid varnish. The sheets are then placed one on top of the other in a powerful steam-heated hydraulic press. The press comes down, giving the sheets a tremendous squeeze and heating them at the same time. When the sheets come forth from the press they are in a much changed condition. What was once 50 or 75 sheets is now a single flat block of exceptionally hard material that will resound healthily when it is struck a sharp blow with a hammer. The sheets are welded together, forming a homogeneous material.

Other forms of insulating materials are molded. For instance, molded, synthetic-resinous or rubber materials are placed in the mold and subjected to heat and pressure at the same instant. The material fluxes and becomes almost semi-fluid, filling every interstice of the die. There is both a chemical and physical change. The chemical change is irreversible and permanent.

Most of the "spaghetti" that we buy is composed of cloth tubing impregnated with either oxidized linseed oil or raw bakelite varnish. This material should be freely used where bus or other wire comes in contact with the wooden parts of the cabinet. In no case should the connecting wires be allowed to make contact with the wood without being heavily insulated. Wood is an exceptionally poor insulator and is usually filled with atmospheric moisture.

The contributor hopes that those who have read this course will give more thought to the insulation of their radio outfits henceforth. Insulation is a mighty important thing, and since we cannot see the leakage that is taking place there is only one thing left to do. That is to insulate our variable condensers and outfits, in the best manner that we know how, using materials that have proven their worth in the workaday world.

The variable condenser is the most important radio device for tuning since it provides means for *infinite* variations of wave lengths over a given range. While it is possible to vary the period of a circuit by adjustment of inductive values, this system is not only more wasteful of energy but is highly impractical from the standpoint of pure mechanics. If infinite variation is to be had in a coil, the mechanical appurtenances necessary to bring this result about are so involved and complex as to make the whole arrangement bulky and unsatisfactory. Furthermore, such a system of wavelength variation could never be as efficient as the system of capacity change.

The variable condenser is the one ideal, and, providing that the resistance of the condenser is a negligible factor and that its general losses are beyond measuration, no more efficient tuning device can be desired. The variable condenser method gives a sharpness at resonance that is unattainable by other systems. However, this cannot be taken to mean that every condenser regardless of its electrical properties produces the same results. Actually, there is a wide variation in condenser efficiency depending solely upon (1) the electrical design and (2) the quality of the material used. Unless strict adherence is given to the scientific niceties of condenser construction as laid down by the best authorities today, unsatisfactory results will be had.

Condenser losses, due to the complexity of the electrical phenomena involved, are of a most insidious nature and much of the total energy received by condenser tuned outfits can be dissipated in useless forms without a hint of such a process to the user. Frightful losses may occur and efficiency may drop as much as 50% in condenser devices alone unless the prescribed rules of construction are adhered to by the manufacturer.

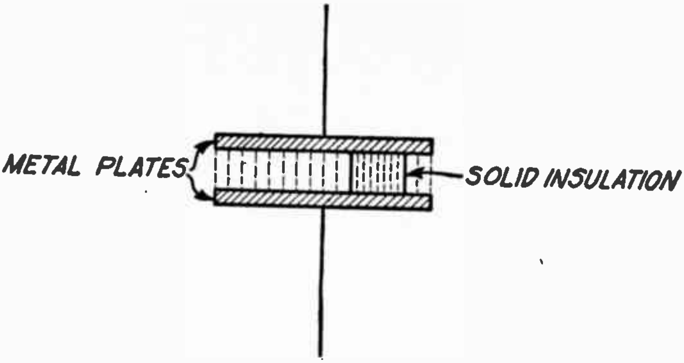
Although a condenser is of comparatively simple construction from a mechanical standpoint it is not, as many believe, a simple matter to defeat the natural tendencies toward loss and inefficiency. Like all of the devices used in radio, the net efficiency depends upon how sucessfully the manufacturer has met the demands determined by the Bureau of Standards and other authorities. Although a condenser may present a very grand appearance to the eye, it may create an appalling loss of energy when checked by precision instruments. At the same time a condenser may have the very best of materials in its construction and yet if they are not properly arranged, the device may function as poorly or even worse than the one involving good design with poor materials.

Although it is not easily conceivable to the lay mind, a condenser, when introduced into an electrical circuit, represents a large element of resistance. Since unwarranted resistance is fatal to radio efficiency it stands to reason that the elimination of this resistance is one of the ideals to which conscientious manufacturers must hold themselves.

With the introduction of the low loss idea, many extravagant claims have been made about the resistance of variable tuning condensers and many manufacturers, to meet the need of the new public demand, have made no more drastic changes than to add a sticker to their cartons claiming "low loss." Since the layman has no means at his disposal to check up these extravagant claims, it follows that thousands of highly inefficient devices have been sold due to the unscrupulous activity of those who have not had the necessary capital to change their tools and method of manufacture.

In stating the resistance of a condenser it is customary to claim that it has a value equivalent to a series resistance of such-and-such an amount. This means that it has a resistance that would allow the same current to pass if it were connected in series with a perfect condenser of the same capacity. Due to the great difficulty of making correct calculations in the higher radio frequencies, these resistance measurements are usually made with a 1,000 cycle source. Overlooking the fact that many of the figures given are altered to make them sound more reasonable, the figure itself means little or nothing for it has been determined again and again that it is not scientific or even correct to assume that there is a fixed relation between 1,000 cycle measurements and measurements at radio frequencies. It means practically nothing to compare the resistance of two differently constructed condensers at high frequencies when the standard 1,000 cycle frequency current has been used as a basis of measurement.

Resistance and insulation in condenser construction are intimately related and it is through this that many mistakes are made. Every dielectric or non-conductor used for electrical separation between the movable and stationary plates has what is known as an absorption factor; that is, the materials are capable of absorbing a certain percentage of the total energy that passes through the device. The larger the quantities of this material introduced, and the greater the mass, the greater the losses will be. The placing of this material is also an important factor for if it is placed where the electrostatic



A PHENOMENON ILLUSTRATED

Figure H: How a piece of solid insulating material will affect the capacity of an air insulated condenser. It will be seen that the solid insulator allows more of the electrostatic lines of force to travel through it than does the air. This can be compared with the effect caused by a piece of iron introduced in a magnetic field. Since iron is a better conductor of magnetic lines of force, the field concentrates through the iron. The electrostatic lines of force are illustrated doing the same thing.

field is most intense, and where the electrostatic lines of force passing through it are great, greater losses will result. This may be compared in a way with magnetic phenomena for it is well known that the magnetic lines of force influenced by a piece of soft iron will depend entirely upon the position of the iron in relation to the coil producing the lines of force. Successful construction then is possible only when material with extremely *low dielectric loss is used and placed in a position where the electrostatic field is at minimum value.*

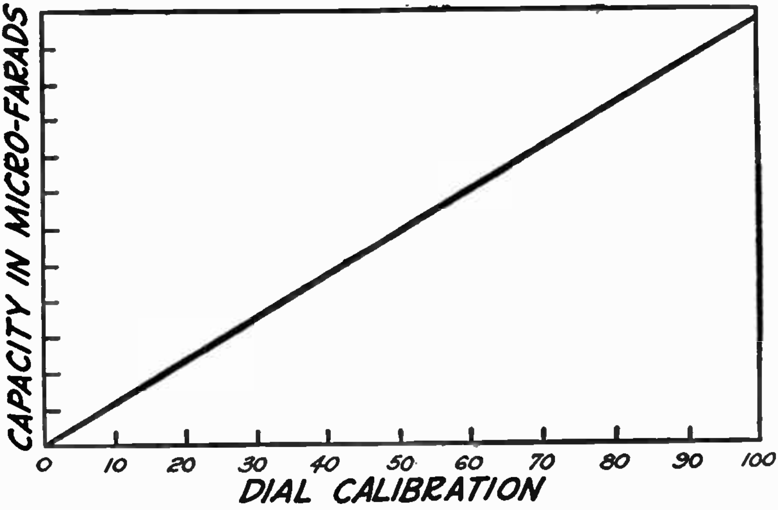
Reference to Fig. H will demonstrate the meaning of this statement. In this case we have two metal plates separated from each other by air and placed at different potentials. Under such conditions there will be an electrostatic field between the plates and the shape taken by this field is shown by the dotted lines. If an extremely poor dielectric substance is placed between the plates, the electrostatic lines of force will at once redistribute themselves, and many of them, instead of passing through the more efficient dielectric, the air, will pass through the poor dielectric with consequent loss in electrical efficiency through the increase of resistance. If the dielectric material is able to pass six times more lines of force than an equivalent space of air, it is said to have a dielectric constant of six. What is needed for high efficiency is a substance that will pass very little more or less lines of force than the air. It is a matter of scientific record that few such materials exist in the world.

It will be seen from the above that condensers merely insulated with bushings (see Fig. E) cannot in any way be reconciled with the demands of low loss construction. Condensers with solid insulated end plates, unless the insulation is of one of the best materials, are also wasters of valuable energy and very inefficient.

It is interesting to note at this point that these dielectric losses through absorption increase with frequency due to the fact that the electrostatic lines of force are building up and collapsing with every change of potential from zero to maximum.

There is still another source of loss due to electrical connections between plates themselves. This means that good clean, tight connections must exist between the plates and between the stationary terminal and the connection formed between it and the rotating plates. This latter connection has been the source of some trouble and in many cases pigtails, or flexible connections, have been introduced. The Bureau of Standards, after much research, has been emphatic in its stand against the use of pigtails due to the losses that they induce. The best practice is that of producing the best possible electrical connection between the end of the rotor shaft and the fixed terminal by means of a contact. The Bureau of Standards holds, and rightly so, that the inductance of the leads of a condenser should be at absolute minimum for the apparent capacity of a condenser at high frequencies will increase with frequency due to inductance in the leads in a similar manner to the variation of the apparent inductance of a coil with distributed capacity. Connections between the binding posts and plates should be short and thick, for this has been found to minimize both inductance and resistance.

In these days of low loss construction a great deal is heard about minimum capacity. Of course the minimum capacity of a condenser should be as close to zero as is consistent with reasonable cost of manufacture. A condenser with a positive zero might be constructed but it would be so costly as to be beyond the means of the average purchaser. Some hold that a low minimum is impossible when metal end plates are used. This is true only under



WHAT A STRAIGHT LINE CONDENSER INVOLVES

Figure I: A straight-line condenser, whether of the frequency, wavelength or capacity types, must show an increase and decrease in capacity that will give a straight line when plotted as illustrated.

a certain condition, i.e., when the distance separating the stationary plates and the end plates is small. There is a law that states that the intensity of the electrostatic field existing between two members at different electrical potentials is *inversely proportional to the square of the distance.* This means that if the distance is doubled, the field is quartered, etc. If a distance equivalent to the distance separating the plates were used between the end plate and the stationary plates, a natural high minimum would result. However, when this distance is made ¾ of an inch or more the resulting minimum capacity is so small as to be almost beyond accurate measurement. Of course, at maximum capacity, that is, when the movable plates are interleaved between the stationary plates, the end plates have absolutely no effect for they are at the same potential as the movable plates. There can be no electrostatic field where there is no difference in electrical potential.

The Bureau of Standards draws attention to the inadvisability of using end plates of dielectric materials with high temperature coefficients. Such materials have changes in mass and shape when subjected to varying temperatures and quite naturally these changes are reflected in capacity. It also usually happens that end plates made of ordinary dielectric materials absorb huge quantities of moisture (sometimes as much as 8%) and through their temperature changes and moisture absorption they warp appreciably. That is the reason why some very cheap condensers, after they have been used for some time, will develop a short circuit. The insulation warps and consequently throws the entire device out of mechanical adjustment. Since small changes in this way effect large changes in the position of the plates due to leverage, it requires but a small change in external conditions to bring about fatal results.

Much has been said about straight-line condensers and there exists in the public mind some amusing fallacies as to the why and wherefore of such instruments. When a condenser is said to be straight-line little or nothing is meant unless some information is imparted on the nature of the straight line, that is, whether it has to do with capacity, wavelength or frequency. Most condensers are manufactured for straight-line capacity. This means in effect that the capacity is calibrated against the dial setting and that the result of this process is a perfectly straight line on the graph, instead of a curve (see Fig. I). The same is true of wavelength and frequency. As far as the ordinary purchaser is concerned straight-line can be totally ignored for it has little to do with efficient operation. What the discriminating fan desires to know is the amount of loss that a condenser has when it is operated in connection with circuits at radio frequencies. If such a purchaser will look for the features mentioned in this treatment he will be able to purchase condensers that will minimize the destructive losses that occur in the average radio receiver.

Several misconceptions are current about condensers for use in radio receiving sets. We have heard suggestions as to how to use condensers properly in tuning, as to what the proper capacity should be, and as to the smallness of the resistance allowable in the condenser.

"Low-loss" condensers have been placed on the market. Competition among the manufacturers of these low-loss condensers is very keen. As a consequence, many statements have been

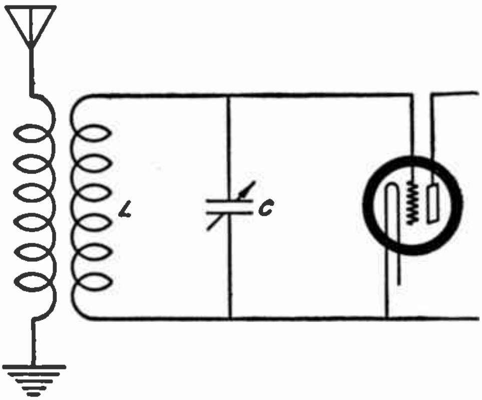


DIAGRAM OF AN ORDINARY
TUNING CIRCUIT

**Figure J: Shows the usual manner of representing a simple vacuum tube tuning circuit where the voltage arises in the windings of the inductor, L.**

made concerning the resistance which are not based on absolute fact.

There are a few physical facts which we must understand to be able to comprehend the problem.

The three-electrode vacuum tube, for example, is used in connectión with circuits that include an inductor and a condenser. The vacuum tube is essentially a voltage-operated device, so that the problem hinges around the voltages set up in the circuit.

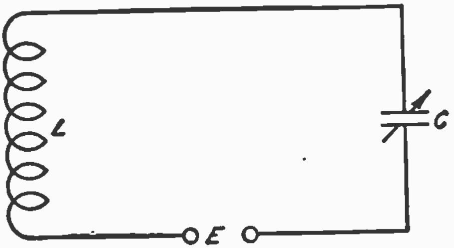
Figure J represents a simple tuning circuit connected to a three-electrode vacuum tube in the usual manner. L is the inductor and C is the condenser. It can easily be shown that the tuning circuit can be represented in the form shown in Figure K. The point is that the results are the same whether we consider the electromotive force as arising in the windings of the inductor, or as being applied in series with it. Actually it arises in the windings, but as the simple series circuit of Figure K is exactly equivalent, we will use this figure in these considerations.

Voltages, or differences of potential, are set up between two points in a circuit due to the *impedance* between these points. The impedance may be a pure resistance, a pure capacity, or a pure inductance, or a combination of these. Actually there are no such *pure* quantities, every electrical device containing all three of these quantites to some degree. For simplicity, however, we will consider the inductor as a pure inductance and the condenser as a pure capacity.

The part of the impedance which is due to either the capacity or the inductance, or both, is known as the *reactance*. The reactance due to the inductance alone is $X_L = 0.00628\ FL$ and that due to the capacity alone is

$$X_C = -\frac{159.3}{fC}$$

When a proper balance between the capacity and inductance in a circuit is obtained which results in resonance, these two reactances are equal and op-



SIMPLIFIED DIAGRAM OF A RECEIVING CIRCUIT

**Figure K:** This shows the equivalent tuning circuit of that in Figure 1. In this circuit the voltage is applied in series with the other elements.

posite in effect, and the total reactance of the circuit is zero.

In these formulas $X_C$ and $X_L$ are the inductive and capacitive reactances respectively, in ohms, f is the frequency in kilocycles, C is the capacity in microfarads and L is the inductance in microhenries. These reactances exist in the circuit even when resonance is obtained, even though their net effect on the total circuit is zero.

The voltage drop between any two points in such a circuit is the product of the current in the circuit and the resistance or reactance between the two points. Thus the voltage drop across a pure resistance is $V = RI$ and the drop across a pure inductance or capacity

$$V_C = X_C I = -\frac{159.3\,I}{f\,C},\quad V_L = X_L I = 0.00628 f L I$$

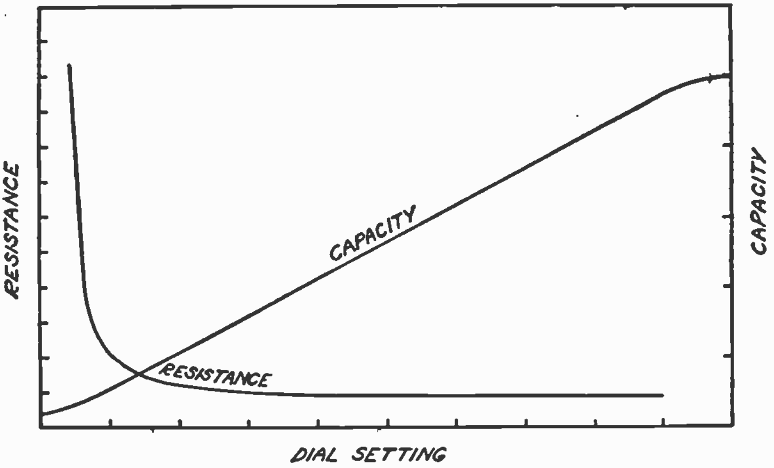
To obtain a large voltage across the inductance or capacity in Fig. J, it is evident that the reactance for a given current and frequency must be high. In other words, a large inductance and small capacity should be used. This is the conclusion that has been arrived at by someone a long time ago, and everyone has been following it as sheep follow their leader. The contributor does not mean that this conclusion is incorrect; he means that it is not one half the story.

The story becomes somewhat different when we consider the resistances in the circuit. The presence of resistance represents a loss of power as given by the formula

$$P = RI^2$$

in which P is the power loss in watts, R the resistance in ohms, and I the current in amperes. It is to be noticed that the loss of power increases in proportion to the *square* of the current; that is, for a given resistance the power loss is quadrupled if the current is doubled. This loss of power results in broadness of tuning as well as inefficient operation of the receiving set and lowering of its receiving range. It is this loss that we are trying to overcome in our low-loss condensers and coils. We will now consider what effects are present in condensers and coils and other parts of the tuning circuits that give rise to these losses.

Until lately there have been no satisfactory methods known by which to measure the resistances of small air condensers. Various bridge methods of measurement have been used from time to time, but these are satisfactory only



THE RESISTANCE CHANGES IN CONDENSERS AT DIFFERENT DIAL SETTINGS

Figure L: Notice that resistance rises sharply at the lower dial settings. These observations indicate that it is well to design your inductors so that you can tune with your condensers at higher dial settings (those above 30).

at lower frequencies than are used in radio reception; generally in the audible frequency range. When high frequencies are used there are losses of power in the bridge which vitiate the results of the measurement.

Substitution methods of measurement have been used, which require the assumption of zero resistance in a condenser specially constructed and used as a standard of comparison. Common sense tells us that zero resistance in any piece of electrical apparatus is impossible, so that this method of measurement must be regarded as very inaccurate.

Experimenters have attempted to compute the resistance of condensers by making the measurements at 1,000 cycles on a bridge and then calculating the probable resistance at radio frequencies. The method used is outlined as follows, together with the objections to the method. Condenser resistances have been measured at low frequencies by the bridge methods and plotted as shown in Fig. L.

This is the curve for a glass condenser of capacity 0.002 microfarad. It will be noticed that this curve is straight throughout its whole length except for a very slight curvature at the lower end. Moreover, it will be noticed that it covers the range from 1,000 meters to 4,000 meters, or from 300 kilocycles to 75 kilocycles. These are frequencies which are not used in ordinary radio work (except in the case of long-wave transatlantic stations).

In this method of measurement, as the curve is practically a straight line, it was assumed to be straight all the way as the broken line shows. Experimenters therefore have assumed that the resistance of a condenser decreases in the same proportion as the wavelength is decreased. A bridge measurement which gives 125 ohms as the resistance of the condenser at 1,000 cycles (300,000 meters) would then have a resistance of 0.125 ohm at 1,000 cycles (300 meters), according to their method of reasoning. That is,

$$\frac{1{,}000}{1{,}000{,}000} \times 125 = 0.125 \text{ or } \frac{300}{300{,}000} \times 125 = 0.125$$

The calculation is given for both wave length and frequency.

That this method cannot be correct, or give even nearly correct values of the resistance is indicated by the slight curvature at the foot of the curve in Fig. L. A curvature so slight as amounting to only 0.01 ohm for a range of 1,000 cycles would not be noticeable on the curve, but its effect would be multiplied 1,000 times if the same curvature were maintained over a range of 1,000,000 cycles. The result would then be in error by 1 ohm and the actual resistance would be 11 times the computed value. This is an exaggerated example, used to illustrate the case, but it can be shown that even if the curvature is very much less than this the error in the result will be several hundred percent from the true value.

The trouble lies in the assumption that the curve is a straight line. This is equivalent to saying that the power-factor (known also as the phase-difference) of the condenser is constant. The power-factor is given in degrees by

$$\psi = 0.36 \, f R C$$

in which f is in kilocycles, R in ohms, and C in microfarads. We can see from the formula that the power-factor cannot be constant. As f varies, the value of R also varies, due to skin effect, so that the power-factor must vary. If it did not vary the resistance would be inversely proportional to the frequency, and we would write

$$R \text{ proportional to } 1/f$$

But on account of the skin effect the correct relation is:

$$R \text{ proportional to } 1/f^m$$

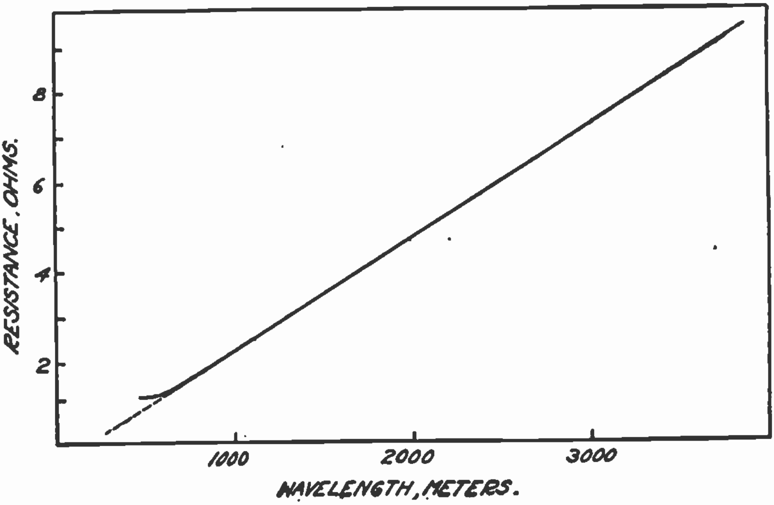
This is the effect that has been neglected in the method described above. As a result of all this a new method has been devised which eliminates the inaccuracies of the above methods, and permits the measurements to be made under the same conditions which prevail in radio circuits. The measurements were on a great many condensers, including all types and all makes. The method was carefully checked by measurements made on known resistances. The resistances ranged from about 0.5 to 2.5 ohms, the low-loss types showing slightly lower resistances than the old types. We will not at the present time go into the resistances of the particular makes. What the contributor wishes to do is to give his reader an unexaggerated idea of the importance of the condenser resistance.

Now, consider the subject of coils, for these are always used with condensers in tuning circuits.

It is well known that coil resistances run very high, expecially at radio frequencies, which we are considering. One manufacturer of a concentrated inductance of 100 turns advertises the resistance of his coil to be 80 ohms at 500 meters. Another manufacturer advertises the resistance of his loop antenna to be about 30 ohms at 200 meters. In fact, as far as the writer knows, no inductances have as yet been designed having resistances which even approach the low values of condenser resistances.

Let us consider, for example, a condenser which has a resistance of 1 ohm used with the loop mentioned above which has a resistance of 30 ohms.

Suppose we replace this condenser with one which has a resistance of 0.5 ohm. The total resistance of the circuit will be reduced only 0.5 ohm out of 30.5 ohms, or less than 2 percent.



RESISTANCE CURVE OF A CONDENSER OPERATING ON THE HIGHER WAVELENGTHS

**Figure M:** It has been assumed that resistance in condensers varies directly with the wavelength. Calculations of resistance made on this assumption are erroneous at low wavelengths where the resistance decreases at a slower rate as indicated by the slight curvature of the graph.

The great worry about condenser resistance is therefore needless, and a great deal of undeserved pressure has been brought to bear upon the manufacturers of condensers by those who would better have devoted their time and energy to designing low-loss inductors.

There is another very important point that should be brought out here. By the new method it was possible to plot the variation of resistance of a condenser with the dial setting. The general shape of this curve is shown in Fig. M. Its shape might be suspected from the inverse relationship between the resistance and cross-section of a conductor.

In Fig. M, the important point to consider is where the curve begins to bend. Experiments have proved that the resistance remains practically constant from 100 on the dial to about 30, at which point it turns up sharply. At 10 on the dial or less the resistance may go up as high as 15 or 18 ohms. This particular condenser had a capacity of .0005 mfd.

Interpreting this in connection with receiving circuits, it is not well to use the condenser at the low dial settings. The inductance used with the condenser should be so designed that the wave range can be covered without having to go lower than about 30, or best 25 on the dial. This should relieve the situation somewhat with regard to the minimum capacities of condensers. If we should not use the lower end of the dial, who cares, then, what the minimum capacity is? The best practice, in consideration of these facts, is to select a condenser that has a large capacity ratio between 100 and 30 on the dial, and to design the inductance to give the wave range desired. This will mean using a larger condenser and small inductance which is often advantageous, since a small coil can be constructed to have lower resistance than a large one.

It is well to point out here, also, that the effect of soldered joints in various parts of the circuit, including those between the plates and elsewhere in condensers, is likewise negligible. More importance should be attached to the design of low-resistance coils. There are many forms on the market, but they are all more or less alike. There are some things in connection with coils that have not generally been considered, and it is probable that a broader way of looking at the problem may result in considerable improvement in design. The writer has built an inductance coil of a special form which permitted reception on a loudspeaker at a distance of 15 miles from the local broadcasting station using a simple one-tube circuit and an old-style condenser.

We are now ready to understand better what the relation of condenser to inductance in a tuning circuit should be. To obtain high grid voltages the capacity should be small and the inductance great. But large inductance goes with greater coil resistance. This means that our grid voltage will not be as high as we expected it to be. A compromise must be effected so that fairly high grid voltages can be obtained by having the reactances high, without sacrificing too much by the increased resistance. The usual 0.00025 or 0.0005 may be used satisfactorily for ordinary work, but in view of all the preceding arguments the author has lately been more inclined toward the 0.001 size, using a small 3 or 4-plate condenser shunted around it for accurate tuning.

Sir Oliver Lodge has contributed some interesting and helpful reflections on variable radio condensers for those who desire to go more deeply into the mathematical side of the subject. To quote:

"When a conductor is charged with electricity, its potential rises. And, if the quantity of electricity supplied to it is doubled, the potential is doubled too. The ratio of the charge to the potential is called the "capacity" of the body.

"There is the same sort of thing in heat. The more heat is supplied to a body, the higher grows the temperature. And the ratio of the amount of heat supplied, to the consequent rise of temperature, is called its 'thermal capacity.'

"The thermal capacity of a body naturally depends on its size or rather its weight; but it also depends on its material. That part of the capacity is called "specific," which means the capacity of each pound or each gram. The specific capacity of lead is one thing, of iron another, and of water is greater than either.

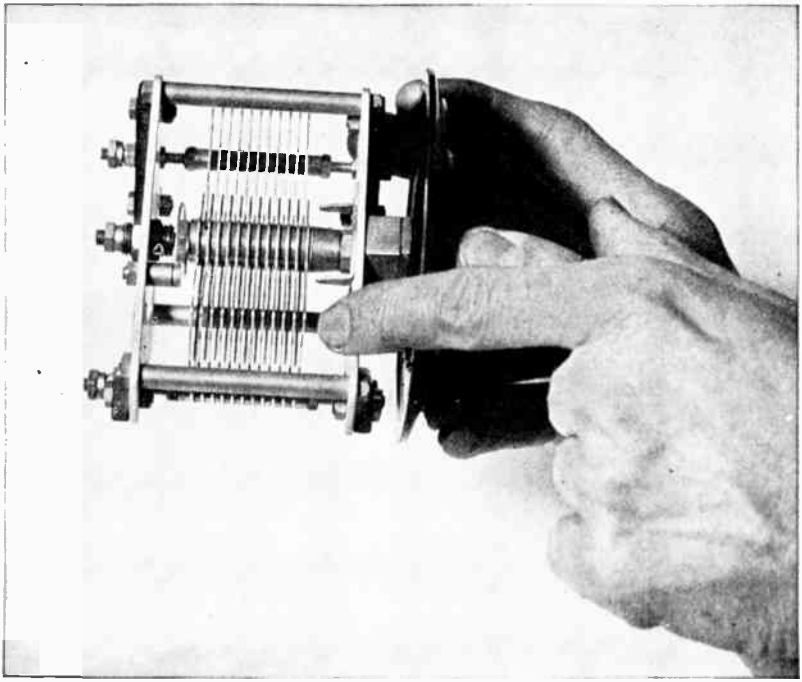
"In this respect, thermal capacity differs from electric capacity. Electric capacity does not depend on the material of the conductor, but, as Faraday showed, on the nature of the material surrounding the conductor. A conductor in air has one capacity; but if plunged into a vessel of oil, or melted resin, or pitch, or some other insulator, it has another and greater capacity. Hence there is a specific inductive capacity for each insulating material, which can be ascertained by experiment.

"In addition to that, however, the capacity of a body changes, not only by reason of the insulator surrounding it, but also by reason of conductors in its neighborhood. If it is brought near the earth, for instance, or near a wall, its capacity increases. And this increase of capacity is calculable from the geometrical conditions, that is, when the shape and distance of bodies is known.

"In some respects, therefore, electrical capacity is less simple than thermal capacity, since the latter has wholly to do with properties of materials, whereas the former is dependent on geometrical conditions besides.

"Take the simplest case—an isolated sphere: the moon, for instance, or a brass ball far away from anything else. A charge on it is measured by the repulsive force it can exert on a similar equal force at a given distance, in accordance with what is called Coulomb's Law. The electrical force varies inversely with the square of the distance, just as gravitation does. But force is always equal to gradient or slope of potential. From this it follows, though not quite obviously, that the electric potential at any point near a charged body is equal to the charge divided by the distance *i.e.*, the simple distance of that point from the charge.

"Assuming this, and applying it to the case of an isolated sphere, let us ask: What is the potential of its center?



A TYPICAL RECEIVING CONDENSER

Figure N: The ordinary receiving condenser has air insulation and the plates are spaced as close as mechanical considerations permit. This is a satisfactory procedure since the potential between the plates is low, and the close spacing gives relatively high capacity. If the air was replaced by another insulating material, the capacity of the condenser would be increased. Any difference, however slight, in the distance between the rotor and stationary plates will affect the capacity of the condenser. Even changes in atmospheric conditions will bring about slight changes in the electro-static capacity.

"The charge resides wholly on the surface; hence the center is at a distance from that charge equal to the radius of the sphere. Consequently the potential is $\frac{Q}{r}$.

"And since the body is a conductor and the electricity is at rest upon it, its potential is uniform, or the same throughout. This $\frac{Q}{r}$ therefore gives the potential of the conductor. And, if you want to know its capacity, you simply divide the quantity by the potential and you get $r$.

"That is, the capacity of an isolated sphere is equal to its radius, and can be expressed in centimeters, meters, miles or any other units of length.

It may be asked: How can a capacity be a length?

"The capacity depends, not on the body itself, except as regards its size and shape. It depends essentially on the properties of the material surrounding it. The material surrounding the moon is the ether of space. The material surrounding a brass ball is the ordinary atmosphere. The two surroundings do not differ appreciably in this respect. They both have practically the same specific inductive capacity. But un-

A COMPACT TYPE OF CONDENSER

Figure O: This tiny condenser has about ten times the capacity of the one shown in Figure N because it is constructed with mica insulation and the plates are spaced only a few thousandths of an inch apart. Part of the condenser is cut away to show the interior construction. The physical size of a condenser means little as an index to the measurement of capacity. This tiny condenser illustrated could have an electro-static capacity many times greater than a condenser many times larger.

fortunately its value is unknown. It is accordingly called K. And when we speak accurately, we ought to say that the capacity of an isolated sphere is K r.

"But for practical purposes, we cannot deal with an unknown quantity. The simplest plan is to assume it to be 1, and proceed with the memory of that perfectly gratuitous and arbitrary assumption at the back of our minds. This is the basis of the electrostatic system of measurement. When a thing is expressed in electrostatic units, the meaning is that the unknown quantity K has been arbitrarily called 1. The worst of it is that we get so used to doing this that we are likely to forget the assumption altogether. The convenience of the assumption is that it enables us to specify our measurements in a very much more simplified manner.

"Now put an outer hollow globe round the brass square. It can be done, and actually used to be done, by applying to it two brass hemispheres bigger than itself, and suspending it symmetrically in the hollow. It can be charged through the suspending wire. If the outer shell is earthed, the inner globe will now be found to have a much greater capacity than before. The charge on it has, so to speak, pulled up from the earth an equal quantity of opposite electricity; and the two charges face each other across the insulating space.

"If we now reckon the potential of the center of the sphere, it will be $\frac{Q}{r}$ due to the one charge, and $\frac{Q}{r}$ due to the other. The potential will then be:

$$Q\left(\frac{1}{r}-\frac{1}{r'}\right)=Q\,\frac{r'-r}{r\,r'}$$

and hence the capacity (Quantity ÷ Potential) of the globe, now that it is surrounded by an outer shell of radius r′, is

$$C = \frac{r\,r'}{r'-r}$$

"Now, we see that r′ — r is the thickness of the insulating space or dielectric separating the two conductors, which we may call Z; and if this space is very thin, that is if the spheres nearly fit, r r′ may be called $r^2$. So the capacity of such an arrangement as this, which is familiar to electricans as a condenser, is $\frac{r^2}{Z}$. Now the area of a sphere is $4\times r^2$.

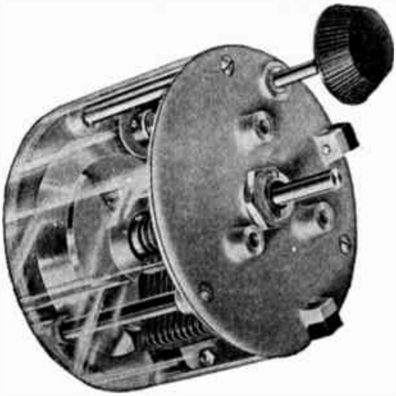
Hence we may specify the capacity of the spherical condenser as,

$$\frac{A}{4\pi Z}$$

"This result is general; for it does not really matter whether the condenser is spherical or not, provided the dielectric thickness is uniform. It will do equally well for a pair of flat plates, one earthed, the other insulated, each plate of area A. So the capacity of a condenser in general is,

$$\frac{A}{4\pi Z}$$

provided only air or ether is between the plates. If, however, some other substance is used as the insulator or dielectric, such as glass or mica or paraffin or oil, we must multiply this value by the specific inductive capacity of the material relative to air, as determined by Faraday; and may thus get four or five times the air-value. This numerical ratio has to be determined by experiment for different materials, and is usually recorded among the data characteristic of different substances.

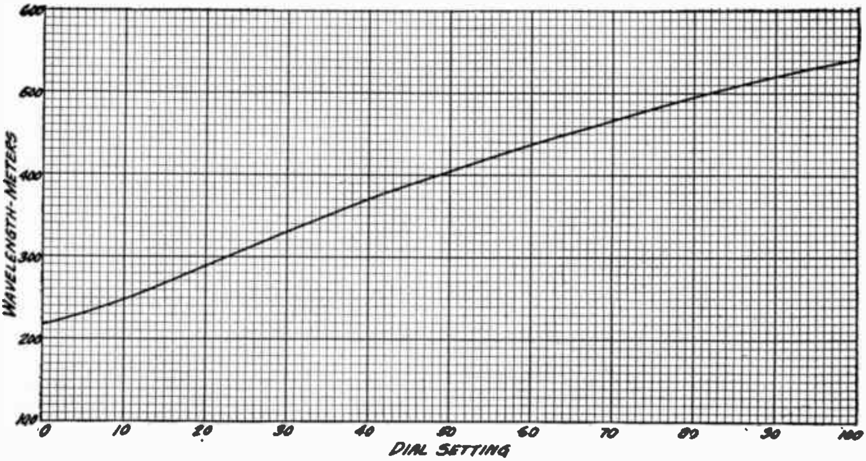


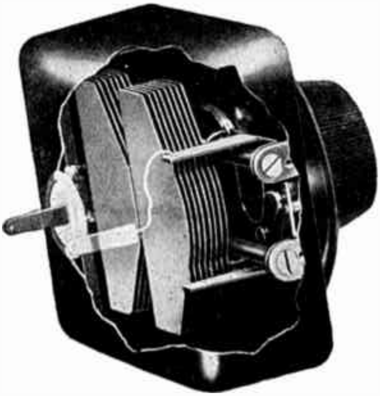
## Acme Condenser

### Specifications

| | |
|---|---|
| Number of plates; 23 | Type; straight line capacity |
| End plates; die-cast metal | Mounting; for panel |
| Insulation; hard rubber | Bearings; steel-brass cone |
| Plates; brass silver plated | Cap.; .0005 mfd. |

## Acme Performance Curve





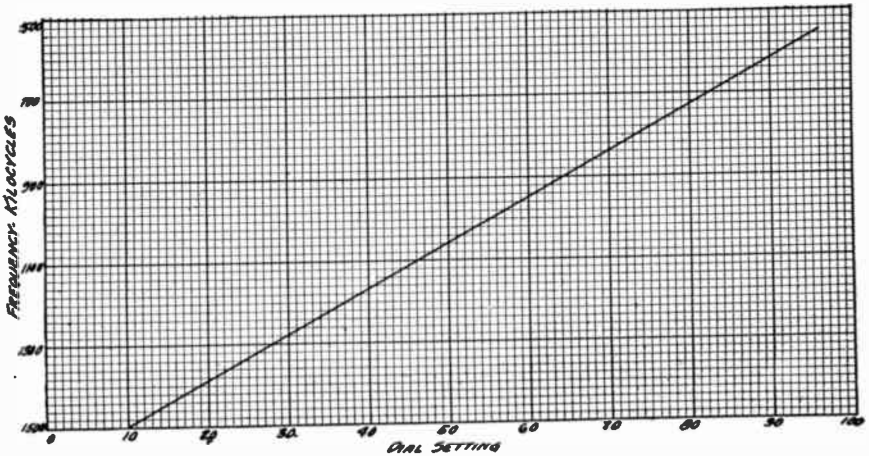
## All-American Condenser

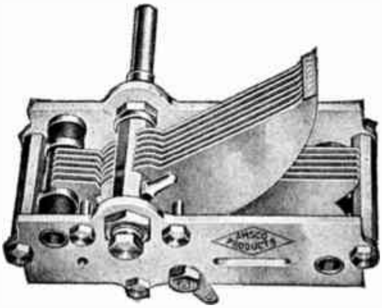
### Specifications

Number of plates; 15
End plates; condenser shielded in meta lcase
Plates; brass
Insulation; Bakelite

Type; straight line frequency
Mounting; for panel
Bearing; brass
Caps. standard sizes

## All-American Performance Curve





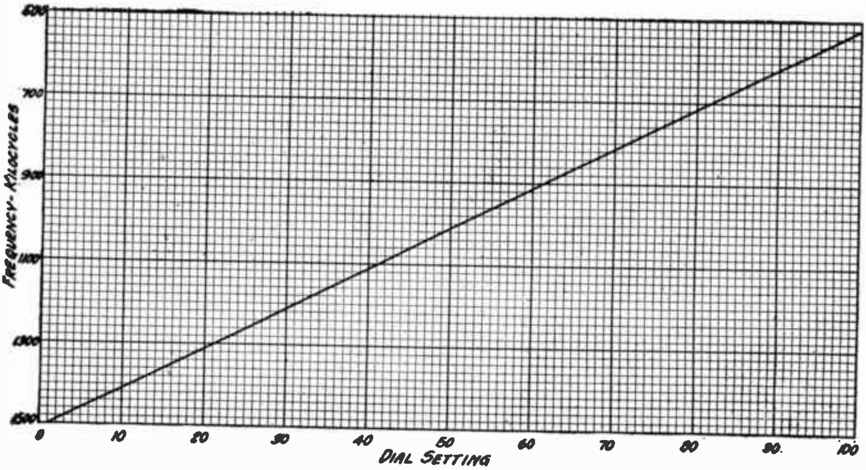
## Amsco Condenser

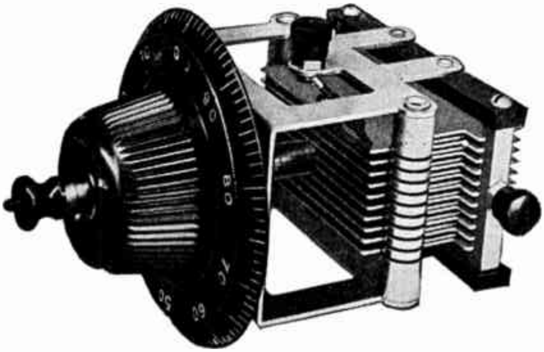
### Specifications

Number of plates; (made in all stand. sizes)
Plates; aluminum
End plates; brass
Insulation; hard rubber

Type: straight line frequency
Mounting; for panel
Bearings; brass cone
Caps;, made in all stand. sizes

## Amsco Performance Curve



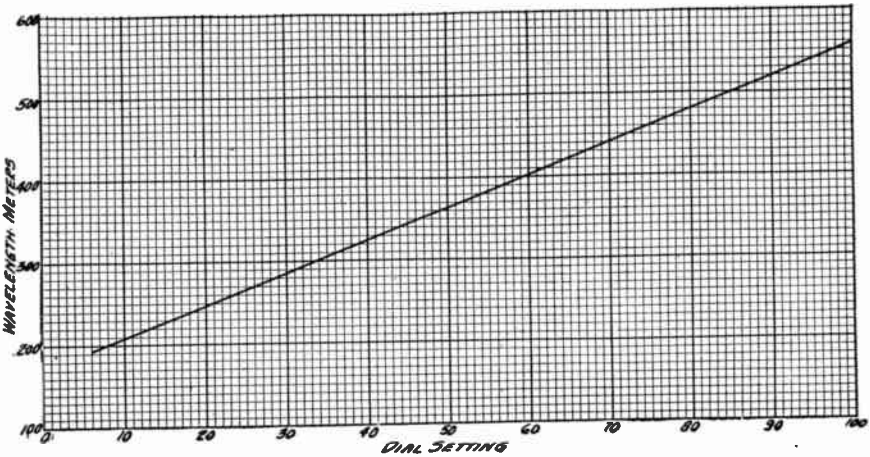


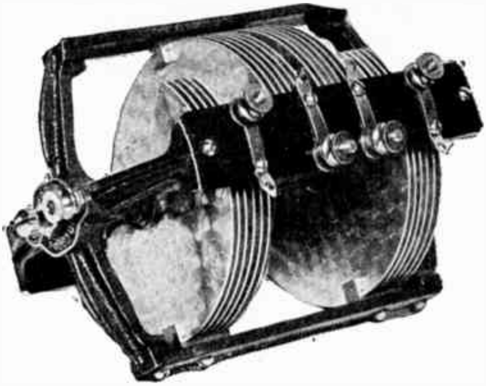
## Barrett and Paden Condenser

### Specifications

Number of plates; 21 (made in var. sizes)
End plates; stamped brass frame
Plates; aluminum
Insulation; hard rubber
Mounting; for panel
Types; straight line wavelength and straight line cap.
Caps.; .00025, .00035 and .0005 mfd.

## Barrett-Paden Performance Curve





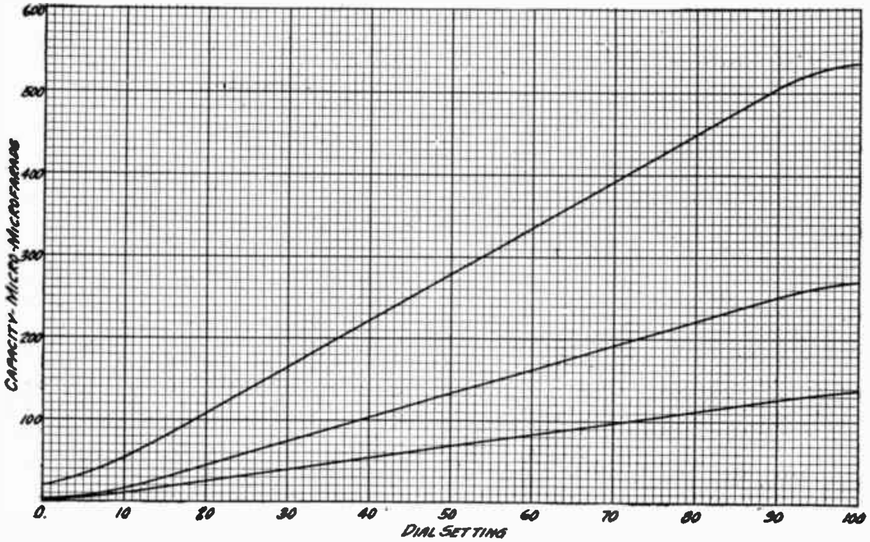
## Bruno Condenser

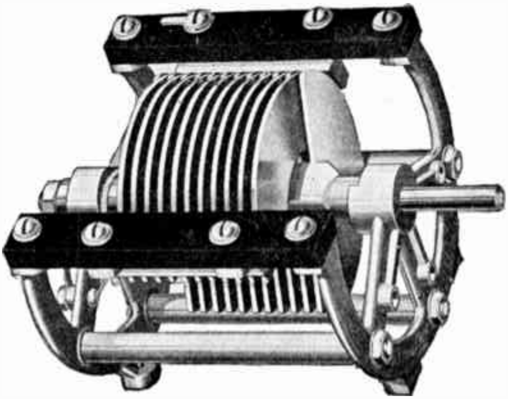
### Specifications

Number of plates; 24 (made var. sizes)
Plates; aluminum
End plates; cast aluminum frames
Insulation; hard rubber
With vernier attachment

Type; straight line capacity
Bearings; metalized graphite
Mounting; for panel
Caps.; .00025, .00032, .0005, .0007, .001 and .00075 mfd.

### Bruno Performance Curves





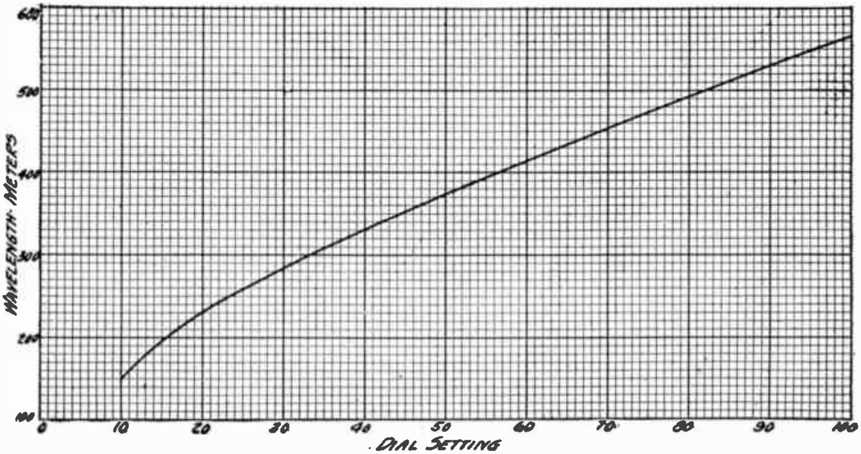
## Buell Condenser

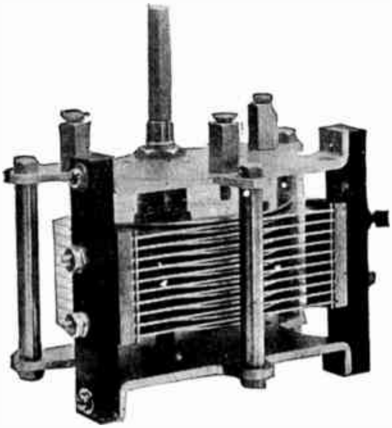
### Specifications

Number plates; 23 (made in var. sizes)
Plates; heavy aluminum
End plates; die cast frames
Insulation; hard rubber

Type; S.L.W. and S.L.C.
Mounting; for panel or base
Bearings; self centering cone
Caps.; 500, 350, 250 and 175 mmfd.

## Buell Performance Curve





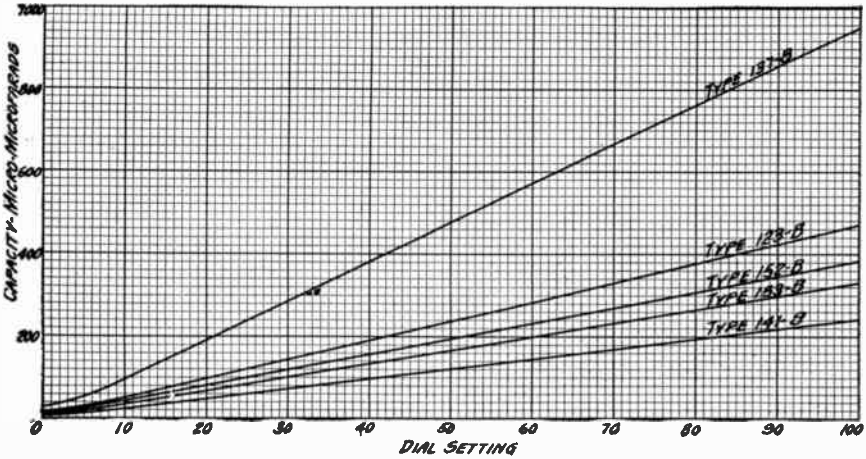
## Cardwell Condenser

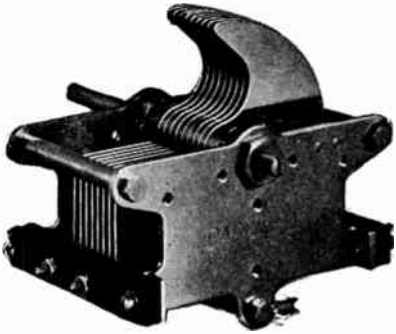
### Specifications

Number of plates; 21
End plates; brass
Insulation; hard rubber
Plates; aluminum

Type; straight line capacity
Mounting; for panel
Bearings; cone brass
Caps.; made in all standard caps.

## Cardwell Performance Curves





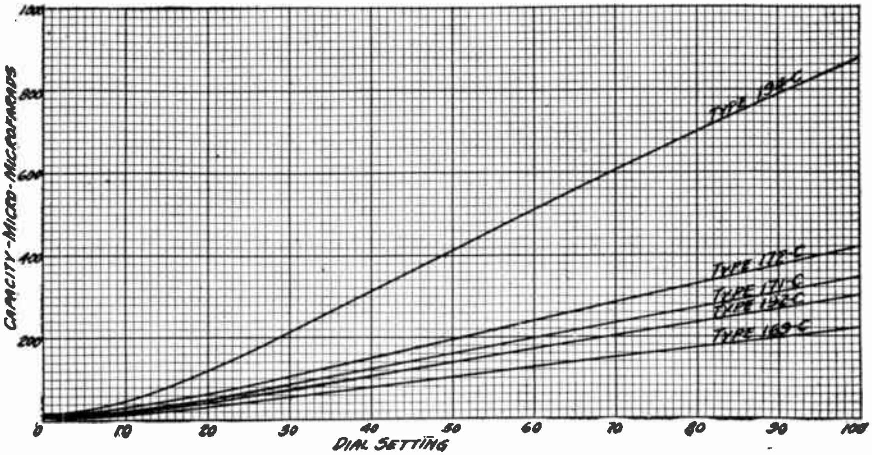
## Cardwell Condenser

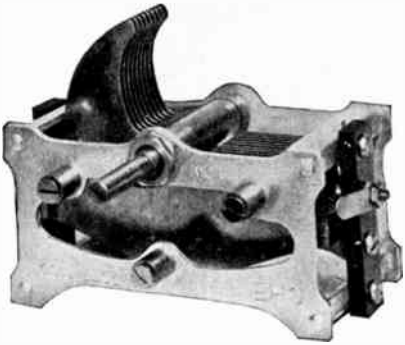
### Specifications

Number of plates; 17
Plates; aluminum
End plates; brass
Insulation; hard rubber

Type; straight line capacity
Mounting; for panel
Bearings; cone brass
Caps.; made in all standard sizes.

### Cardwell Performance Curves





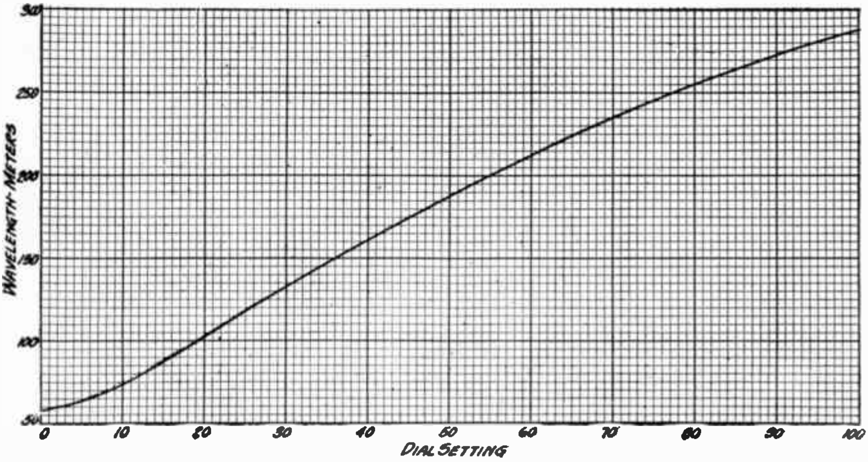
## Chelten Condenser

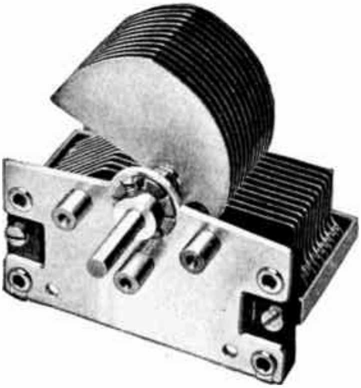
### Specifications

Number of plates; 17 (made in var. sizes)
Plates; aluminum
End plates; brass
Insulation; hard rubber

Type; straight line wavelength
Mounting; for panel
Bearings; brass cone
Caps.; made in all stand. caps.

## Chelten Performance Curve





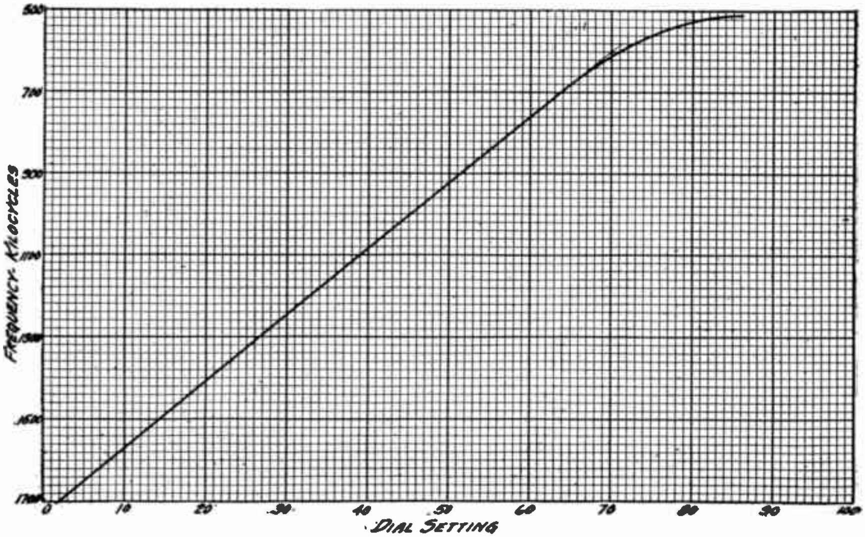
## D.X.L. Condenser

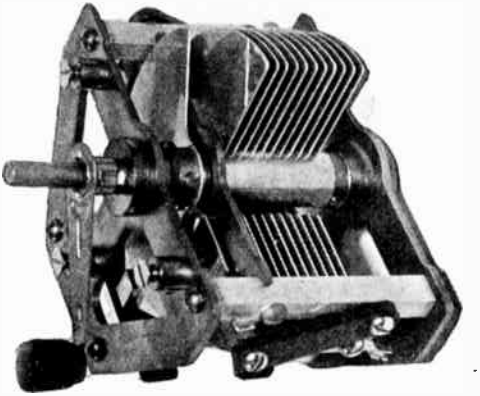
### Specifications

Number of plates 23 (made in var. sizes)
Plates; brass silver-plated
End plates; heavy brass nickeled
Insulation; hard rubber

Type; straight line frequency
Mounting; for panel
Bearings; cone type
Caps.; .00025, .00035 and .0005 mfd.

### D. X. L. Performance Curve





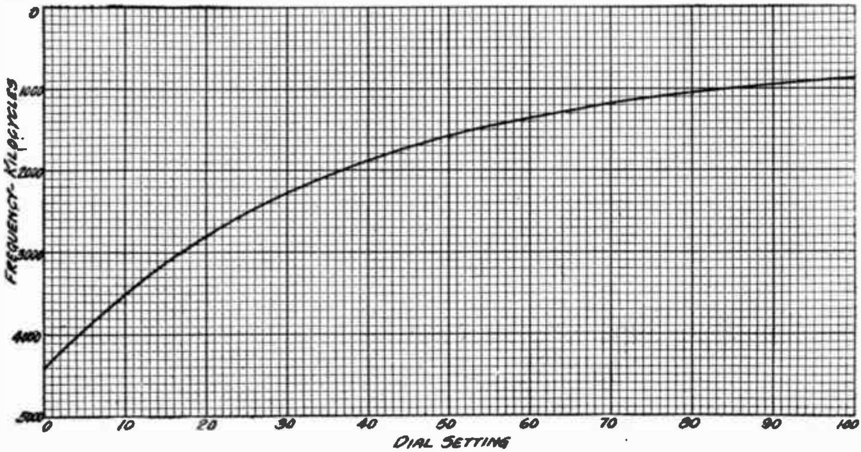
## Duplex Condenser

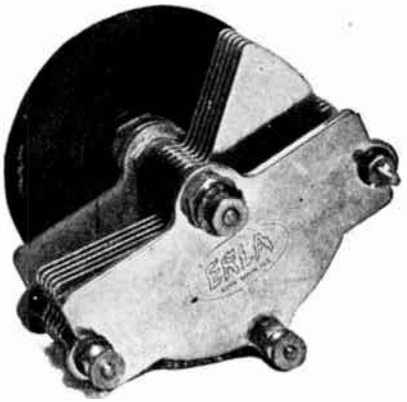
### Specifications

Number of plates; 21 (made in three sizes)
Plates; aluminum
End plates; aluminum
Insulation; bakelite

Type; straight line frequency
Mounting; for panel
Grounded rotor
Caps.; .00025, .00035 and .0005 mfd.

### Duplex Performance Curve





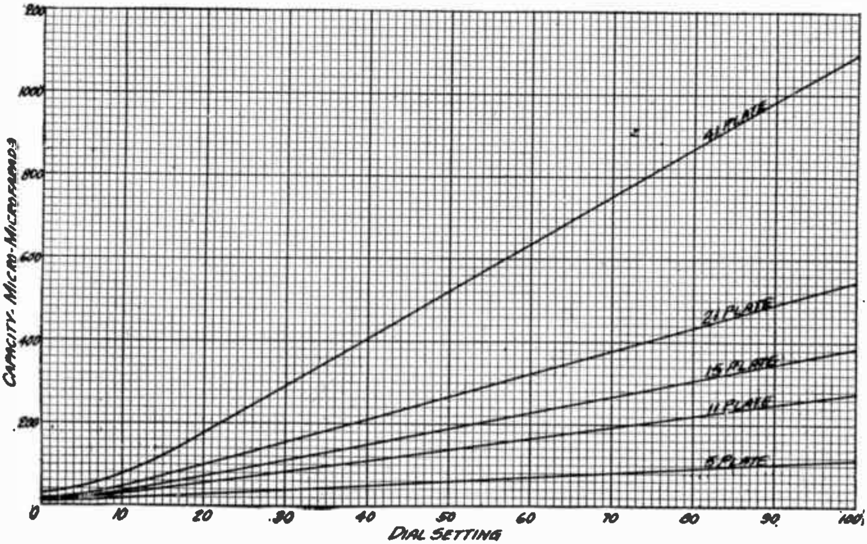
## Erla Condenser

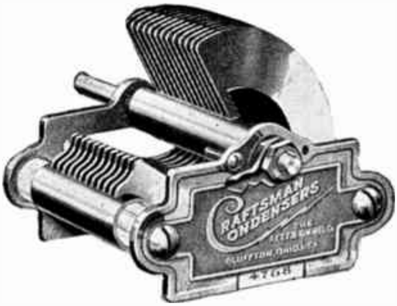
### Specifications

Number of plates; 11 (made in different sizes)
End plates; nickeled brass
Insulation; hard rubber
Plates; aluminum

Type; straight line capacity
Mounting; for panel
Made in caps. of 115, 275, 375, 550, 1070, mmfds.

### Erla Performance Curves





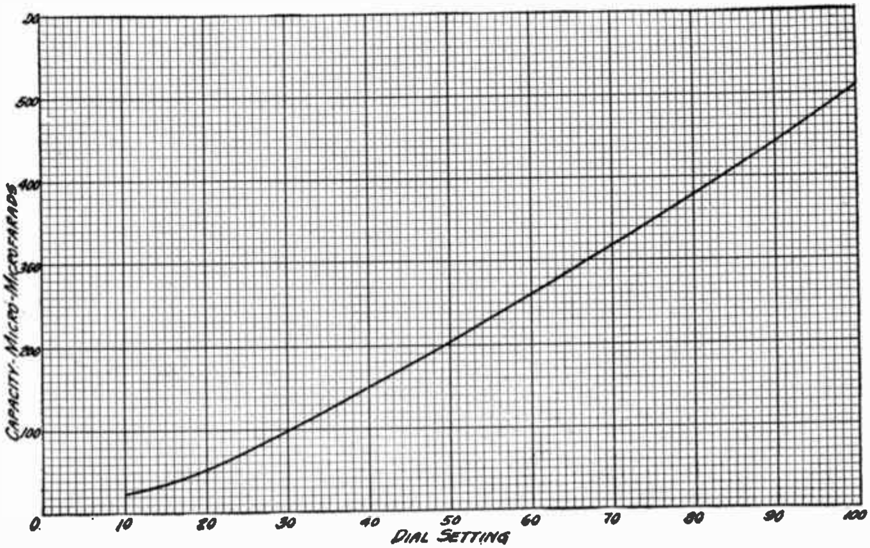
## Fett and Kimmel Condenser

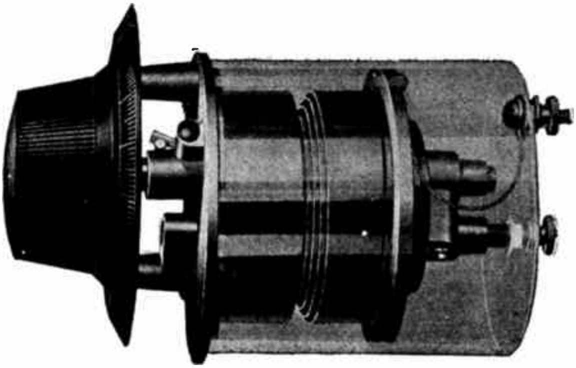
### Specifications

Number plates; 24 (made in three sizes)
Plates; aluminum
End plates; cast metal
Insulation; pyrex glass

Type; straight line capacity
Mounting; for panel
Bearings; cone brass
Caps.; .00025, .00035 and .0005 mfd.

## Fett and Kimmel Performance Curve



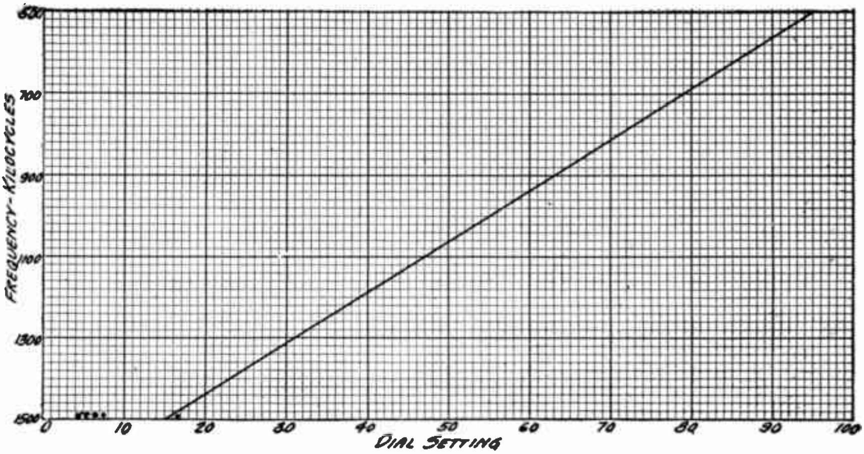


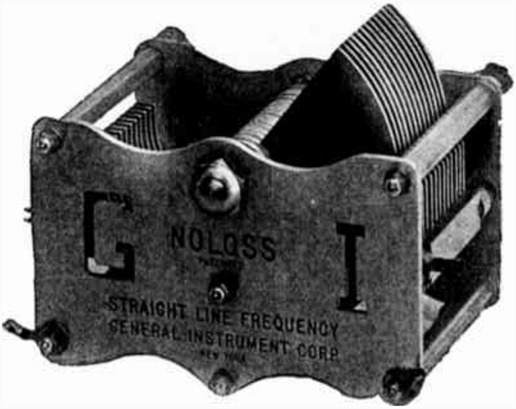
## Furnell Condenser

### Specifications

| | |
|---|---|
| Number of plates; two; spiral form | Mounting; for panel |
| Plates; spiral brass | Type; straight line frequency |
| Insulation, Bakelite | Caps.; made in three sizes |

## Furnell Performance Curve



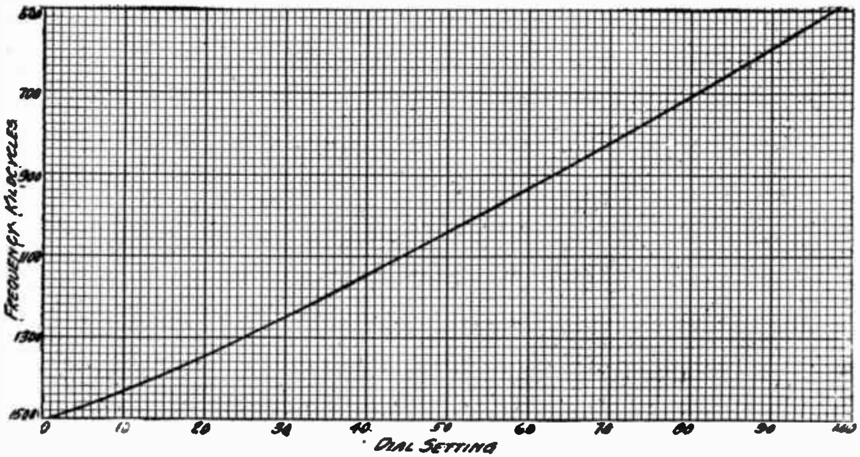


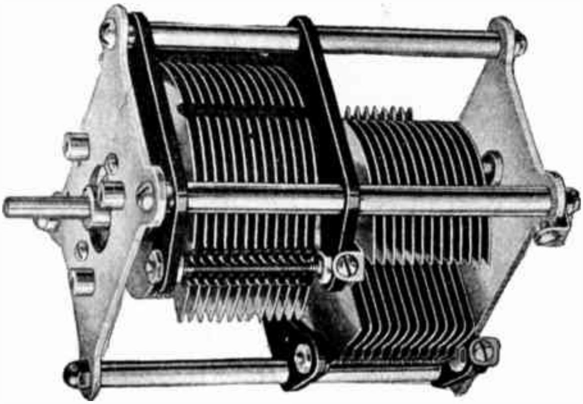
## General Instrument Condenser

### Specifications

| | |
|---|---|
| Number of plates; 23 (made in all stand. sizes) | Type; straight line frequency |
| End plates; brass | Bearings; brass |
| Insulation; pyrex glass | Caps.; made in all standard capacities. |
| Mounting; for panel | |

### General Inst. Performance Curve





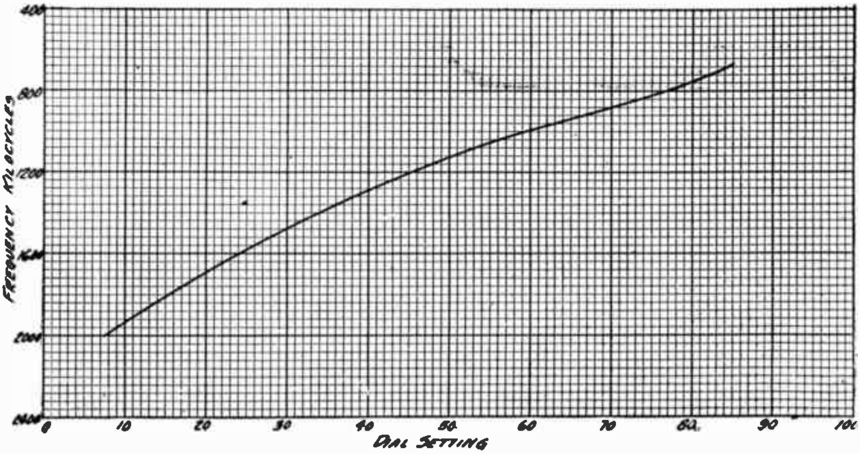
## General Radio Condenser

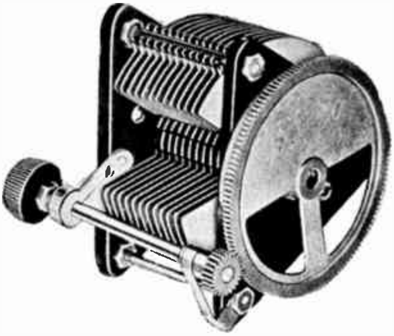
### Specifications

Number of plates; 26 per unit (made in var. sizes)
Plates; brass
End plates; aluminum
Insulation; Bakelite

Type; straight line frequency
Mounting; for panel
Bearings; brass
Caps.; 500, 350 and 250 mmfds.

## General Radio Performance Curve





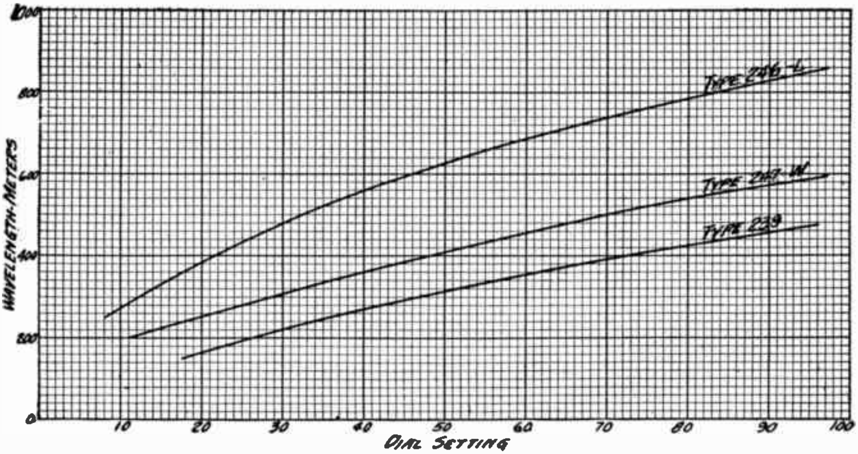
## General Radio Condenser

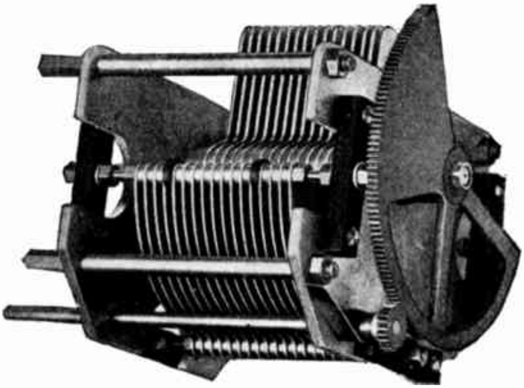
### Specifications

Number of plates; 26 (made in var. sizes)
Plates; heavy brass
End plates; Bakelite
Insulation; Bakelite

Type; straight line wavelength
Gear vernier
Mounting; for panel
Caps.; 500, 350 and 250 mmfds.

## General Radio Performance Curves





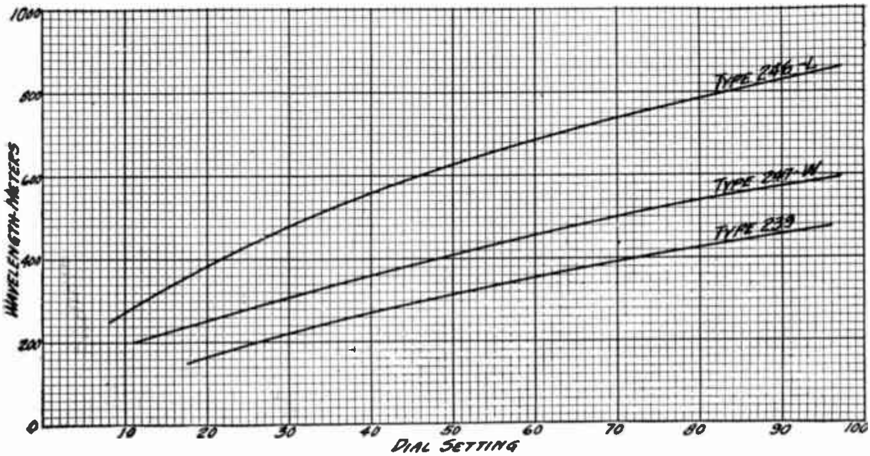
General Radio Condenser

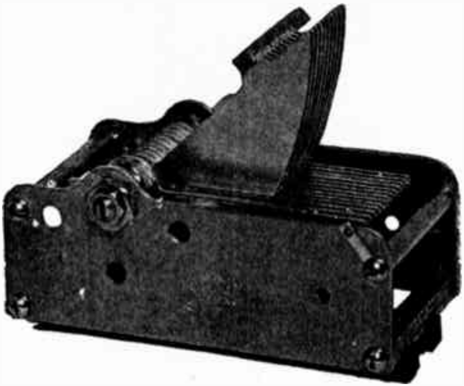
## Specifications

Number plates; 33 (made in var. sizes)
End plates; heavy brass
Plates; aluminum
Insulation; hard rubber

Type; straight line wavelength
Bearings; locked cone
Mounting; for panel
Caps.; 1000, 2000 mmfds.

## General Radio Performance Curves





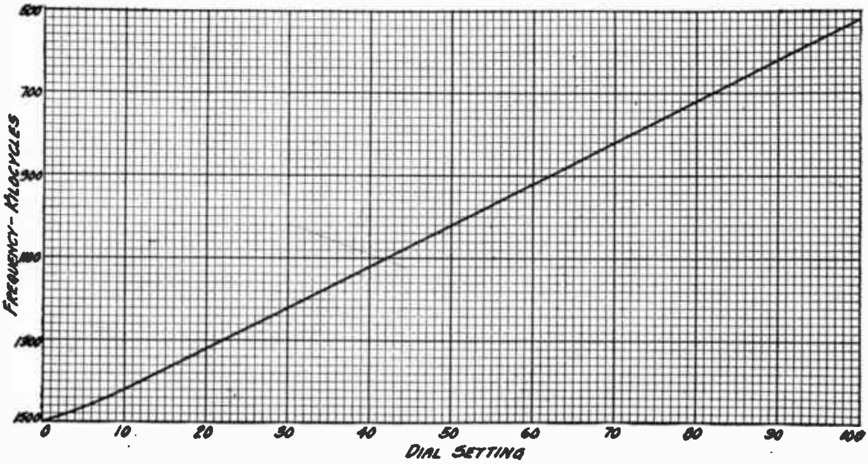
## Haig and Haig Condenser

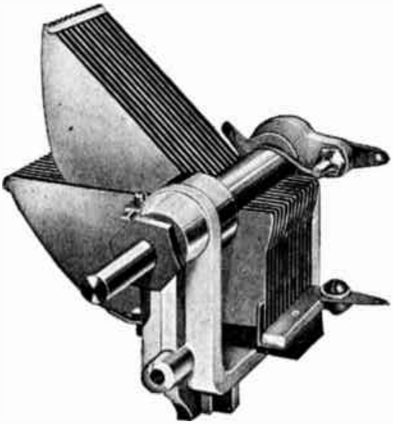
### Specifications

Number of plates; 23 (made in var. sizes)
Insulation; hard rubber
Plates; aluminum
Mounting; panel

Type; straight line frequency
End plates; aluminum
Bearings; heavy brass cones
Caps.; made in all standard sizes

## Haig and Haig Performance Curve



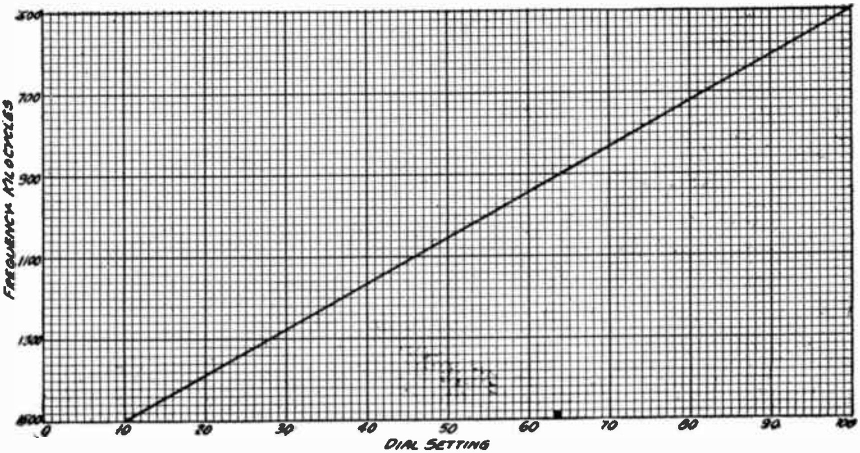


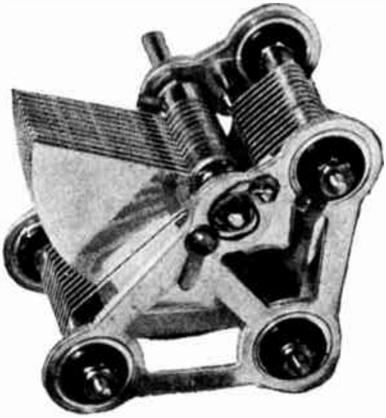
## Hammarlund Condenser

### Specifications

| | |
|---|---|
| Number of plates; 25 (made in var. sizes) | Bearings; adjustable ball |
| Plates; brass | Mounting; for panel |
| Insulation; Insolantite | Type; straight line frequency |
| End plates; cast metal frame | Caps.; made in all standard sizes |

## Hammarlund Performance Curve





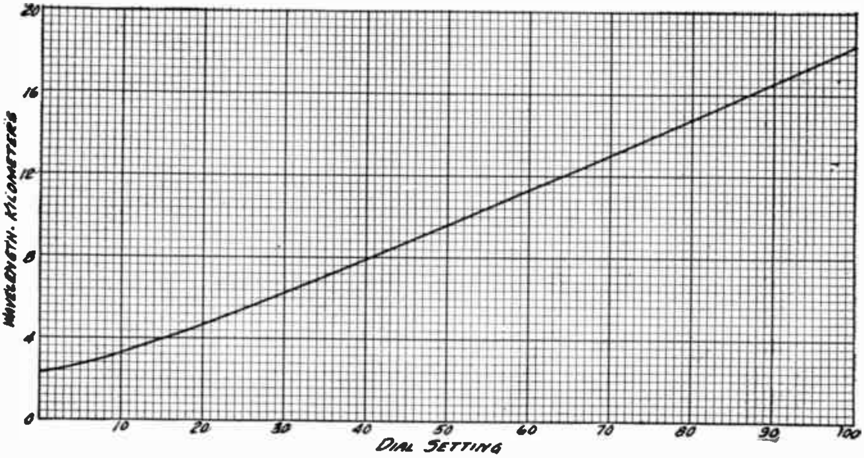
## Heath Condenser

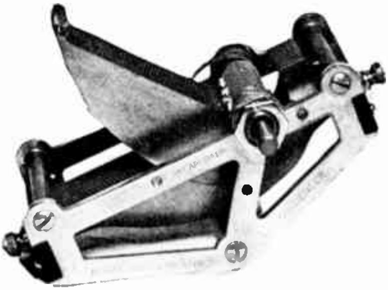
### Specifications

Number of plates; 23 (also made in 11, 17 and 43)
Plates; aluminum
End plates; aluminum
Insulation; Bakelite
With or without vernier

Type; straight line wavelength
Bearings; brass
Mounting; for panel
Caps.; .00025, .00035, .0005 and .001 mfd.

## Heath Performance Curve





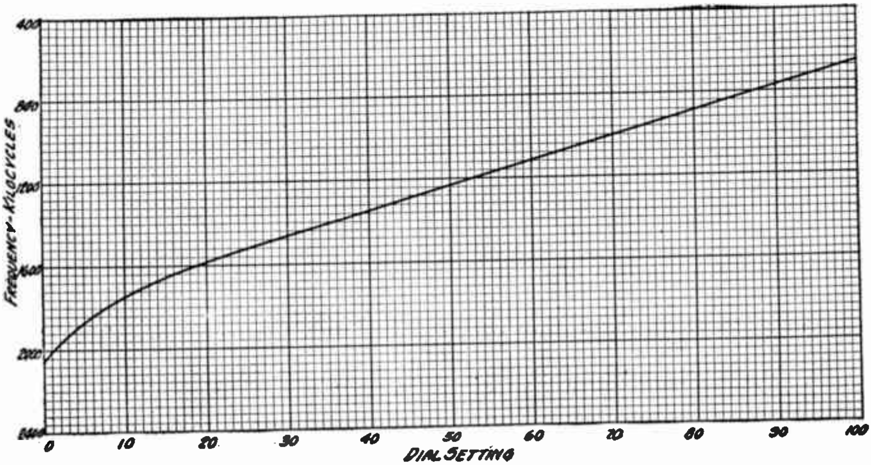
## Karas Condenser

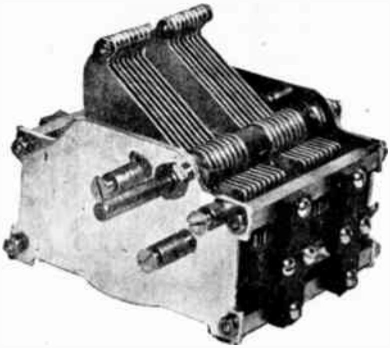
### Specifications

Number plates; 23 (also 17 and 11)
Plates; brass
End plates; heavy metal frames
Insulation; hard rubber

Type; straight line frequency
Bearings; brass adjustable
Mounting; for panel
Caps.; .005, .00037, .00025 mfd.

## Karas Performance Curve





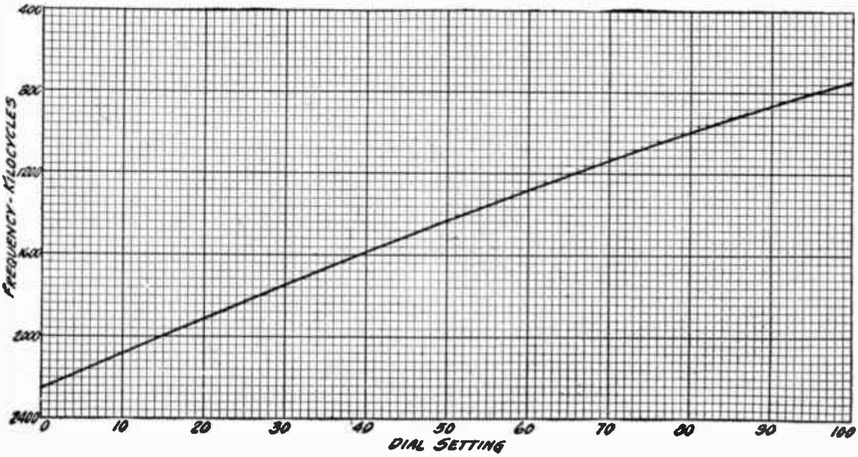
Lombardi Condenser

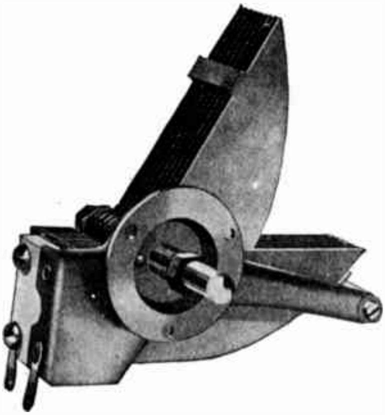
## Specifications

Number of plates; 17 in each unit
End plates; brass
Plates; aluminum
Insulation; hard rubber

Type; S.L.F and S.L.W.
Bearings; self aligning
Mounting; for panel
Caps.; .0005, .00035 and .00025 mfd.

## Lombardi Performance Curve





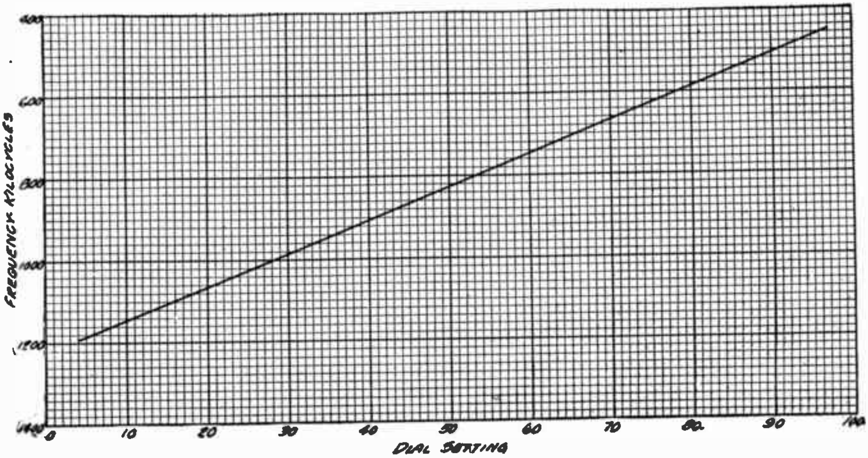
## Pacent Condenser

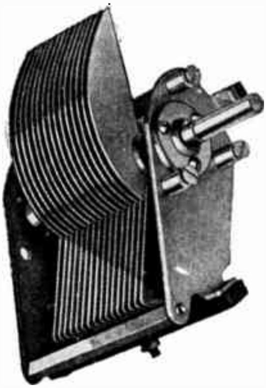
### Specifications

Number of plates; 17 and 23
Plates; brass
Insulation; Isolantite
End plates; brass frame

Type; straight line frequency
Mounting; for panel
Bearings; brass
Caps.; .00035 and .0005 mfd.

### Pacent Performance Curve





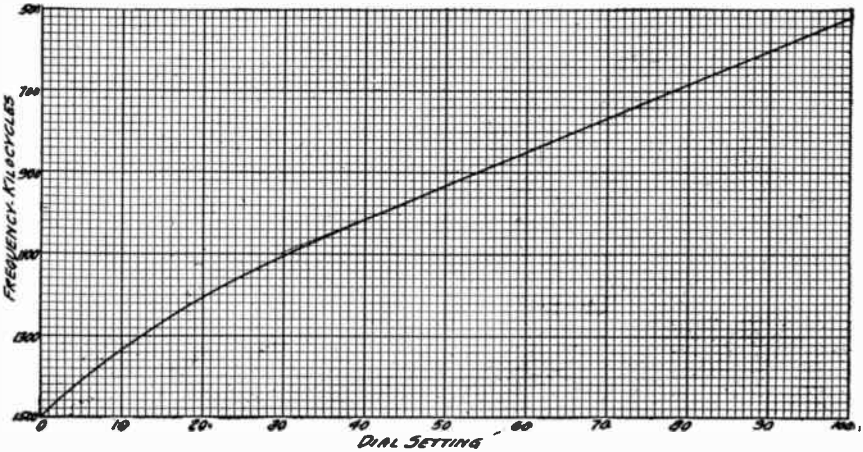
## Pearl Condenser

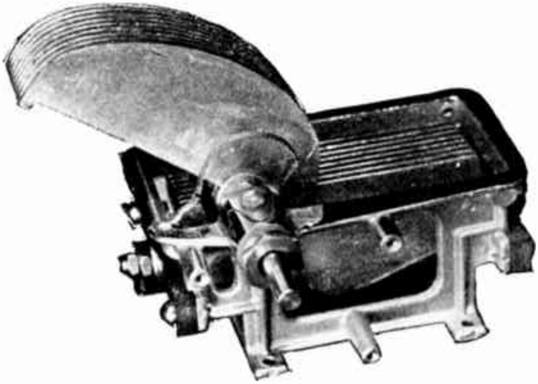
### Specifications

Number of plates; 23, 29, 33, 45
End plates; sheet brass
Insulation; hard rubber
Plates; aluminum
Type; straight line frequency

Bearing; self-aligning ball
Mounting; for panel
Maximum cap. for 23 plate .00025; 45 plate .0005 mfd.
Connection; pigtail

## Pearl Performance Curve





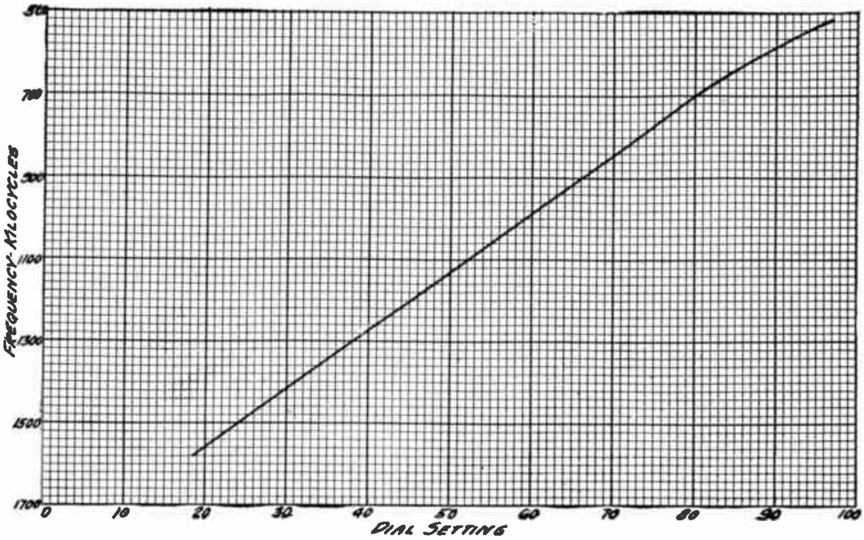
## Perlezs Condenser

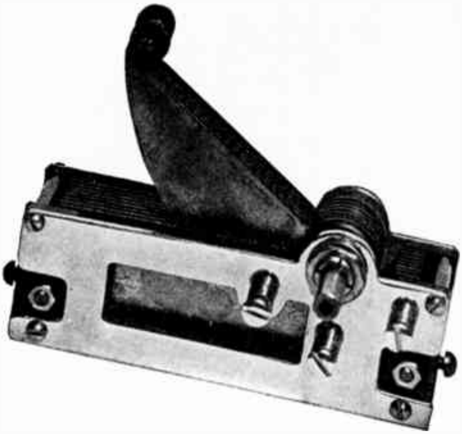
### Specifications

Number plates; 17 (made in var. sizes)
Plates; die-cast metal
End plates; die cast
Insulation; transparent Bakelite
Type; straight line frequency

Mounting; for panel
Bearings; brass
Caps.; .00025, .00031, .00035 and .0005 mfd.

## Perlezs Performance Curve





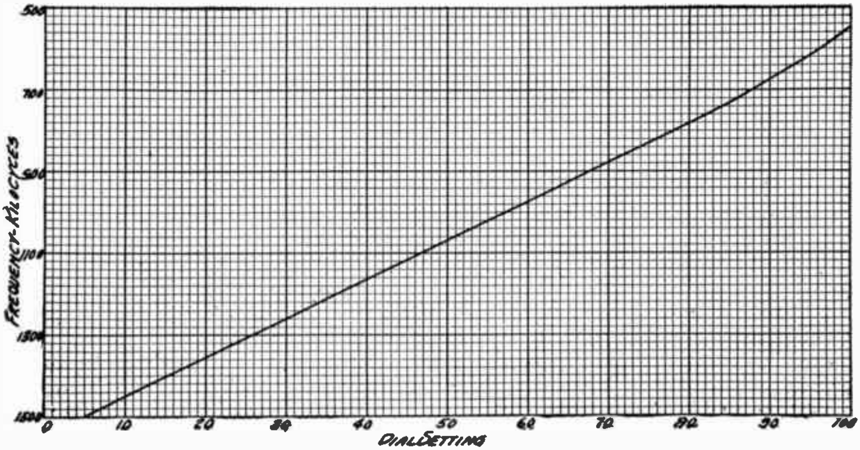
## Rasla Condenser

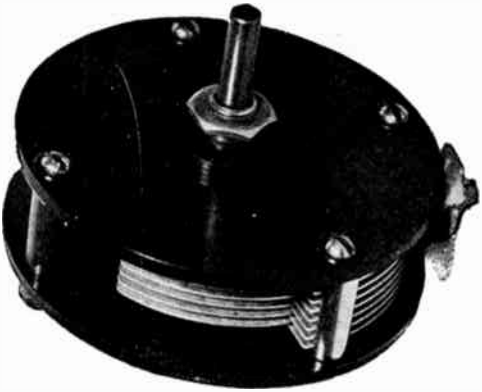
### Specifications

Number of plates; 15 (made in four sizes)
Plates; brass
Insulation; hard rubber
End plates; brass

Type; straight line frequency
Mounting; for panel
Bearings; brass cone
Caps.; .00025 to .0005 mfd.

## Rasla Performance Curve





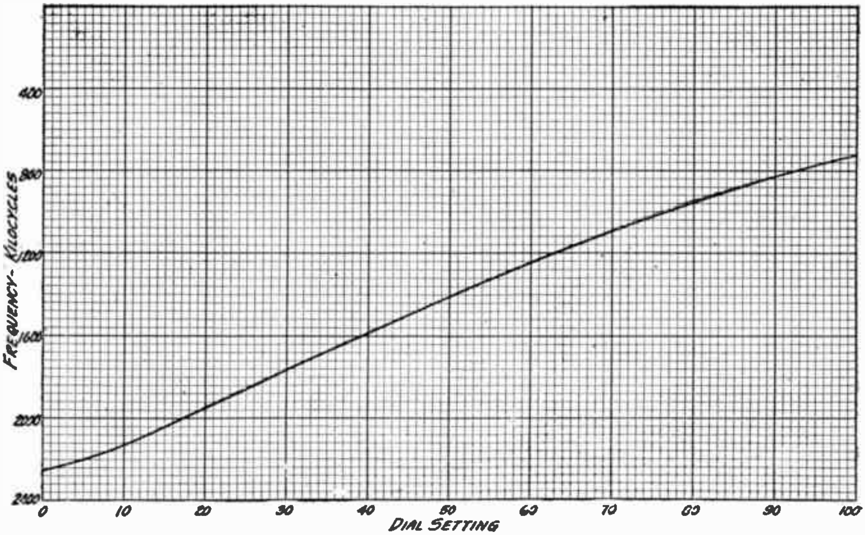
## Rathbun Condenser

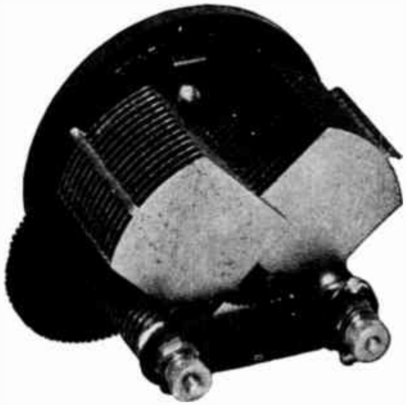
### Specifications

Number of plates; 17 (made in all stand. sizes)
Plates; aluminum
End plates; moulded Bakelite
Insulation; Bakelite

Type; straight line frequency
Mounting; for panel
Bearings; brass
Caps.; all stand. caps.

## Rathbun Performance Curve



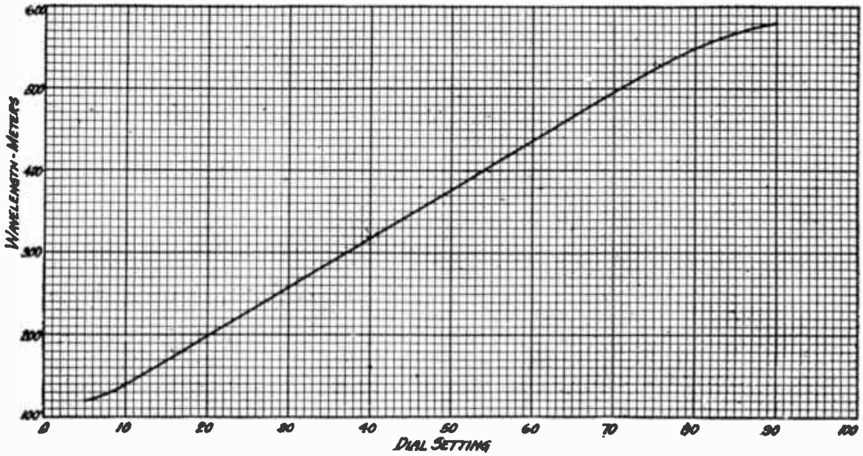


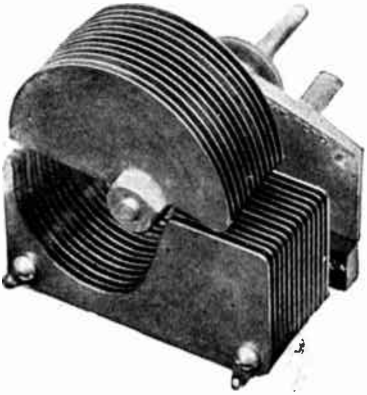
Remler Condenser

## Specifications

| | |
|---|---|
| Number of plates; 27 | Provided with engraved dial |
| Insulation; moulded Bakelite | Max. cap.; type 630, .00035 mfd.; type 631, .0005 mfd. |
| Plates; brass | Mounting; for panel |
| Twin rotor; no stationary plates | |

## Remler Performance Curve





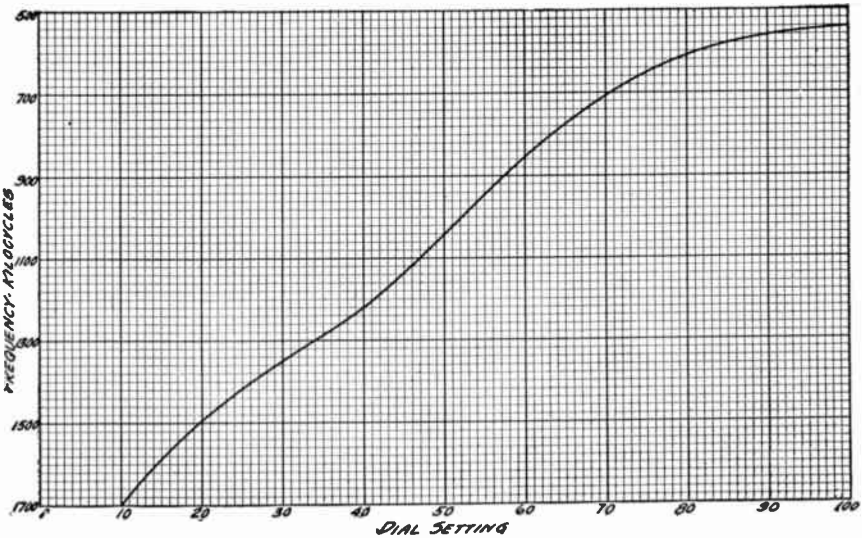
## Silver-Marshall Condenser

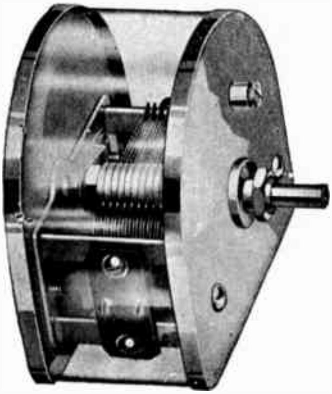
### Specifications

**Number of plates; 25 (also 11, 17, 35)**
**Plates; silver plated brass**
**End plates; one of cast metal**
**Insulation; hard rubber**

**Type; made in S.L.W. and S.L.F.**
**Mounting; for panel**
**Caps.; .0005, .00035 and .00025 mfd.**

### Silver-Marshall Performance Curve





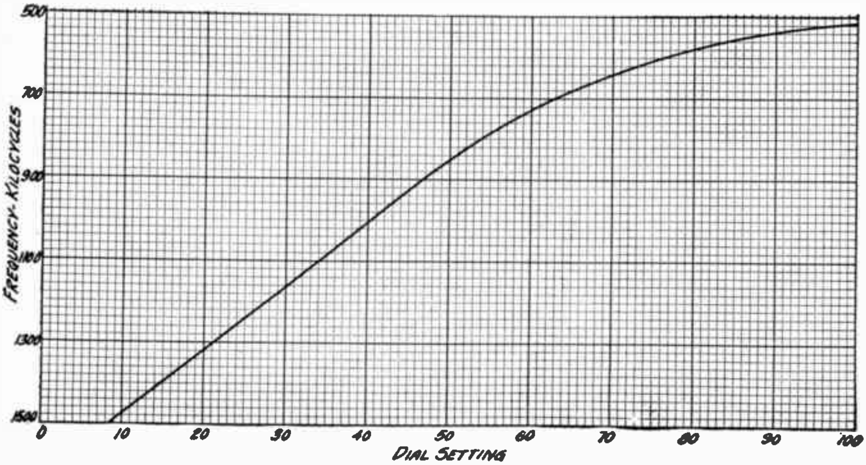
## Walbert Condenser

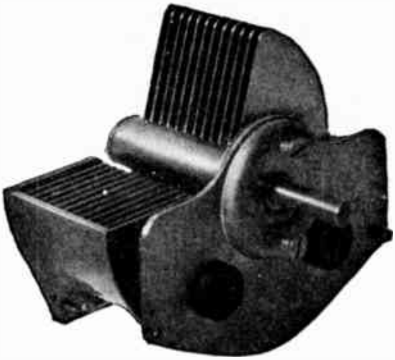
### Specifications

Number of plates; 21 (made in var. sizes)
Plates; brass
End plates; brass
Mounting; one hole; panel
Connection; phosphor bronze spring

Type; straight line frequency
Bearings; brass
Covered with celluloid
Made in caps. of .00035, .0005 and .000105 mfd.

## Walbert Performance Curve



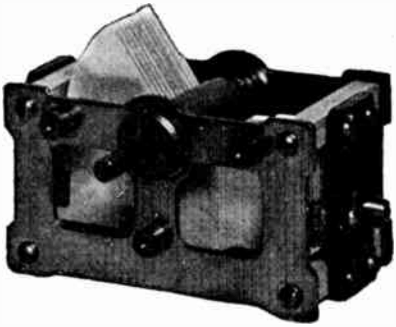


Allen-Bradley Condenser

## Specifications

Number plates; 23
End plates; brass
Plates; brass
Insulation; hard rubber

Type; straight line cap.
Bearing; self adjusting
Mounting; for panel
Caps.; .00025, .00035, .0005 and .001 mfd.

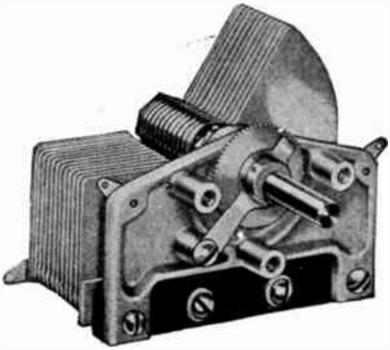


Beacon Condenser

## Specifications

Number plates; 21 (made in var. sizes)
Plates; aluminum
End plates; brass
Insulation; Bakelite

Type; straight line capacity
Mounting; for panel
Bearings; cone brass
Caps.; made in all standard caps.

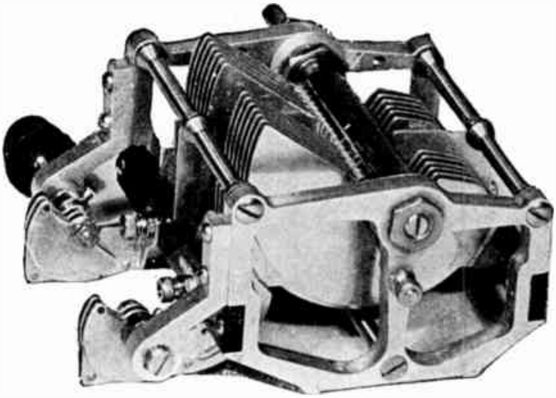


Benjamin Condenser

Specifications

Number of plates; 25 (also 13 and 17)
Insulation; hard rubber
Plates; aluminum
Connection; spring

End plates; cast metal
Mounting; for panel
Connection; spring
Caps.; .00025, .00035 and .0005 mfd.

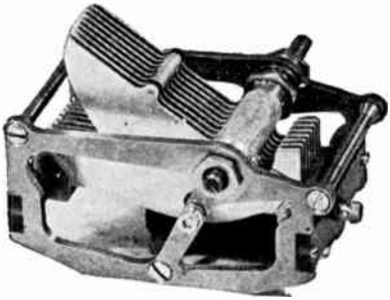


Bremer-Tully Condenser

Specifications

Number of plates; 13 in each unit
Plates; aluminum
End plates; cast aluminum frames
Insulation; transparent Bakelite

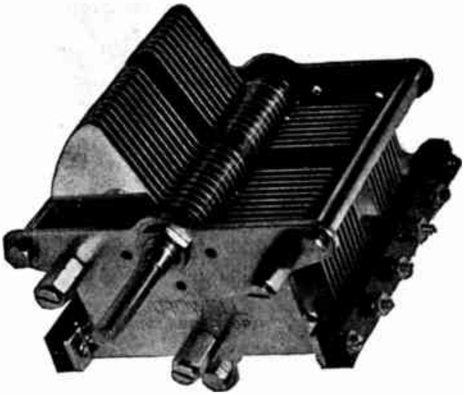
Type; straight line frequency
Bearings; adjustable brass
Mounting; for panel
Caps.; .00025 and .00035 mfd.



## Bremer Tully Condenser

### Specifications

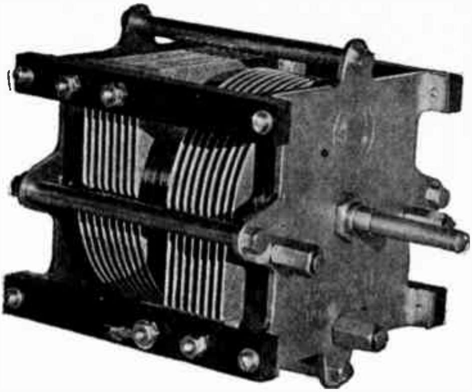
| | |
|---|---|
| Number plates; 13 and 17 | Type; straight line frequency |
| Plates; aluminum | Bearings; adjustable; brass |
| End plates; cast aluminum frames | Mounting; for panel |
| Insulation; transparent Bakelite | Caps.; .00025 and .00035 mfd. |



## Cardwell Condenser

### Specifications

| | |
|---|---|
| Number of plates; 17 (made in var. sizes) | Type; straight line capacity |
| Plates; aluminum | Mounting; for panel |
| End plates; brass | Bearings; cone brass |
| Insulation; hard rubber | Caps.; made in all stand. sizes |

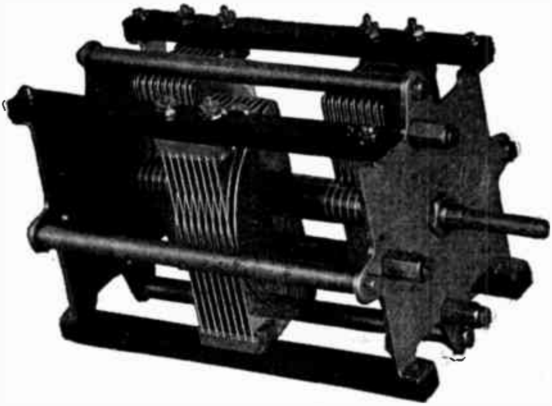


Cardwell Condenser

Specifications

Number of plates per unit; 17
Plates; aluminum
End plates; brass
Insulation; hard rubber

Type; straight line capacity
Mounting; for panel
Bearings; cone brass
Caps.; all standard caps



Cardwell Condenser

Specifications

Number of plates per unit; 17
Plates; aluminum
End plates; brass
Insulation; hard rubber

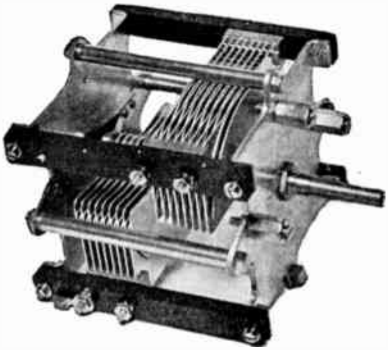
Type: straight line capacity
Mounting; for panel
Bearing; cone brass
Caps.; all standard cap

Cardwell Transmitting Condenser

Specifications

Number Plates; 17
Plates; aluminum
End plates; brass
Insulation; hard rubber

Type; for C. W. transmitters
Bearings; cone brass
Mounting; provided with cast brackets
Caps.; all standard sizes



Cardwell Condenser

Specifications

Number of plates per unit; 17
End plates; brass
Insulation; hard rubber
Plates; aluminum

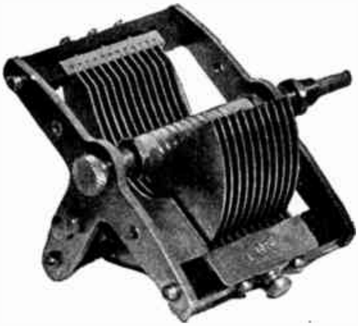
Type; straight line capacity
Mounting; for panel
Bearings; cone brass
Caps.; all standard caps.

Cardwell Condenser

## Specifications

Number plates; 17 (made in var. sizes)
Plates; aluminum
End plates; brass
Insulation; hard rubber

Type; straight line frequency
Mounting; for panel
Bearings; cone type
Caps.; made in all stand. caps.

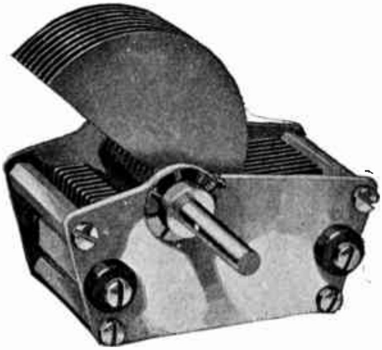


Crest Condenser

## Specifications

Number of plates; adjustable 2 to 23
Insulation; hard rubber
Plates; brass
End frames; brass
Bearings; brass
Finish; brass or nickel

Type; Semi-straight line frequency
Connection; through bearings
Mounting; for panel
Max. cap.; .000522 mfd.
Min. cap.; .00011 mfd.
Resistance; 18 ohms

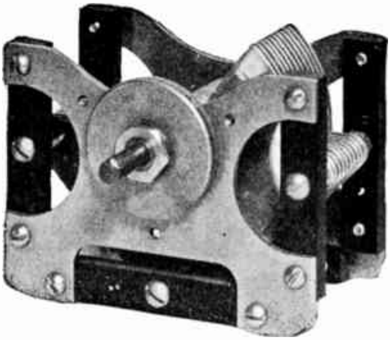


D.X.L. Condenser

Specifications

Number of plates; 19 (made in var. sizes)
End plates; heavy brass nickeled
Plates; silver-plated brass
Insulation; hard rubber

Type; straight line frequency
Mounting; for panel
Bearings; cone type
Caps.; .00025, .00035 and .0005 mfd.



Elgin Tool Works Condenser

Specifications

Number of plates; 21 (made in var. sizes)
Plates; aluminum
End plates; brass
Insulation; hard rubber

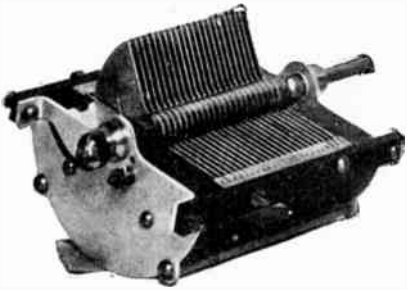
Type; straight line cap.
Mounting; for panel
Bearings; cone brass
Caps.; made in all stand. caps.

Elraco Condenser

### Specifications

Number of plates; 11, 17, 23
End plates; sheet brass
Insulation; Bakelite
Plates; aluminum
Mounting; for panel

Type; straight line wavelength
Connection; phosphor bronze spring
Bearings; brass cone
Max. cap.; 11 plate .00025; 23 plate, .0005 mfd.

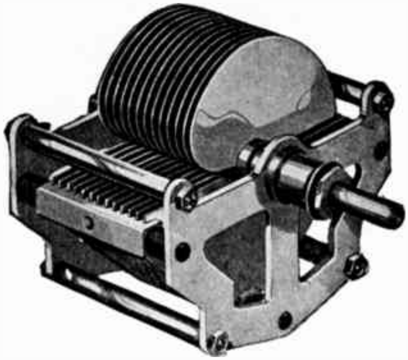


Gardiner and Hepburn Condenser

### Specifications

Number of plates; 43 (made in var. sizes)
Plates; aluminum
End plates; aluminum
Insulation; hard rubber

Type; straight line capacity
Mounting; for panel
Bearings; brass cone
Caps.; made in all standard sizes

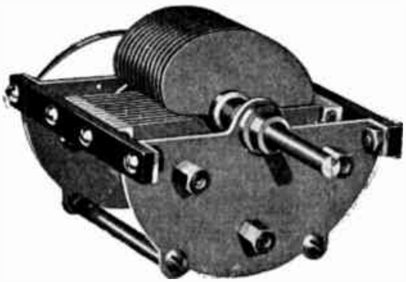


Gardiner Hepburn Condenser

### Specifications

Number of plates; 25 (made in var. sizes)
End plates; aluminum
Plates; aluminum
Insulation; hard rubber

Type; straight line wavelength
Mounting; for panel
Bearings; cone brass
Caps.; made in all stand. caps.

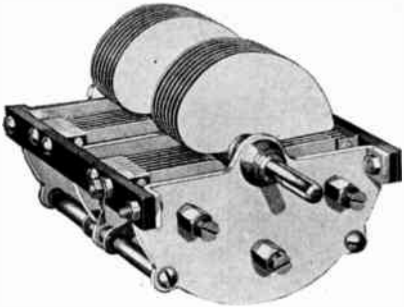


Gardiner and Hepburn Condenser

### Specifications

Number of plates; 26 (made in stand. sizes)
Plates; aluminum
End plates; aluminum
Insulation; hard rubber

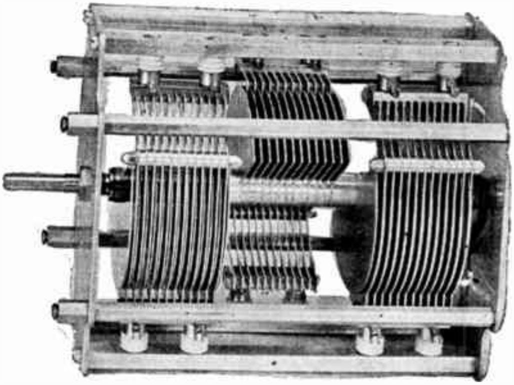
Type; straight line wavelength
Mounting; for panel
Bearings; cone brass
Caps.; made in all stand. caps.



## Gardiner and Hepburn Condenser

### Specifications

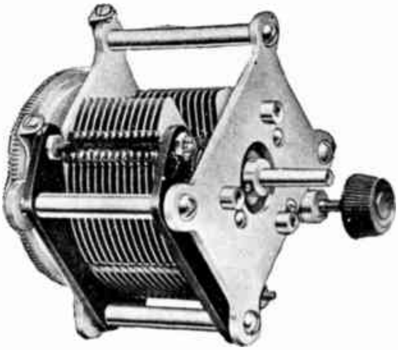
| | |
|---|---|
| Number of plates; 15 plates per unit | Type; straight line wavelength |
| Plates; aluminum | Mounting; for panel |
| End plates; aluminum | Bearings; cone brass |
| Insulation; hard rubber | Caps.; made in all stand. caps. |



## General Instrument Condenser

### Specifications

| | |
|---|---|
| Number of plates in each unit; 25 | Type; straight line frequency |
| End plates; polished brass | Bearings; brass cone |
| Plates; aluminum | Mounting; for panel |
| Insulation; pyrex or isolantite | Made in all standard caps. |

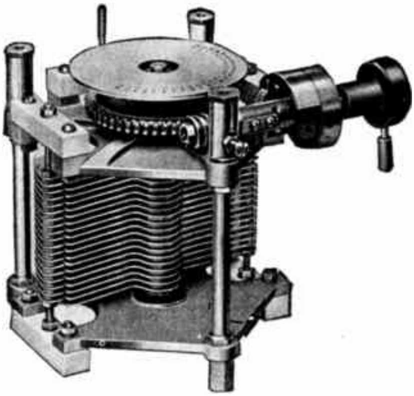


General Radio 334 Condenser

### Specifications

Number of plates; 26 (three sizes)
End plates; brass
Insulation; bakelite
Bearings; brass

Type; straight line wavelength
Mounting; for panel
With or without vernier
Caps.; .0005, .00035 and .00025 mfd.

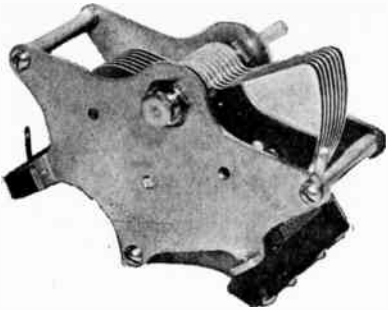


General Radio Precision Condenser

### Specifications

Number plates; 36
End plates; cast metal
Insulation; treated porcelain
Plates; heavy aluminum

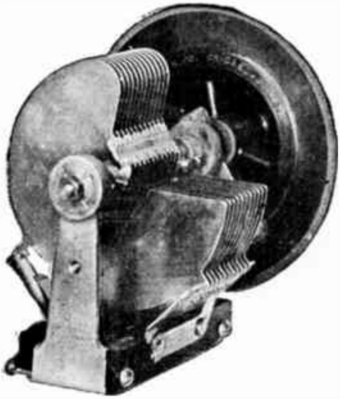
Type; straight line cap.
Mounting; for cabinet only
Vernier; precision type



## Haig and Haig Condenser

### Specifications

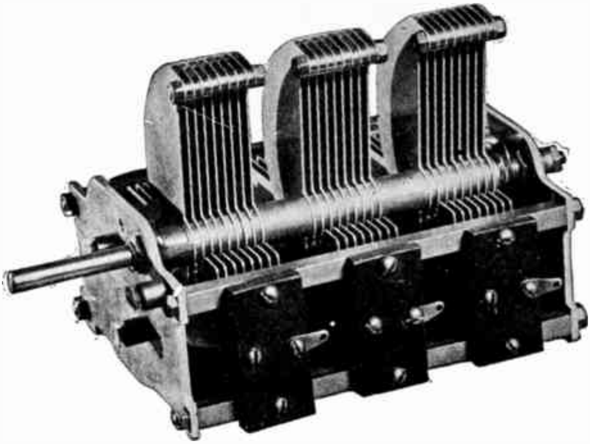
| | |
|---|---|
| Number plates; 17 (made in var. sizes) | Type; straight line wavelength |
| Plates; aluminum | Mounting; for panel |
| End plates; aluminum | Bearings; cone brass |
| Insulation; hard rubber | Caps.; made in all standard caps. |



## Kellogg Switchboard Condenser

### Specifications

| | |
|---|---|
| Number plates; 23 (made in all stand. sizes) | Type; straight line capacity |
| Plates; brass | Mounting; for panel |
| End plates; aluminum frames | Bearings; brass cone |
| Insulation; hard rubber | Caps.; all standard sizes |



## Lombardi Condenser

### Specifications

Number of plates; 2 sets 17 (made in var. sizes)
End plates; brass
Plates; aluminum
Insulation; hard rubber
Made in triple and double units

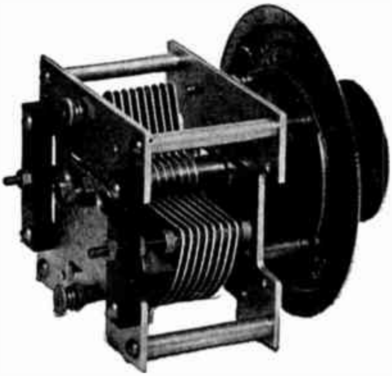
Type; S.L.F or S.L.W.
Bearings; self aligning
Mounting; for panel
Caps.; .0005, .00035 and .00025 mfd.

## Manhattan Condenser

### Specifications

Number of plates; 23 (also 13, 17 and 43)
Plates; brass
End plates; heavy brass
Insulation; hard rubber

Type; straight line capacity
Vernier; special type
Mounting; for panel
Caps.; .00028, .00037, .0005, .001 mfd.



National Condenser

### Specifications

Number of plates; 17 (made in var. sizes)
Plates; aluminum
End plates; aluminum
Insulation; hard rubber

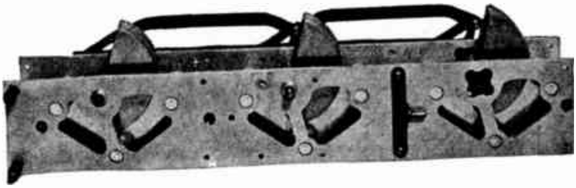
Type; straight line capacity
Mounting; for panel
Bearings; brass cone
Caps.; made in all stand. sizes

New York Coil Condenser

### Specifications

Number of plates; 23 (made in all stand. sizes)
Plates; aluminum
End plates; brass
Insulation; hard rubber

Type; straight line capacity
Mounting; for panel
Bearings; cone brass
Caps.; all stand. sizes



## Pfanstiehl Condenser

### Specifications

Number of plates per unit
Plates; aluminum
End plates; aluminum
Insulation; isolantite

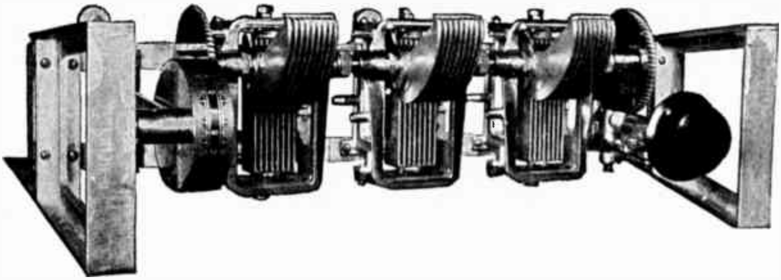
Type; straight line
Mounting; for panel operation
Bearings; brass cone
Caps.; all standard sizes

## Phenix Condenser

### Specifications

Number of plates; 25 (made in var. sizes)
Plates; aluminum
End plates; cast metal frame
Insulation; hard rubber

Mounting; for panel
Type; straight line frequency
Bearings; brass
Caps.; all standard sizes



## Perlezs Condenser

### Specifications

Number plates each unit; 17
Plates; die-cast metal
End plates; die cast
Insulation; transparent bakelite

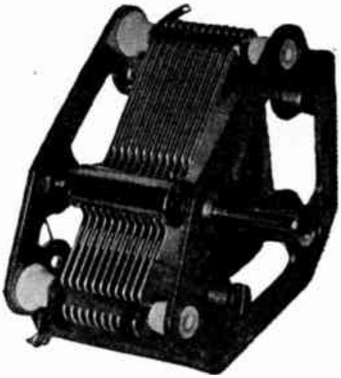
Type; straight line frequency
Mounting; base or panel
Bearings; brass
Caps.; .00025, .00031, .00035, .0005 mfd.

## Precise Condenser

### Specifications

Number of plates; 25
Plates; brass
End plates; stamped brass frame
Insulation; hard rubber

Type; comb. S.L.F. and S.L.C.
Mounting; for panel; 4-hole
Max. caps.; .0005 mfd. and .00035 mfd.



Power-Plus Condenser

Specifications

Number of plates; 22
Plates; aluminum
Insulation; porcelain
End plates; brass

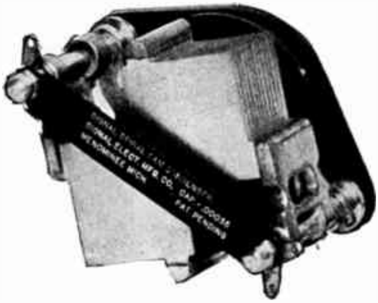
Type; straight line frequency
Mounting; for panel
Bearings; split bronze, conical
Caps.; .00025, .00035, .0005 mfd.

Quam Condenser

Specifications

Number of plates; made in three sizes
Plates; aluminum
Insulation; pyrex glass
End plates; one pyrex and one cast metal

Type; straight line caprcity
Mounting; for panel
Bearings; brass
Caps.; .00025, .00035 and .0005 mfd.

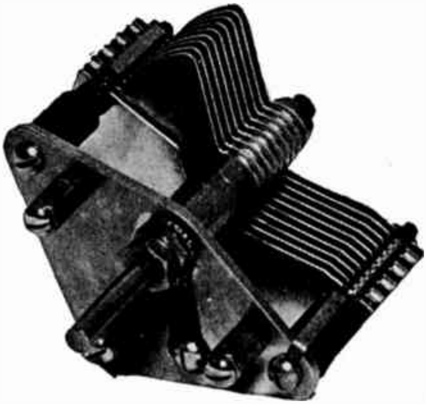


Signal Condenser

Specifications

Number plates; 24 (made in three sizes)
Plates; brass
End plates; Bakelite
Insulation; Bakelite

Type; straight line frequency
Mounting; for panel
Bearing; brass
Caps.; .00025, .00035 and .0005 mfd.



U.S. Tool Condensers

Specifications

Number of plates; 19 (made in var. sizes)
Plates; aluminum
End plates; brass
Insulation; hard rubber

Type; straight line capacity
Mounting; for panel
Bearings; cone brass
Caps.; made in all stand. caps.

## Amplex Condenser

Use; grid circuit
Dielectric; mica
Container; moulded Bakelite
Connectors; binding posts
Caps.; adjustable

## Bremer-Tully Condenser

Use; grid circuit
Dielectric; air
Container; moulded Bakelite
Connectors; binding posts
Caps.; ½ to 30 mmfd.

## Deutschman Condenser

Use; receiving circuits, filters, by-pass.
Dielectric; impregnated paper
Container; sheet metal
Terminals; soldering lugs
Caps.; .1, .25, 1, 2, 3, 4, and 5 mfd.

## Dubilier 601 Condenser

Use; receiving circuits
Dielectric; mica
Container; clamped between Bakelite sheets
Terminals; soldering lug with eyelets
Caps.; .00005, .0001, .00025, .0005, and .001 mfd.

## Dubilier 640 Condenser

Use; receiving circuits resistance coupled amplifiers
Dielectric; mica
Container; clamped between two Bakelite sheets
Terminals; soldering lugs
Caps.; .006, .0075, .01, .015 and .02 mfd.

## Dubilier 640 Condenser

Use; receiving circuits
Dielectric; mica
Container; clamped between Bakelite sheets
Terminals; soldering lugs
Caps.; .00025, .0005, .001, .002, .0025, .003, .004 mfd.

## Dubilier Filter Condenser

Use; B-battery eliminator circuits
Voltage rating; 160 to 400 D.C. and 110 to 220 volts A.C.
Dielectric; impregnated paper
Container; sheet metal
Caps.; 1, 2 and 4 mfd.

## Dubilier By-Pass Condenser

Use; by-pass in receiving circuits
Voltage test; 135 normal
Dielectric; impregnated paper
Container; sheet metal
Terminals; soldering lugs
Caps.; .1, .25, and 5 mfd.

## Dubilier Condenser

Use; transmitting circuits
Dielectric; mica
Normal load; 5 amperes
Insulation; Isolantite
Container; cast aluminum
Terminals; brass
Caps.; .100, .075, .050, .020, .010, .0075, .0020, .0010, .0005, .00025, .00010 mfd.

## Dubilier 580 Condenser

Use; transmitting circuits
Normal voltage rating; 5,000 volts at 60 cycles
Dielectric; mica
Terminals; rubber covered pigtails
Caps.; .0003, .0004, .0005, .001, .002, .005, .01, .02 mfd.

## Dubilier 577 Condenser

Use; transmitting circuits
Normal voltage rating; 1,000 volts at 60 cycles
Dielectric; mica
Container; sheet metal
Caps.; .0001, .00025, .0005, .001, .0015, .002, .0025, .005, .0075 and .01 mfd.
Terminals; rubber covered pigtails

## Faradon Condenser

Use; receiving circuits
Dielectric; mica
Container; clamped between metal plates
Terminals; lugs to fit binding posts
Caps.; all standard caps.

## Hilco Condenser

Use; receiving circuits
Dielectric; mica
Container; pressed sheet metal
Connectors; soldering lugs
Caps.; made in all standard sizes

## Micamould Condenser

Use; receiving circuits
Dielectric; mica
Container; moulded Bakelite
Terminals; soldering lugs
Caps.; made in all standard caps.

## New York Coil Condenser

Use; receiving circuits
Dielectric; mica
Container; clamped between akelite Bsheets
Terminals; adjustable for soldering lugs or binding posts
Caps.; all standard caps.

## Potter Condenser

Use; filter and by-pass
Dielectric; impregnated paper
Container; sheet metal
Terminals; soldering lugs
Caps.; all standard caps.

## Sangamo Condenser

Use; receiving circuits
Dielectric; mica
Container; moulded Bakelite
Terminals; binding screws
Caps.; made in all standard caps.

## Sterling Variable-Fixed Condenser

Use; receiving circuits
Dielectric; mica
Container; Bakelite body
Terminals; lugs
Caps.; adjustable

## Wireless Corporation of America Condenser

Use; filters for B-eliminator circuit
Dielectric; impregnated paper
Container; sheet tin
Connectors; soldering lugs
Caps.; unit contains all condensers necessary for B-eliminator circuit.

## X-L Variable-Fixed Condenser

Use; receiving circuits
Dielectric; air
Container; moulded Bakelite
Terminals; binding posts
Capacity; adjustable

## END OF SECTION IX

## SECTION X

# Coils

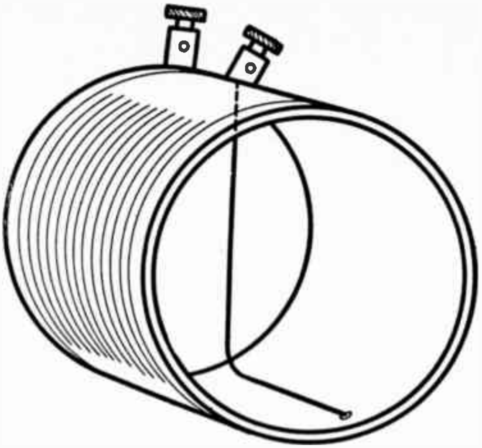
To look upon a single layer coil of wire wound upon a homely cardboard cylinder, one might think, and logically enough, that such coils function on very simple principles and that they could not be involved in the delicate formulæ of the engineer. If such a coil should be prepared for use in a direct current circuit, this speculation would be justified, but when they are used in a radio-frequency circuit, many very interesting things take place. As a matter of fact, it would be possible to write a book about the things that happen, although this may amaze the layman who visualizes nothing but a magnetic field about the coil when it passes current.

In the following paragraphs we will consider only those phenomena that effect radio reception. The reader will also notice as he goes on that the phenomena discussed become more and more involved and while the serious student may wish to continue through to the last, the reader who does not care to enter into mathematical discussion may stop midway feeling that he has a good practical understanding of coils and their function.

In Section IV we learned that coils of wire were used for two general purposes. Their most important use was in the process of tuning. By connecting a coil of wire to an aerial and varying the length of the coil through a movable contact it was found that the wavelength of an aerial system could be adjusted to different values depending upon the amount of wire in the coil. Coils are also used as the medium for the transfer of electrical energy from one circuit to another through electromagnetic induction.

In our early discussion of the simple laws of electricity, we saw how two different circuits involving two coils in proximity could be used for a transfer of energy. The first circuit involving a current source and a coil would transfer energy to a second circuit containing nothing but a coil with a current detecting instrument. We see this principle used again and again in radio circuits where one coil is coupled to another so that energy may be transferred from the first to the second circuit and so on. In some radio receivers the electrical energy is transferred as many as ten times. That is it jumps (electromatically) across ten gaps between the aerial and the reproducing device.

During the past two years radio engineers have set out on a campaign to reduce the electrical losses in radio receiving equipment. A great deal of their effort has involved coils and many improvements have been made that have helped to stop the appalling waste that takes place in the ordinary types. Let us for the moment focus our attention on the very common form of coil in Fig. A. Here we have an insulated tube which may be bakelite, hard rub-



A SIMPLE INDUCTANCE COIL

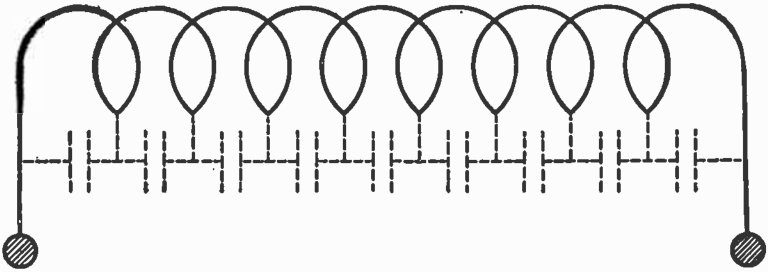
**Figure A:** A simple inductance coil of the type usually found in radio receivers. Coils take various forms, but this type is conventional.

ber, fibre, cardboard, glass or wood. Upon the outer surface of this tube is wound a number of turns of insulated wire and the ends of this wire are connected to two binding posts or terminals mounted at one end of the tube. To lay any claim to perfection such a coil would have to have (1) very low resistance, (2) no distributed capacity and (3) a maximum inductance for the amount of wire used.

The first of these important features does not depend entirely upon the ohmic resistance of the wire. The best we can do in selecting the wire for a coil is to see that it has a sufficiently large cross section, that the insulation is of the best possible kind (silk, for instance) and that the wire is of pure copper. As we shall see later, the wire alone does not determine the resistance; it is only one factor. In the case of direct current, the wire alone would be the only thing considered in determining the number of ohms of resistance in the circuit. The use of high-frequency currents changes all of this and our very simple little coil becomes a veritable bundle of the most intricate phenomena.

In a previous paragraph we mentioned distributed capacity. Unless the reader has studied literature of this type before, the term will be a new one to him. We know that capacity is a term used in connection with condensers and we know further that condensers are made up merely of two conducting surfaces or elements such as metal plates separated by a non-conducting medium such as air or glass. A simple combination of these elements is capable of storing electricity providing there is a *difference in electrical potential.* Such capacities are also capable of transferring energy from one circuit to another through what is known as *electrostatic coupling.*

Where there is a difference of electrical potential there is always a capacity effect; by this we mean that the elements involved tend to act as an electrical condenser. We know that



ILLUSTRATING THE CAPACITY BETWEEN TURNS.

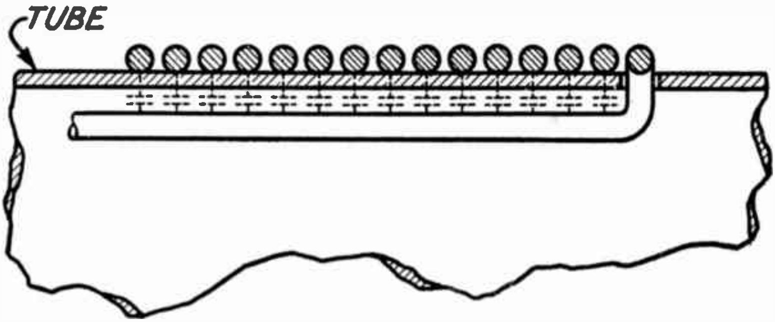
Figure B: The dotted lines in the diagram represent the small condensers that are formed between the turns of an inductance coil used in a radio receiver.

when current is allowed to pass through a coil such as we have been dealing with there will be a higher potential at the entrance to the coil than at the exit. No matter how well the wire in the coil conducts electricity, it will offer some resistance and this will create a *potential difference* between the terminals. Not only this but there will be a potential difference between every turn of the coil, because of the electrical resistance offered. If there is a potential difference between each turn of the coil and the turns are insulated from each other, we may look upon the coil as having a number of tiny condensers connected between its turns. Reference is made to the sketch (Fig. B) where this effect is diagrammed. We do not need to merely imagine the presence of these little condensers for they are there just as surely as the coil itself and it is this effect that is called *distributed capacity* and it is a phenomenon that associates itself only with alternating currents in the higher frequencies.

It will be evident that coils with a minimum distributed capacity are desirable for we shall see that the charging of all of these little condensers involves a loss of energy and that we must strive in designing coils to minimize this capacity effect between turns.

The nature of the insulation on the wire and the distance separating the turns of the wire will effect this so-called distributed capacity. If we should wind a coil with silk covered wire, measure its capacity and then apply to the wire a coat of shellac we should find that the distributed capacity would be greatly increased and that the electrical efficiency of the coil would drop to a lower level. It might be well to warn the reader here against this practice. Oftentimes the shellacing of a coil will render a radio receiver totally inoperative. If the coils in a Cockaday four-circuit tuner are shellaced, the receiver becomes practically useless, due to the drastic increase in capacity.

Let us go back to the simple coil that we have been analyzing and see if we cannot find other capacity effects. It will be noticed from the drawing that the terminals are mounted at one end of the coil and that the wire from one end of the coil runs down the inside wall of the tube to make connection to one of the terminals. This wire runs directly under the turns of wire on the outside of the coil and it is separated from them not only by the insulation of the wire but by the material of which the tube is constructed. Here we have a wire running under wires of a higher



ANOTHER SOURCE OF USELESS COIL CAPACITY

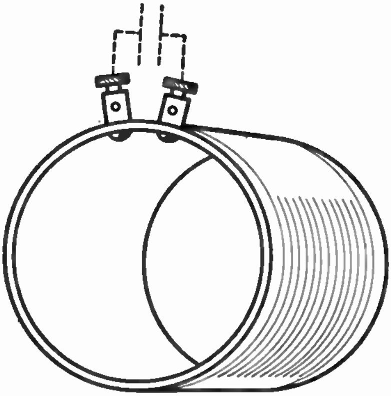
**Figure C:** How capacity is formed between the turns and lead wire of a coil. This difficulty may be easily overcome, however, by running the lead wire through the tube concentrically.

potential and consequently we must have a capacitative effect. This effect will be as illustrated in the accompanying sketch, Fig. C.

We know that the terminals of the coil must be at different potentials and, if they are mounted as shown in the original sketch (Fig. A), we know that there must be a capacitative effect between them. This is also shown in Fig. D. If these terminals are placed close together, the capacity of the condenser of which they form the plates can be very high for we must remember that the maximum potential difference is at the ends of the wire. Since the capacity of condensers decreases as the distance between the plates is increased (this follows an inverse law), it will be seen that efficient coils should have their terminals as far removed from each other as possible.

Condensers used in combination with coils form a practical tuning combination and such combinations are widely employed in radio receivers. Let us see now what effect this distributed capacity would have in a coil used in combination as depicted in Fig. E. Here it will be seen that the condenser is connected in parallel or shunted across the terminals. Back in our discussion on condensers, we learned that when condensers are connected in parallel the capacity is added. From this it will be seen that the capacity of the condenser connected across the coil will be added to the distributed capacity of the coil itself. Thus, if the coil has a distributed capacity of 50 mmfd. (mmfd. = micro-micro farad) and the variable condenser a minimum capacity of 20 mmfd., the minimum of the system in general will be 70 mmfd. If the condenser has a maximum of 250 mmfd. the maximum of the system will be 300 mmfd. Such a combination will give a range of capacity of approximately 1 to 4 or wavelength of 1 to 2, since the wavelength varies as the square root of the capacity.

If the capacity of the coil should be reduced to 25 mmfd., the minimum capacity with the same condenser would be 45 mmfd. and the maximum 275 mmfd. With this combination we would have a capacity range from 1 to 6 and a wavelength range of from 1 to 2.4 instead of from 1 to 2 as in the case of the coil with the distributed capacity of 50 mmfd. From this, it is evident that the wavelength variation will be greatest



THE CAPACITY BETWEEN COIL TERMINALS

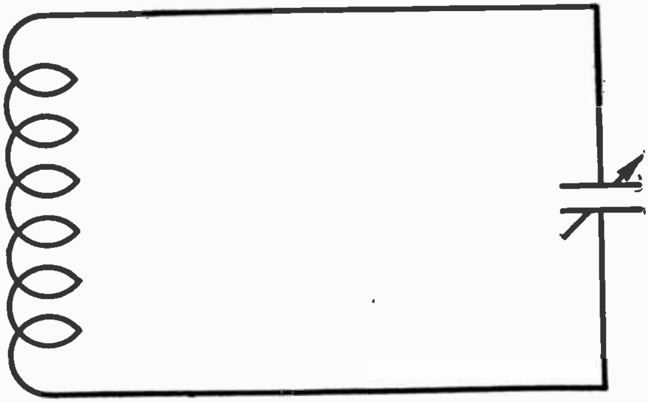
Figure D: If the binding posts of a coil are mounted close together as illustrated, a capacity will be formed between them. This capacity, like all other unwanted capacity in a coil, helps to reduce the efficiency.

in systems of this nature when the distributed capacity of the coils used is minimum. Not only this, but there is a great saving in energy and the electrical losses will be less when the distributed capacity is low.

Coils should be designed to get as great a tuning range as possible with a given variable condenser. This condition is met when the capacity of the variable condenser is small and the number of turns in the coil large. Signal strength will be high when large amounts of wire are used. However, this object is defeated when the distributed capacity is allowed to reach a great value. The Fig. F herewith shows a conventional type of coil investigated some time ago by Prof. Morecroft of Columbia University. It will be noted that the two leads from the coil make connections to the terminals inside of the tube. When first tested, this coil had a natural period or a natural wavelength of 117 meters. When the two leads were taken away from the terminals in the wooden end, the wavelength was reduced to 93 meters. When the long lead was run through the coil as concentrically as possible, the wavelength was reduced to 86 meters and a further reduction to 71 meters was the result when the binding posts were placed one at each end of the coil near the ends of the wire. This also reduced the distributed capacity from 13.7 mmfd. to 5.05 mmfd.

In general it must be said that coils should have a minimum of bulk, or better that the forms upon which the coils are wound should have a minimum bulk. This is so because we do not want to introduce a large amount of dielectric material into the magnetic and electrostatic field produced by the coil. The material must be moisture proof and it must have sufficient strength to be mounted so that the turns will remain intact and vibration will be eliminated.

We must come back to the subject of



A COIL AND A CONDENSER

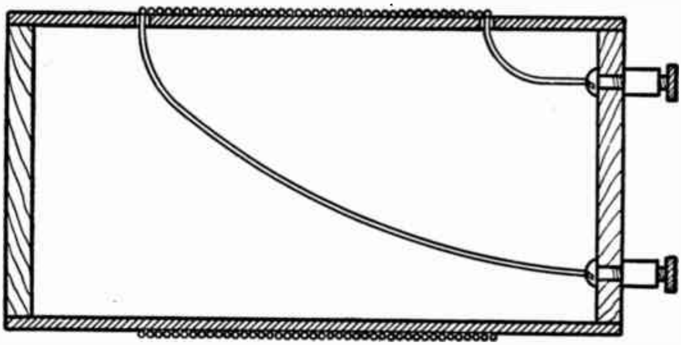
**Figure E:** The text will explain how the combination of a coil and a condenser in a radio receiver will be affected by the presence of a large amount of distributed capacity in the coil.

distributed capacity to consider means of reducing this effect by winding the wire so as to minimize the electrostatic field produced by potential differences. Since we know that the capacity of two bodies to store electric current decreases inversely as the square of the distance separating them, it should be our object to place the turns of every coil as far apart as possible. To follow this practice blindly would be very impractical for our coils would be so cumbersome as to require many times the space that they now occupy. Some coils are being based on this principle using a separation of about 1/16th of an inch between the turns and winding the coil upon very slender frames having little bulk. Such coils are said to have low losses and it is true that they are more efficient electrically than ordinary types.

Lorenz, an electrical experimenter, developed a method of winding coils that greatly reduces this destructive distributed capacity. By winding the wire upon a series of pegs arranged in a circle he was able to zigzag it in the fashion illustrated (Fig. G). If this method is examined closely it will be seen that no two wires parallel each other for any distance at close proximity. The turns are close to each other only at points where the wires cross and, of course, there will be a capacity effect at these points but it will be so small as to be well beyond values ordinarily obtained.

There is still another method of winding Lorenz coils by mounting the pegs radially and zigzagging the wire to form a pancake type of coil. (See Fig. H.) Spider web is the name usually applied to coils of this type and owing to this zigzagging method, the distributed capacity of these coils is also reduced to a fair minimum.

The most practiced method of varying the inductance of plain coils is that of providing the coil with tapped joints as illustrated (Fig. I). The introduction of these points, due to their electrical effect, immediately contributes to the losses already taking place. They not only add resistance to the coil, but distributed capacity as well, for there will



A COIL MADE FOR RESEARCH PURPOSES

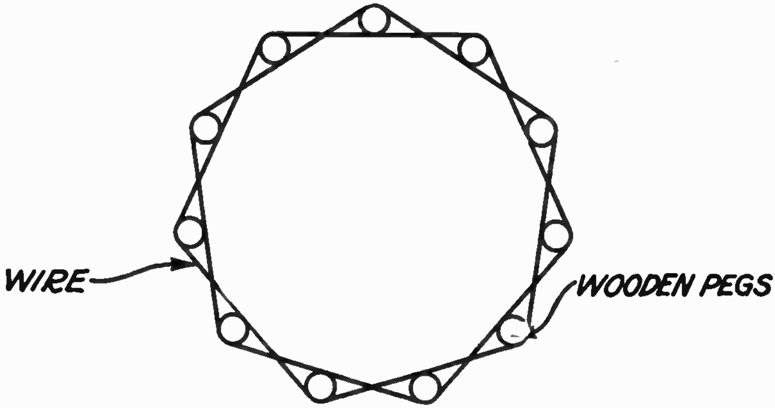
Figure F: Prof. Morecroft of Columbia University investigated a coil built in the manner illustrated above and found out many interesting things. The results are given in the text.

be a difference of electrical potential between each point and between each lead. Of course, this cannot help but establish a capacitative effect between these members and to this there will be added resistance. The effect would be the same as that illustrated; we would have a coil used with a number of very small resistances and small capacities.

In viewing our tapped coil diagram, we will notice that when the switch point is not on the last tap that there is an unused portion of the coil. This is usually referred to as a *dead end*. As a matter of demonstrative fact, there is really no such a thing as a dead end and if we could apply the proper measuring instruments we would find that this dead end was a greedy consumer of energy and that it would do a great deal to reduce the general efficiency of the coil.

Perhaps the average reader of this manuscript has heard honeycomb coils alluded to in conversation between amateur radio telegraphers. The honeycomb coil which we have illustrated in Fig. J is really a coil of the Lorenz type, since the various turns are caused to cross each other at different angles. This quite naturally reduces distributed capacity and produces a more efficient radio inductance. Such coils are ordinarily employed with small plugs and there is a measurable capacity across the terminals of such plugs. This capacity will act as a condenser shunted across the coil. However, this need not worry the novice for even with this drawback, honeycomb coils are decently efficient and they are very convenient for use as loading coils, wave trap inductances, and tuners. When used as a variable tuning device, the honeycomb coil must be provided with a standard. The holders for the coils proper are made movable so that the inductive relationship between the coils (and thereby the wavelength) can be altered. When the coils are close to each other, there is close coupling and maximum wavelength and when they are away from each other, there is minimum coupling and minimum wavelength.

Since these coils are interchangeable in their mountings, and since they may be purchased in a wide variety of sizes,

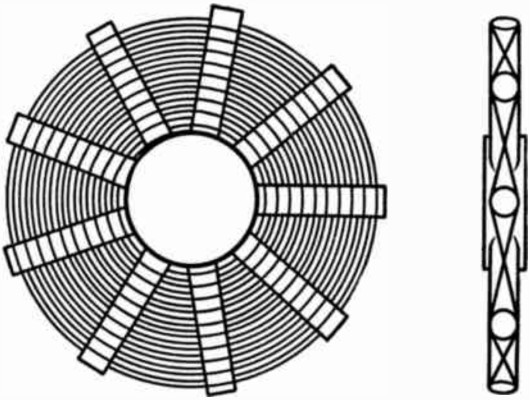


A FORM OF THE LORENZ COIL

Figure G: By winding wire zig-zag on pegs in the manner illustrated, the distributed capacity may be reduced greatly.

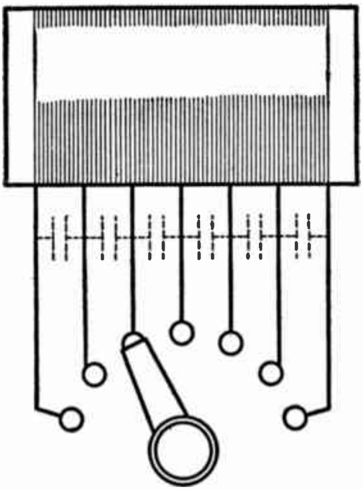
they are very convenient in making large changes in the wavelength of any receiver. The amateur experimenter equipped with a group of these coils may change the wavelength of his receiver from the broadcasting range to the high transatlantic telegraph range by simply inserting a new set of larger coils which is a mere matter of a few seconds.

To facilitate the use of such coils we have included two tables which will be found quite accurate for the duo-lateral or honeycomb coils that are now obtainable in every radio store. In one table



ANOTHER FORM OF LORENZ COIL

Figure H: This is also a Lorenz coil wound in a different fashion. The wire is zig-zagged around pegs placed radially.



CAPACITY BETWEEN COIL TAPS

Figure I: This is what happens when the taps of a coil are placed too close together.

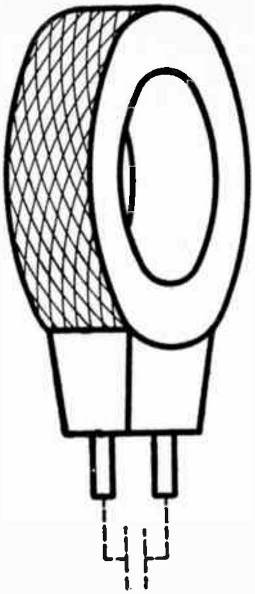
we show the natural wavelength range of the coils with different turns. In the second table the average wavelength obtained with honeycomb coils and 5, 11, 21, and 43 plate condensers is given. In such cases, it is assumed that the variable condenser used is connected directly across the terminals of a coil.

There are many, many different types of coils and we could carry this discussion on for hundreds of pages without having exhausted the fund of data that is available. What we wish to do is to familiarize ourselves with the most pertinent features of coils in general. This grounding will permit us to use good judgment in the choice of coils for receiving sets, and, after all, modern receiving sets are largely a matter of vacuum tubes, coils and condensers. The rest of the material used must be of an accessory nature.

In the accompanying sketch (Fig. K) we see still another type of coil which is called the "D" coil, so named because its two halves form the letter D. It might just as well be called a figure-8 coil, for it also forms this figure. It will be seen that this coil is wound by slotting a tube in the manner illustrated. The wire used may range anywhere from 14 gauge to 28 gauge depending upon the range of wavelengths desired.

Due to its peculiar construction and the fact that the magnetic fields produced by each half of the coil oppose each other, the coil produces a very small total magnetic field. This makes the device of value in reducing to a minimum stray magnetic coupling with other coils in the receiver. To put it more clearly, this coil may be used closer to other coils without danger of magnetic coupling.

In still another sketch (Fig. L) we see what is known as a bank wound coil and here again the effort is toward increasing the electrical efficiency by decreasing losses through distributed capacity and resistance. By bank wound



**A HONEY-COMB COIL**

Figure J: This picture not only shows the conventional form taken by honey-comb coils but also the distributed capacity that may exist between the terminals.

## HONEY-COMB COIL CHARACTERISTICS

| No. of Turns | Inductance in Millihenrys at 800 Cycles | Natural Wavelength in Meters | Distributed, Capacity Micro-micro Farads |
|---|---|---|---|
| 25 | .039 | 65 | 30 |
| 35 | .0717 | 92 | 33 |
| 50 | .149 | 128 | 31 |
| 75 | .325 | 172 | 26 |
| 100 | .555 | 218 | 24 |
| 150 | 1.30 | 282 | 17 |
| 200 | 2.31 | 358 | 16 |
| 249 | 3.67 | 442 | 15 |
| 300 | 5.35 | 535 | 17 |
| 400 | 9.62 | 656 | 13 |
| 500 | 15.5 | 836 | 13 |
| 600 | 21.6 | 1045 | 14 |
| 750 | 34.2 | 1300 | 14 |
| 1000 | 61.0 | 1700 | 13 |
| 1250 | 102.5 | 2010 | 11 |
| 1500 | 155.0 | 2710 | 13 |

coils we mean coils that are wound with staggered turns of wire. We will obtain a very good idea of the procedure followed in winding such coils upon tubes. First, two turns are wound upon the tube, one following the other. When the second turn is finished, the wire is given a little kink and the next turn is placed so that it will come between and on top of turns 1 and 2. Then the wire is kinked again and turn 4 is made. Then turn 5 is placed on top of 2 and 4, etc. By following the bank wound method we obtain a very compact coil with a most respectable low degree of distributed capacity.

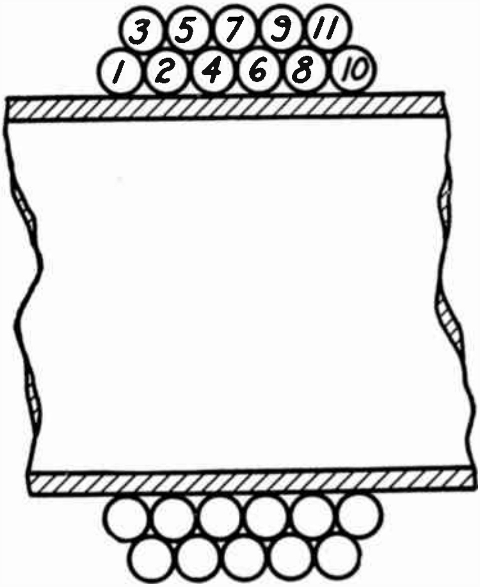
It is more than likely that the average readers of this discourse will understand very little about wire sizes or the general nomenclature in use by wire manufacturers. Yet a little more than a smattering of facts is necessary if the student is to gain more than a superficial mastery over the subject of radio. Perhaps there is no better place to insert material of this nature since we have

## MINIMUM AND MAXIMUM WAVELENGTHS OBTAINABLE WITH DUOLATERAL COILS WHEN USED WITH VARIABLE CONDENSERS*

| Type No. of Pacent Var. Con. | 3 Plate | | 5 Plate | | 11 Plate | | 21 Plate | | 43 Plate | |
|---|---|---|---|---|---|---|---|---|---|---|
| Capacity Range of Condenser in Micro-micro Farads Max. | 49 | | 91 | | 208 | | 418 | | 877 | |
| Capacity Range of Condenser in Micro-micro Farads Min. | 7 | | 8 | | 10 | | 13 | | 21 | |
| **Coil Numbers** | Wave Length in Meters | | Wave Length in Meters | | Wave Length in Meters | | Wave Length in Meters | | Wave Length in Meters | |
| | Min. | Max. | Min. | Max. | Min. | Max. | Min. | Max. | Min. | Max. |
| US 25.............. | 75 | 105 | 75 | 130 | 75 | 180 | 120 | 245 | 120 | 355 |
| US 35.............. | 105 | 145 | 105 | 175 | 105 | 245 | 160 | 335 | 160 | 480 |
| US 50.............. | 145 | 205 | 145 | 250 | 150 | 355 | 220 | 485 | 220 | 690 |
| US 75.............. | 195 | 290 | 200 | 365 | 210 | 520 | 340 | 715 | 340 | 1020 |
| US 100.............. | 250 | 380 | 255 | 475 | 260 | 675 | 430 | 930 | 430 | 1330 |
| US 150.............. | 335 | 550 | 340 | 705 | 355 | 1020 | 680 | 1410 | 680 | 2060 |
| US 200.............. | 435 | 730 | 445 | 935 | 465 | 1350 | 900 | 1880 | 900 | 2700 |
| US 249.............. | 535 | 910 | 560 | 1170 | 575 | 1700 | 1100 | 2370 | 1100 | 3410 |
| US 300.............. | 680 | 1120 | 690 | 1430 | 720 | 2140 | 1400 | 2870 | 1400 | 4120 |
| US 400.............. | 830 | 1450 | 870 | 1880 | 890 | 2750 | 1800 | 3830 | 1800 | 5500 |
| US 500.............. | 1050 | 1840 | 1080 | 2390 | 1120 | 3430 | 2300 | 4870 | 2300 | 7000 |
| US 600.............. | 1270 | 2200 | 1300 | 2840 | 1360 | 4130 | 2800 | 5700 | 2800 | 8200 |
| US 750.............. | 1600 | 2760 | 1680 | 3570 | 1710 | 5100 | 3500 | 7200 | 3500 | 10400 |
| US 1000.............. | 2090 | 3660 | 2140 | 4750 | 2240 | 6900 | 4700 | 9600 | 4700 | 13800 |
| US 1250.............. | 2570 | 4670 | 2640 | 6000 | 2770 | 8900 | 6000 | 12500 | 6000 | 18000 |
| US 1500.............. | 3320 | 5800 | 3400 | 7500 | 3570 | 11000 | 7500 | 15400 | 7500 | 22100 |

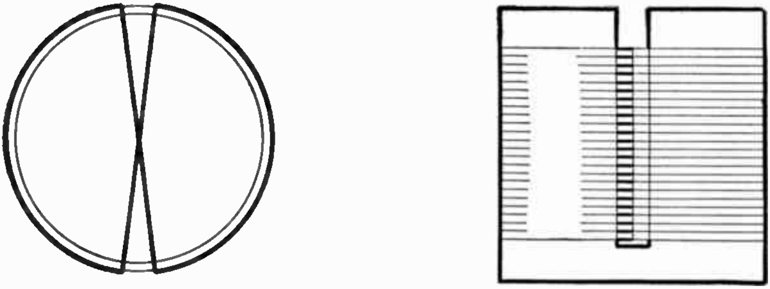
Note—In making calculations of the 21 and 43 Plate condensers a minimum capacity of 100 micro-microfarads has been assumed which includes the capacity of accessories in the circuit.

*Courtesy of Pacent Electric Company.



HOW BANK WOUND COILS ARE MADE

Figure L: The method used in winding a bank wound coil. The numbers on the wires indicate the order in which they are laid down.



THE CONSTRUCTION OF THE D COIL

Figure K: A simple but effective coil with a fair degree of electrical efficiency to its credit.

just completed a popular explanation of coil phenomena and are about to embark upon technical features of design.

When a wire is referred to by a certain number, as, for example, "No. 16 or No. 28," this number means the "gauge" of the wire. It is a way of specifying the thickness. It would be much more convenient and scientific simply to set down the diameter of the wire in thousandths of an inch or in millimeters, but years ago engineers got into the habit of specifying the sizes of wires and rods and plates by the particular slot or hole in a "gauge plate" into which the wire or other thing would fit. The habit has persisted. These slots or holes were numbered, hence the present numbers used to designate the sizes of wire.

Many such systems of gauges have been in use in different countries and at different times. In the United States, for use with copper wire, only one of these systems has survived. This is the American Standard or "Brown and Sharpe" gauge, often referred to as the "B. and S." gauge. The numbers in it are purely arbitrary, like the width letters for shoes. The gauge numbers do have, however, a mathematical relation to each other such that an increase of three numbers means a decrease of the cross-section of the wire by just one-half; which means, in turn, a doubling of the electrical resistance of each foot of the wire.

It is useless, however, to bother about remembering this mathematical relation. The table printed with this article gives the numbers in the Brown and Sharpe gauge, with the diameters of the wires in "mils," one mil being one thousandth of an inch. In this table, for example, number 18 wire is seen to have a diameter of 40 mils, which means that its thickness is 40 thousandths, or one twenty-fifth of an inch.

In many of the books you will see tables of "circular mils." This is the *square* of the diameter of the wire in mils. For example, number 18 wire equals, in circular mils, the square of 40, or 1,600. Note that this is *not* the area of the cross-section of the wire, for the wire is circular instead of square and the area of its cross-section is not the square of its diameter but must be calculated from the geometrical formula for the area of a circle.

Fortunately the possible confusion about the circular mils has little importance in radio calculations as circular mils are not much used by radio writers. The best thing to do is to use always the *diameter* of the wire in mils. If figures are given in circular mils take the square-roots of the numbers and you will have, in all cases, the diameters of the wires in mils.

The electrical resistance of a copper wire depends on its cross-section. In the table are given the resistances of wires of the different gauge numbers for direct current at ordinary room temperatures. In practice these resistances must be considered merely as approximate values, since the resistance of wire varies slightly with the hardness or softness of the wire, with the temperature and sometimes with other things. The figures in the table are close enough for all ordinary purposes.

Bear in mind that these resistances are for *direct* current. For ordinary alternating currents, such as are used in power work or in house lighting, the resistances are about the same, but for radio-frequency currents the resistances are quite different because of the skin effect. It is impossible to give a general table for resistances at radio frequencies since the frequency, the nature

## THE SIZES AND PROPERTIES OF DIFFERENT KINDS OF COPPER WIRE

| B & S Gauge | Diam. Mils. | Feet Per Pound | Ohms Per Foot | TURNS PER INCH | | | |
|---|---|---|---|---|---|---|---|
| | | | | Bare | S. C. C. | D. S. C. | Enameled |
| 8 | 128 | 20 | .00064 | 7.8 | 7.3 | .... | 7.7 |
| 9 | 114 | 25 | .0008 | 8.7 | 8.2 | .... | 8.6 |
| 10 | 102 | 32 | .0010 | 9.8 | 9.2 | .... | 9.6 |
| 11 | 91 | 40 | .0013 | 11.0 | 10.3 | .... | 10.8 |
| 12 | 81 | 50 | .0016 | 12.3 | 11.5 | .... | 12.1 |
| 13 | 72 | 63 | .0020 | 13.8 | 12.8 | .... | 13.5 |
| 14 | 64 | 80 | .0026 | 15.6 | 14.3 | .... | 15.1 |
| 15 | 57 | 100 | .0033 | 17.5 | 15.9 | .... | 16.9 |
| 16 | 51 | 127 | .0041 | 19.6 | 17.9 | 18.3 | 18.9 |
| 17 | 45 | 160 | .0052 | 22.2 | 20.0 | 20.4 | 21.3 |
| 18 | 40 | 200 | .0065 | 25.0 | 22.2 | 22.7 | 23.8 |
| 19 | 36 | 260 | .0082 | 27.7 | 24.4 | 25.2 | 26.5 |
| 20 | 32 | 320 | .0104 | 31.2 | 27.0 | 28.0 | 29.7 |
| 21 | 28.5 | 408 | .0131 | 35.1 | 29.9 | 31.0 | 33.1 |
| 22 | 25.3 | 515 | .0165 | 39.5 | 33.9 | 34.4 | 37.2 |
| 23 | 22.6 | 650 | .0208 | 44.2 | 37.6 | 37.9 | 41.5 |
| 24 | 20.1 | 820 | .0262 | 49.7 | 41.5 | 41.8 | 46.5 |
| 25 | 17.9 | 1,030 | .0330 | 55.8 | 45.7 | 46.1 | 52.1 |
| 26 | 15.9 | 1,300 | .0416 | 62.8 | 50.2 | 50.8 | 58.5 |
| 27 | 14.2 | 1,640 | .0525 | 70 | 55 | 55 | 65 |
| 28 | 12.6 | 2,060 | .0662 | 79 | 60 | 61 | 73 |
| 29 | 11.3 | 2,600 | .0834 | 88 | 65 | 66 | 82 |
| 30 | 10.0 | 3,280 | .105 | 100 | 71 | 72 | 91 |
| 31 | 8.9 | 4,140 | .133 | 112 | 77 | 78 | 103 |
| 32 | 8.0 | 5,230 | .167 | 125 | 83 | 84 | 115 |
| 33 | 7.1 | 6,570 | .211 | 140 | 90 | 91 | 130 |
| 34 | 6.3 | 8,330 | .266 | 158 | 97 | 99 | 145 |
| 35 | 5.6 | 10,480 | .335 | 178 | 104 | 106 | 161 |
| 36 | 5.0 | 13,200 | .423 | 200 | 111 | 114 | 180 |
| 37 | 4.5 | 16,600 | .533 | 222 | 118 | 121 | 204 |
| 38 | 4.0 | 21,000 | .673 | 250 | 125 | 128 | 227 |
| 39 | 3.5 | 26,500 | .848 | 285 | 135 | 137 | 256 |
| 40 | 3.1 | 33,400 | 1.070 | 322 | 141 | 145 | 286 |

of the winding, the character of insulation on the wire, the tube that it is wound on and even other factors, may affect the measured resistance of a coil.

For use in winding coils and in calculating the amount of wire needed for them the tables of turns per inch will be found useful. This means linear inch, along the coil, one layer deep. The figures are approximate only, as the wire made by different manufacturers differs slightly. "SCC" means "single-cotton-covered"; that is, a wire wrapped with one layer of cotton insulation. Similarly. "DSC" means "double-silk-covered" wire, having two layers of silk insulation. There are also "double-cotton-covered" and "single-silk-covered" wires but they are little used in radio work. Enameled wire, having a thinner and transparent insulation, is much used in radio.

Wires of unusual shape, as for example, square bus-wire, are usually specified by the number of the round wire to which they are equivalent in electrical resistance. This means that such wires have the number of the round wire having the same cross-section. A number 16 bus-wire, which is a common size for wiring radio sets, has as much copper in it per foot as has a number 16 round wire. There will be, therefore, about 1,275 feet of such wire in a pound.

In England an entirely different set of gauge numbers is sometimes used for wires. It is called the "British Imperial Standard Wire Gauge," frequently abbreviated to "S. W. G." A few British publications use the Brown and Sharpe gauge just as we do, but if the gauge system is not specified it is safe to assume, in British work, that the S. W. G. system has been used. This system is also used more or less in other countries, though in France it is customary to specify, also, the diameter of the wire in millimeters. A millimeter is one thousandth of a meter or about .04 inch. One millimeter equals 39.37 mils, and one mil equals .0254 millimeter. These figures permit easy conversion of either one into the other.

The B. and S. gauge, the S. W. G. system, the measurement in mils and the similar measurement in millimeters are the only four ways commonly used to specify the size of copper wires. But for iron and steel wires three other gauges are sometimes used: the Roebling gauge (also called the Washburn and Moen gauge), the Birmingham gauge and the Stubs steel-wire gauge. The Stubs *iron-wire* gauge (as contrasted with that for steel wire) is the same as the Birmingham gauge. All this is rather complicated but it has, fortunately, little application to radio as these gauges are not used for copper wires.

The approximate relations between the two gauges that are used for copper wires are given in the following table:

No. 10 S.W.G. (British) equals No. 8 B. and S. (American)
No. 14 S.W.G. (British) equals No. 12 B. and S. (American)
No. 18 S.W.G. (British) equals No. 16 B. and S. (American)
No. 22 S.W.G. (British) equals No. 21 B. and S. (American)
No. 26 S.W.G. (British) equals No. 25 B. and S. (American)
No. 30 S.W.G. (British) equals No. 28 B. and S. (American)
No. 34 S.W.G. (British) equals No. 31 B. and S. (American)
No. 42 S.W.G. (British) equals No. 38 B. and S. (American)

These relations are not exact, but give an idea of the relation between the two gauge systems. For the exact diameters of wires in the two systems, as well as for details concerning exact resistances and the like, it is necessary to consult the more comprehensive tables in the handbooks of electrical engineering.

By special permission of the Director of the United States Bureau of Standards, Washington, D. C., we are able to include in this data on coils a very practical and at the same time very accurate manuscript by Morris S. Strock of the Bureau radio staff:

"In the tuned circuit of every radio receiving set there are one or more coils of wire which carry the feeble alternating currents induced in the antenna by the incoming radio waves.

"Such currents go to make up a minute amount of electrical power. If the coils in which these currents flow are improperly made, they will waste a larger portion of this power than is necessary. This condition limits the flow of useful current with the result that the current value may not be quite high enough to produce an audible signal in the telephone receivers. In this case the substitution of more efficient coils would give understandable reception from a distant station when otherwise it could not be heard.

"A receiving set that employs regeneration or radio-frequency amplification will detect exceedingly minute currents, yet, there is always a threshold current value (in the vacuum tube) below which even these sensitive circuits will fail.

"There are two other reasons for using efficient coils, and these reasons involve the signals obtained from *any* transmitting station. The first of these additional reasons tells us that efficient coils increase the selectivity of the circuit.

"Selectivity is something every receiving circuit needs, and means of improving it are *well worth while*.

"Coils of low power loss will permit of good amplification without excessive filament currents or high plate voltages.

"This means that the signals will be less noisy and less distorted—and, to all those who are interested in broadcast programs, what single consideration is more important than that of securing reproduction which is natural and lifelike?

"Let us take an inventory of the factors that cause these power losses, in order to learn how to avoid them.

"*First*, it should be stated that power losses in a coil increase as the resistance of the coil is increased.

"Resistance—more properly called high-frequency resistance—may be measured. Radio-frequency resistance changes somewhat with the frequency, but at all radio frequencies the same features of coil construction always cause an *increase* in apparent resistance. Therefore, change of apparent resistance with frequency need not be considered in detail.

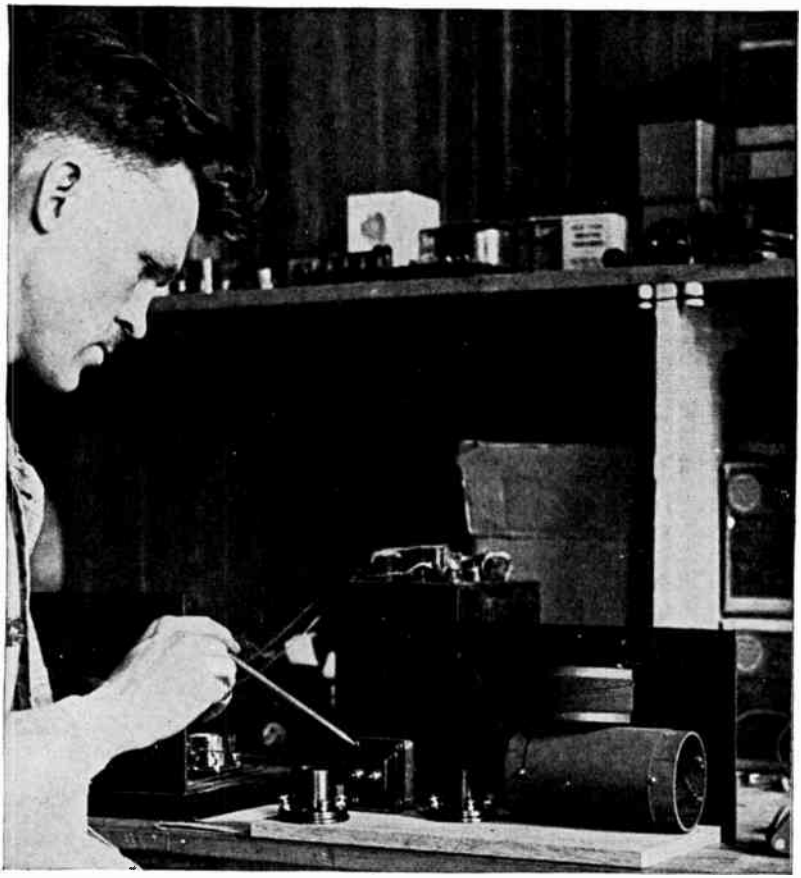
"Alternating currents of radio frequency are unevenly distributed through the conductor, their effect being most pronounced on the surface, and the higher the frequency the greater this *skin effect* will be. Therefore, if the surface area of the conductor is increased, its resistance will usually be decreased. For braided or stranded conductor this statement may not be literally true. For instance, at frequencies below 1,000 kc (wavelengths over 300 meters) a solid conductor sometimes has a lower radio-frequency resistance than stranded Litzendraht cable of greater surface area.

"*Second*, the insulating material between the turns of the coil increases its apparent resistance.

"This is due to a phenomenon called dielectric absorption. The insulation acts much the same as the insulation (dielectric) of a condenser, and if the insulating material is a poor dielectric the losses are relatively high.

"*Third*, the insulating material of the form upon which the coil is wound and other insulating material in the field of the coil, will also increase its resistance and for the same reasons just given.

"*Fourth*, any metal in the field of the coil will increase its radio-frequency resistance because the metal object has eddy currents induced in it and these currents absorb useful power from the circuit. At the back of the panel in many radio receiving sets is placed a metal shield which serves a certain useful purpose; it will, however, considerably *increase* the resistance of coils mounted too close to it.



KEEP THE AUDIO TRANSFORMER AWAY FROM THE TUNING COIL

Figure M: In arranging the instruments, remember that audio transformers necessarily contain a lot of iron which has a particularly strong choking effect at radio frequencies.

"*Fifth*, leakage of current between the turns of the coil will increase its radio-frequency resistance. This most usually occurs when the conductor insulation collects moisture.

"*Sixth*, unused turns (dead ends) often increase the resistance of a coil. The dielectric effect previously mentioned, increases the distributed capacity of the windings and in the case of dead ends, a resonance effect may be obtained which causes the radio-frequency resistance to rise to a high value.

"*Seventh*, taps taken from the coil and connected to switch points, increase its resistance. The switch points being imbedded in insulating material, the phenomenon of dielectric absorption comes into play.

"Results of actual tests showing how the radio-frequency resistance of coils is increased will emphasize the remarks just given and point the way to practical hints forming the subject-matter of this contribution.

"A first example involves a typical coil (shown at the left in Fig. O) such as might be used in the antenna circuit of a receiving set. (For the present, the hand of the observer holding the metal rectangle is to be ingored; this will be considered shortly.)

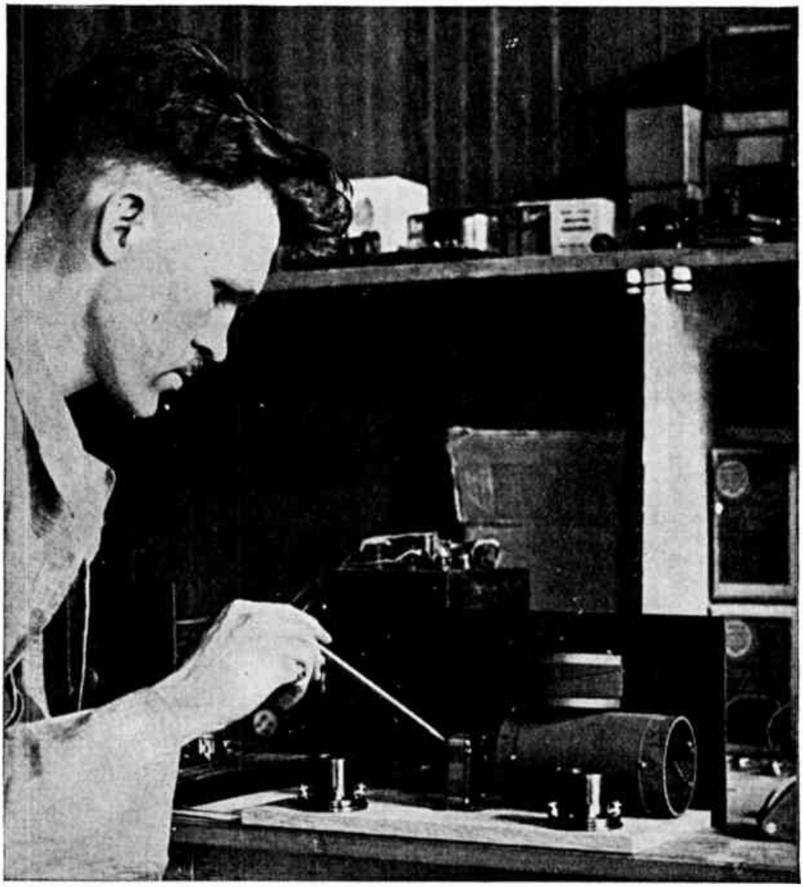
"This coil was made by winding sixty turns of No. 20 DCC wire around a four-inch cylinder of phenolic insulating material (bakelite, so called, but actually it may be something else). At 750 kc (400 meters) the radio-frequency resistance of this coil was 3.2 ohms—and now comes the significant part of the experiment. An identical coil was wound on a dry cardboard cylinder and its resistance at the same frequency was only 1.1 ohms. Thus the humble cardboard, used in a dry place, was superior electrically (although not mechanically) to the more aristocratic insulating material. This is not true, however, when the cardboard absorbs moisture.

"Now, consider the one-sixteenth inch brass rectangle shown at the left of this coil. Metal parts of greater weight or size than this are frequently used in mounting coils. For mechanical reasons this may be necessary, yet the amount of metal should be reduced as much as possible. The metal piece shown in the photograph was placed inside the coil and the apparent resistance was thereby increased 0.5 ohm.

"A final test of this coil shows the effect of leakage. A few drops of clean water were allowed to soak through the insulation over the area shown by the dotted lines, and the resistance of the coil was increased 0.6 ohm. This hints at the importance of protecting the coil winding from moisture, especially in the case of cotton insulation which readily absorbs moisture from damp air. These measurements were made in a dry atmosphere so that the cotton insulation was extremely effective.

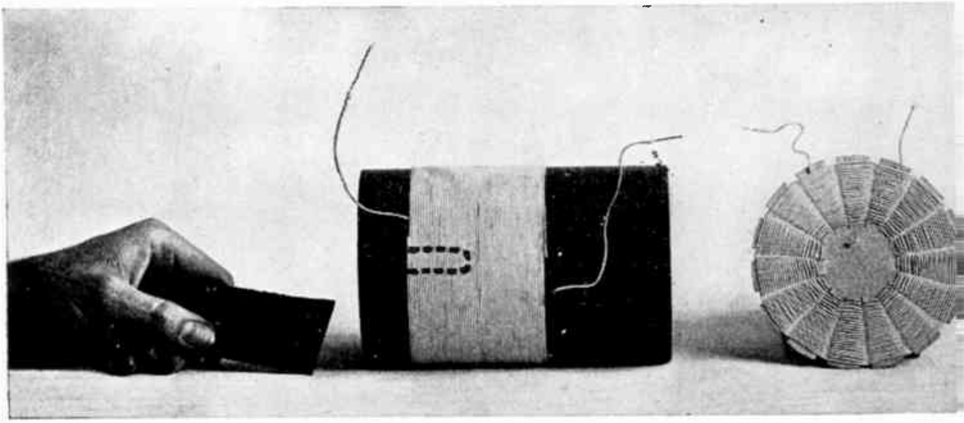
"At the right of Fig. O is shown a so-called spider-web coil which was wound from No. 24 DCC wire on *dry* cardboard. This type of winding supposedly gives lower radio-frequency resistance than a winding in cylindrical form because of a slight spacing of the turns. This factor is, in itself, an advantage, yet due to the peculiar form of winding the losses may be unnecessarily high. At 713 kc (420 meters) the resistance of this coil was 3.9 ohms. Another coil was made by winding the same kind of wire on a cylinder of dry cardboard so that the same inductance was secured—that is, either coil could be substituted in the measuring circuit without changing its frequency. The radio-frequency resistance of the second coil was only 2.9 ohms.

"We now come to an excellent example of how a coil should *not* be made. This is shown in Fig. P—the primary portion of a two-circuit tuner (loose coupler) made in the days when little was known of coil losses. If the designer had *tried* to secure a high radio-frequency resistance he could scarcely have done better! Note the large brass rod for the sliding secondary, the insulating material completely covering the winding (70 turns of No. 22 SSC wire), the large switch points embedded in the insulating material, and finally, the large metal support for the coil form. This construction incorporates excellent *mechanical* features and one good electrical feature—firm contact on the switch points. In securing these results, however, the radio-frequency power losses were greatly magnified. A



THE WRONG WAY TO ARRANGE THE INSTRUMENTS

**Figure N:** If you place the audio transformer up against the tuning coil as shown, it may cut down the efficiency of the set as much as fifty percent. It will make the signals weaker and will cause the tuning to be very broad.



EXPERIMENTAL COILS THAT GAVE SURPRISING RESULTS

Figure O: The dotted lines on the center coil indicate the area that was wet with a few drops of clean water. Wetting just this small portion of the coil greatly increased the resistance. The spiderweb coil was not as efficient as a straight cylindrical coil of the same inductance value.

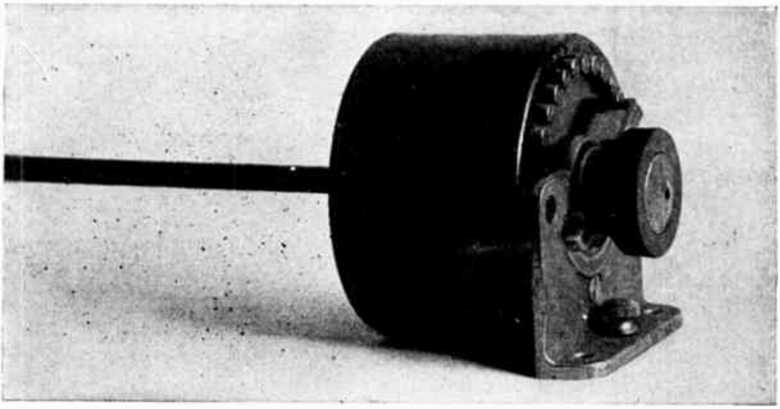
measurement of resistance including all the turns of this coil, gave a value of 25 ohms at 483 kc (620 meters)—*at least five times the necessary value.*

"Thus far we have taken an inventory of the causes of power losses in coils and have given practical examples of these losses. Working from this foundation, we will now give practical hints for reducing or eliminating power losses. It must be borne in mind that merely substituting an efficient coil for one of poor design in a receiving circuit will not give any startling improvement in results, if the rest of the circuit and the antenna and ground system have an unnecessarily high radio-frequency resistance. Reasonable precautions in wiring and careful selection of parts should, however, take care of these difficulties. In the case of coils, the experimenter has quite a field, for he frequently makes them himself, or, if the purchased article is used, it can usually be rewound if necessary.

"An ideal coil, as far as power losses are concerned, would be one made by winding a conductor of zero resistance into a coil having no material support and using the whole thing in an isolated position. This fantastic illustration emphasizes the importance of taking precautions which will approach this condition. These precautions will apply to all coils used in: wavetraps; single-circuit tuners; two-circuit tuners; regenerative tuners; tuned-radio-frequency transformers in reflex or neutrodyne circuits. Single-layer coils only, are assumed—multi-layer coils, except those having spaced turns, should *never* be used for broadcast or amateur frequencies.

"First considerations involve the conductor.

"Unless space is rather restricted it is a good rule to use nothing smaller than No. 20 copper wire. An instance was once noted, where, in the wiring of a receiving set; an inexperienced person had used steel wires! This introduced an unnecessary resistance of several ohms and the set would not operate satisfactorily. When some of the longer



AN EXAMPLE OF ELECTRICAL INEFFICIENCY

Figure P: This primary portion of a two-circuit tuner (loose coupler) was made in the old days when little was known of coil design. It has almost every fault mentioned in this Section, including large masses of metal in the field and too much insulation material surrounding the coil. It has five times the resistance at radio frequencies that such a size coil should have!

steel wires were replaced with copper wires, the circuit gave good results.

"Stranded (Litzendraht) cable, consisting of enameled strands of fine wire braided in a special manner, often gives a lowered resistance at frequencies above 1,000 kc (wavelengths below 300 meters) provided the following precautions are observed:

"(1) Testing each strand for continuity;

"(2) Testing each strand, for possible shorting through insulation, with every other strand;

"(3) Observing great care in winding so that no strands will be broken;

"(4) Equal care in soldering terminals so that no strands will be missed.

"A violation of any of these conditions may cause an excessively high radio-frequency resistance. Precautions (1), (3) and (4) are necessary because the fine strands break easily and are difficult to solder; precaution (2) is necessary because 'pin holes' are common in the enamel insulation. The best way to remove enamel from these fine strands is by heating cautiously to a dull red and plunging into alcohol.

"The insulation and spacing of the conductor is also important. Enamel insulation, alone, is not desirable because it gives a noticeably higher radio-frequency resistance than silk or cotton-covered wire of the same size. The enamel is a poor dielectric and because of its thinness, gives the coil a high distributed capacity—hence the resistance is increased. Double-cotton-covered wire is good, because the cotton insulation gives good spacing between turns, and the cotton itself, when dry, is an efficient dielectric. Enameled wire which has a double-cotton-covering has a peculiar advantage in that the enamel excludes moisture and prevents leakage losses while the cotton takes care of the spacing. Here the dielectric effect of the enamel is not serious because of greater spacing of the turns. Wire that has single cotton or single silk insulation is not desirable; double silk insulation is very good and does not absorb moisture as readily as cotton.

"Having decided upon the conductor and its insulation, it is logical to consider the winding form.

"Phenolic insulating materials, commonly used for this purpose, are usually not as good from the dielectric viewpoint as dry cardboard or wood, although their non-hygroscopic properties are excellent, as well as their ability to withstand high voltage. In the receiving circuit, however, no such voltages exist, so this latter advantage is *nil*. These materials are mechanically stronger than any other kind and this advantage is worth considering if the equipment is for rough portable use.

"Other winding forms are hard rubber, cardboard and wood. Hard rubber has excellent non-hygroscopic properties and most hard rubber has lower dielectric losses than cardboard or wood; it is also better from the mechanical viewpoint.

"Wood forms are not common except for use in rotors but for this purpose they may be made almost as efficient as cardboard. The wood should be treated the same as the cardboard but the drying process should be longer. One difficulty in the use of wood is that it may have been rather green when turned out at the factory. If a close examination reveals no sign of cracking and if the wood itself appears dry it is most probably well seasoned.

"Wood or cardboard forms as purchased should not have been varnished or treated with any compound, particularly black varnish, which may increase the power losses.

"In mounting the completed coil, precautions must still be observed but mechanical requirements of metal mean the sacrifice of some electrical efficiency. However, as little metal as possible should be used, especially inside of the coil. Also, the coil should be mounted at least two or three inches from any shields at the back of the panel. Taps should be connected by short wires to switch points which should be small in order to reduce the dielectric effect of the insulating material in which they are imbedded.

"Two general factors can be taken advantage of to reduce coil losses. *First*, use no more turns or taps than are necessary; if a variable condenser is used, it will take care of the fine tuning adjustment. *Second*, do not use a long coil of small diameter, nor a very short coil of large diameter; to do so means that more wire will be needed to secure a given amount of inductance,—with the result that the radio-frequency resistance will be somewhat greater. It can be shown experimentally that the maximum inductance with a *given length* of wire is attained when it is wound in a coil with a diameter equal to about 2.3 times its length. This is a good standard to go by, but the limits are rather wide and coils somewhat longer or shorter, relative to their diameters, may be used, the approximate extremes in either direction being shown in Fig. Q.

"Coils of various fancy forms of winding may be purchased or the experimenter may be capable of winding them himself. Some of these coils actually have low losses while others may not be as efficient as simple single-layer coils wound with precaution. When coils are purchased, select those having lowest losses by avoiding:

"(1) Small conductors; (2) conductors having fine individual strands,—broken strands cause high resistance; (3) closely spaced enameled wire; (4) bulky coil forms; (5) coil terminals mounted in large blocks of insulating material; (6) large pieces of metal used in mounting; (7) heavily varnished windings; (8) more taps or turns than are necessary.

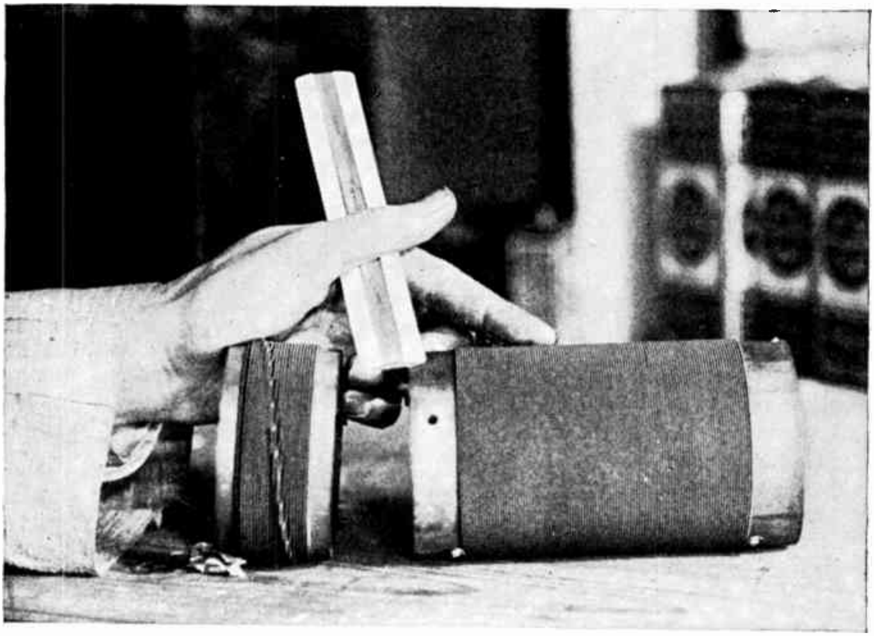
"One brief concluding sentence suggests the marrow of this contribution:

"As proved by laboratory tests, radiofrequency coils in a receiving set waste power, and definite precautions in coil construction reduce these power losses, enabling the set to give clearer signals."

Those who wish to ascend to greater technical heights in the matter of coil design and construction will find in the following pages a beautiful contribution to the subject by no less an authority than Sir Oliver Lodge. While the facts presented may be beyond the point that the average experimenter cares to go, the mathematics are by no means beyond high school education.

"In the first place, to keep the distributed capacity to a low value the actual wire used in coils for a receiving set should be thin, so as to expose but little surface. The wire should be of the highest conductivity, but the smaller its diameter the better, so far as this desideratum is concerned. Also the shorter the length the better, since the capacity varies directly with the length. The only disadvantage of a very fine wire is that its resistance is high. But, after all, resistance does not much matter. For a receiving station the current is feeble, and the thinnest wire will serve. It may be coated with silk, cotton or enameled. And if a stranded core is employed, the enameling of each separate strand is sufficient to keep them isolated from each other.

"But it is well to wind the turns of



THE RELATION OF COIL DIAMETER TO LENGTH IS IMPORTANT

**Figure Q:** These coils represent about the limits of diameter and length for the highest efficiency. Avoid long, small coils and very large, short coils; both extremes are bad because they require more wire to get the same inductance—and this increases the loss.

wire not too close together. Hence a fairly thick cotton covering might be applied outside the real insulation, so as to diminish the capacity effect of each turn upon the others. The thickness of the ultimately covered wire may therefore, be three or four, or even ten times the thickness of the copper core; but we may doubt if it is ever necessary or advisable to use a covering as thick as that. And were it not for the practical experience which has developed "basket" or open winding, the author should have been disposed to advocate a close compact coil wound so as to give maximum inductance for a given length. In any case, maximum inductance must be aimed at, whether the covering of the wire be thick or thin. We shall assume then that the wire to be used has an external diameter or thickness T, and that the copper core has the thickness *t*, and shall proceed to consider what is to be done with it.

"Given the antenna capacity and the wavelength or range of wavelengths desired, we can at once determine the inductance or range of inductances necessary. Here is the formula, which gives the coil inductance as the square of the wavelength divided by forty times the antenna capacity; *everything being expressed in the same units of length*:*

$$\text{Inductance} = \frac{\text{Square of wavelength}}{\text{40 times the capacity}}$$

$$\text{that is } L = \frac{\lambda^2}{40C}$$

"For instance, to receive on a wavelength of 200 meters with an antenna whose capacity is 1 meter, which would be a likely value for a single wire elevated by a pole 20 meters high, the coil must have an inductance,

$$L = \frac{40{,}000}{40} = 1{,}000 \text{ meters.}$$

that is, 1 kilometer, or $10^5$ centimeters, or a tenth of a millihenry. To get a wavelength of 1,000 meters with an antenna of 2 meters capacity would need an inductance

$$L = \frac{10^6}{80} = 12{,}500 \text{ meters,}$$

that is, 12½ kilometers or 1¼ millihenry. Twice this value would be needed if the capacity of the antenna were halved. But if the wavelength were to be doubled the inductance must be quadrupled.†

"Now, to get the necessary inductance in a coil, using the smallest length of wire, it must be wound on a frame of the following shape and dimensions, *viz.*, a disc coil of external diameter 14 units, of internal diameter 8 units, and with the channel for the wire a square, 3 units to a side. There remains only to determine the size of the unit which will give the required inductance L, for wire of given external thickness T. The formula for determining the actual size of the coil's external diameter D, is:

$$D^5 = 66.6LT^4$$

---

*See appendix at end of this Section.

†See Appendix for explanation. The following table will effect conversion from conventional capacity units to length units: the latter being in many respects more convenient except for large capacities:

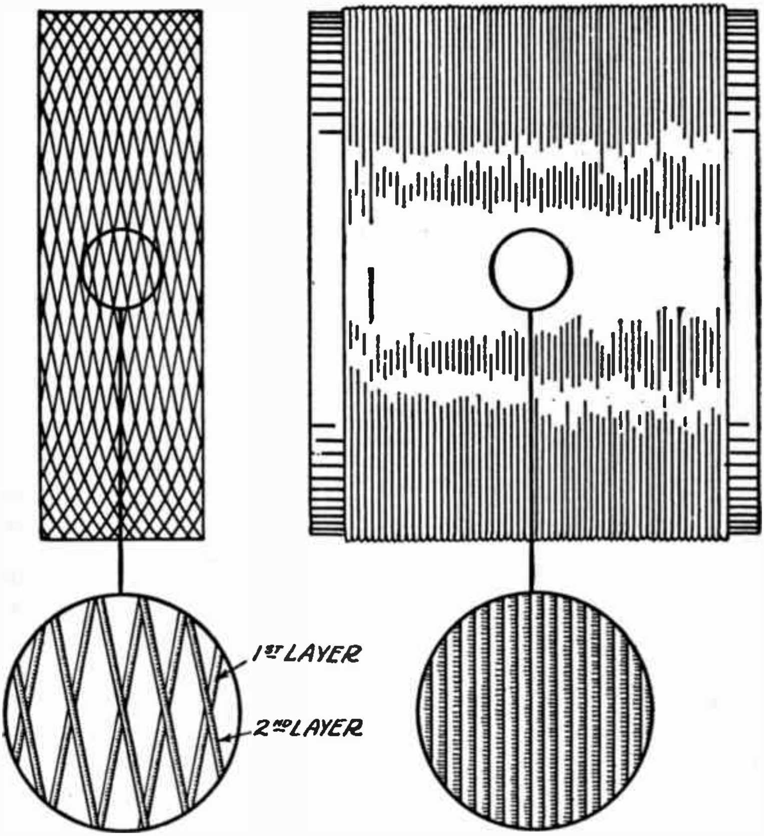
1 microfarad = 9 kilometers
1 millimicrofarad = 9 meters
1 micromicrofarad = .9 centimeter

For practical purposes a capacity expressed in micromicrofarads may be interpreted at once as nearly equal to the same number of centimeters. A ten percent allowance can be made if desired, for a centimeter is ten percent bigger than a micromicrofarad.

For *inductances* the conversion is still easier:

1 henry = 10,000 kilometers = a thousand million centimeters
1 millihenry = 10 kilometers = a million centimeters
1 microhenry = 10 meters = a thousand centimeters
1 millimicrohenry = 1 centimeter

Hence, to express inductances in centimeters is always quite easy.



WIRES SPACED

WIRES TOUCHING

TWO STANDARD METHODS FOR WINDING COILS

Figure R: The coil on the left is known by numerous names, such as basket weave, honeycomb and duolateral; the turns of wire cross each other at an angle and therefore, the capacity between turns (called the "distributed capacity" of a coil) or between layers is low. Compare this method of winding with the coil on the right, which is an ordinary solenoid winding. Here the turns of wire lie right along side of each other and close together; the distributed capacity of such a coil is high, especially if a number of layers are wound over each other.

And once having determined D, the size of the coil is known in every detail, also the number of turns of the given kind of wire, and the length of wire necessary.

"The use of this formula will be best illustrated by an example.

"Suppose the inductance required is one millihenry, that is to say, 10 kilometers or $10^6$ centimeters; and let the thickness of the covered wire be 2 millimeters or 1/5 centimeter; then $D^5$, comes out from the above formula as

$$D^5 = \frac{66.6}{625} \times 10^6,$$

or a trifle more than $10^5$; and therefore the extreme diameter $D = 10$ centimeters practically. The internal diameter *d* will then be

$$d = \frac{8}{14} D = 5.7 \text{ centimeters;}$$

the breadth of the coil b, or the side of the square channel in which the wire is wound will be,

$$b = \frac{3}{14} D = 2.142 \text{ centimeters;}$$

the number of turns n, of covered wire of thickness five turns to the centimeter will be

$$n = \left(\frac{b}{T}\right)^2 = 115;$$

the mean radius of a turn r, is,

$$r = \tfrac{1}{4} (D) + d) = 4 \text{ centimeters;}$$

and hence the total length of wire is,

$$l = 2 \pi \quad nr = 27.6 \text{ meters.}$$

"Or it may be more convenient to work with inches, so far as the workshop dimensions are concerned. If we are dealing with the same inductance we must divide $10^6$ centimeters by 2.54 to bring it to inches. Or we may take as example a round number: Let the required inductance be $L = 400{,}000$ inches, while T, the thickness of the wire, = 1/10 inch. Then we can reckon the external diameter of the coil, in inches, as:

$$D = {}^5\sqrt{\frac{66 \times 400{,}000}{10{,}000}} = 4.84 \text{ inches.}$$

So that the internal diameter will be $d = 2.72$ inches. And the side of the square channel $b = 1.03$ inch. The number of turns will be,

$$n = \left(\frac{b}{T}\right)^2 = 106,$$

and the length of the wire used,

$$l = \tfrac{1}{2} \pi (D + d) = 1{,}260 \text{ inches or 35 yards.}$$

"The result we see is not a large coil, even for so thick a covered wire. By diminishing the thickness of the wire the coil can be much decreased in size. For if the size of the channel is given, then the use of a wire of half the thickness will give a 16-fold inductance, because it depends inversely on the fourth power of the thickness. This is indeed obvious. For if the wire is half as thick, double as many turns can be put in each layer, and there will be twice as many layers, so the number of turns altogether is quadrupled. And as the inductance depends on the square of the number of turns, that will be magnified 16 times.

"As regards size of bobbins for a given thickness of wire, we can make this statement: doubling the linear dimensions of the bobbin for a given wire will magnify the inductance of the resulting coil 32 times. This is not quite so obvious, but it clearly appears from the formula, since L varies with the fifth power of D, and $2^5 = 32$.

"The first idea of self-induction originated with Faraday, long ago, but he was quite vague about it, and called it "the electrotonic state of a conductor." It puzzled him a good deal, and he treated it almost as if it were some chemical property of the metal, acquired under electrical influence. He named it "electrotonic state" in November, 1831, during his great discoveries in electromagnetic induction generally.

"The idea became rather more definite in the hands of Sir William Thomson (Lord Kelvin), who in 1853 gave the mathematical theory of electrical oscillation. He perceived a sort of analogy between Faraday's electrotonic state and electrostatic capacity—only he perceived it was kinetic instead of static—and he therefore called it "the electrodynamic capacity of a discharger." In other words, he found that it was a *constant* belonging to all the wire circuit through which a Leyden jar discharged. Thus in an oscillating circuit there were the two things, both essential to oscillation:

"*First*, the electrostatic capacity of the charged areas:

"*Second*, the electrodynamic capacity of the connecting wire or discharging rod. Resistance came in subordinately, as a damper of oscillation, in a comparatively simple way which he thoroughly understood.

"Then, later on, it was realized that just as two wires lying alongside of each other had a mutual coefficient of induction, so that the one induced currents in the other (as discovered by Faraday)—each being susceptible to the rate of variation of the current in the other—so it might be said that every longitudinal part of a single wire reacted on the other parts of the same wire, or, in other words, that the wire was itself susceptible to the rate of variation of the current in itself. Hence it was possible to speak of not only the mutual induction of two parallel conductors, but of the self-induction of one. And so Maxwell introduced the term "self-induction," and made it quite definite and calculable. Later, Heaviside styled it inductance, to correspond with resistance.

"There are two ways of calculating this quantity, now commonly denoted by the letter L. One is to reckon the number of magnetic lines of force which effectively surround a wire carrying a current—the momentum, so to speak, of its magnetic field—and to call that momentum L1, where 1 is the strength of current. The other is to treat the wire as if stranded, and to reckon the mutual induction of the strands on each other. This can be done by taking it as equal to the mutual induction of two parallel wires at what is called the "geometric mean distance apart": that is to say, at a distance determined by the shape and size of the cross section of the single wire—a distance which can be reckoned as the average distance of the points in such a section from each other. It is all worked out in Maxwell's great treatise, published in 1873; and he gives an expression for this geometric mean distance for different shapes of section. It is important, because it applies, not only to a single wire, but to the cross section of the wound channel in a coil. That cross section may be square, or oblong, or round—as when the coil is shaped like a curtain ring.

"In practice the section is usually oblong or square. It may be oblong *broadways*, as when one or a few layers are wound cylindrically on a tube; or oblong *depthways*, as when short layers are wound so as to be piled on top of each other, making a sort of disc.

"For a coil with one narrow dimension (that is to say, for a winding whose section is a thin oblong, whether the coil is wound horizontally or vertically) the geometric mean distance asunder of its parts is .223, or say a quarter, of its larger sectional breadth.

"For a square section, the value is .45 times the length of one of the sides, that is, about half the side of the square.

"For a circular section it is .78 or say three quarters of the radius.

"For an oblong section in general, the accurate expression is decidedly complicated, involving logarithms and tangents, but it may be taken as approximately a quarter of the width and depth of the section added together; more accurately, $\frac{b+d}{\sqrt{(20)}}$, which is very nearly right. The complete formulas will be found in Maxwell, or quoted

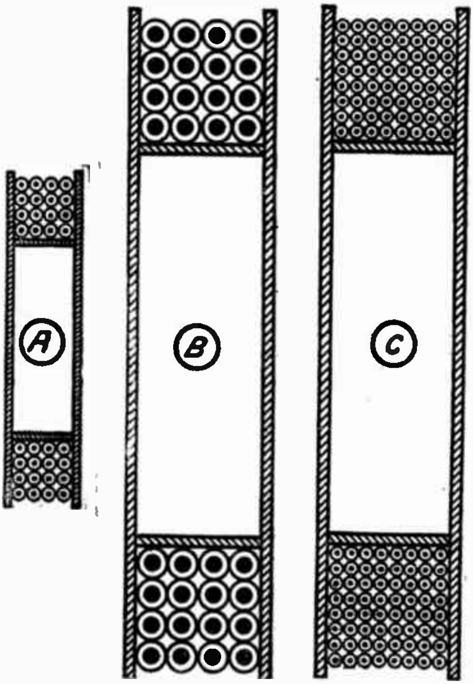


FIGURE S

It is interesting to note that if we build a coil of certain dimensions A, it will have a certain inductance. If we double all its dimensions, including the diameter of the wire (as in coil B), the inductance will increase very slowly in proportion to the added size. If, however, we keep the wire the same size as in the first coil and at the same time double all the other dimensions of the coil, as in C, we will find that the coil has inductance 32 times greater than coil A.

in Professor Fleming's comprehensive treatise and we need not attend further to it now, because we want to concentrate on the most compact section—either a circle or a square. For it is this compactness which gives the maximum self-induction.

"That, however, is not all that is necessary to be known, by any means. That only determines the shape of the channel in which the wire is wound. We must know the average size of the channel in relation to the circle of wire so formed, that is to say, we must know the external and internal diameters of the coil in terms of its sectional dimensions. Maxwell calculates that too, though he says it was first worked out by the mighty mathematician Gauss, in 1867; though under what circumstances and for what reason Gauss can have calculated it, we do not know. It will be instructive to some readers if we indicate the manner of calculation, though those who like may skip the algebra, which we may defer for the immediate present. Anyhow, the *result* is clear and definite and simple enough. The width and depth of the channel's cross section must be approximately three-fourteenths of the external diameter of the coil, or three-eighths of the internal diameter, the external diameter being fourteen-eighths or 1¾ times the internal. (See Fig. S.) That determines completely the shape of the best coil, whatever its size may be. Every coil that we now proceed to speak of is to be of this shape, they will differ only in size, one will be like another magnified. But the wire which is wound on the coils will not be magnified. If it were, the number of turns would remain the same, and the inductance would increase very slowly in proportion to the additional size. It would, in fact, in that case simply increase with the linear dimensions, or, what amounts to the same thing, it would be proportional to the length of wire used.

"But if the wire is maintained at a constant thickness, no matter what the size of bobbin on which it is wound, the inductance increases vastly as the dimenions increase. It increases not only because of the greater length of each turn of wire, but also in proportion to the square of the number of turns. If the linear dimensions are doubled, the number of turns are quadrupled, and therefore the length of wire is quadrupled. The inductance depends on the square of the number of turns, and therefore is quadrupled twice over, making it 16-fold, and the linear dimensions being doubled makes it altogether 32-fold. That is to say, increasing the size of the coil, for a given thickness of wire, increases the inductance as the fifth power of the size. In other words, doubling all the linear dimensions multiplies the inductance by 32.

"The formula connecting the three things—outside diameter of coil (D), thickness of covered wire (T), and maximum inductance ($L_m$)—is as follows:

$$\frac{D^5}{T^4} = 66.6L_m$$

"Here the D, T, and L must all be expressed in the same units, no matter what those units are; and for convenience L should therefore, in such cases, always be expressed as a length, not in such units as henries or fractions thereof, though these are useful for other purposes.

"So also it is best, for radio apparatus, to express capacity as a length, and not in farads or microfarads or micromicrofarads. It is much better to express it in meters, because one usually wants to employ it to calculate the wavelength. The wavelength is $2\pi$ times the geometric mean of the inductance-length and the capacity-length, that is, about 6 times the square root of their product. Thus, suppose L is 10 kilometers, and C is 1 meter, the wave length would be 600 meters. If L is 1 kilometer, and C is 10 meters, the wavelength is the same. If L is 16 millihenries, or 16 x $10^6$ centimeters, and C is 100 centimeters, the wavelength will be 240,000 centimeters, or about 2½ kilometers.

"By thus working in length units, the calculation is quite simple, and can be done in one's head; and slips of extensive magnitude can be avoided, because there is a common-sense feeling about the size of the quantities dealt with, all the time, which prevents their being accidentally taken hundreds or thousands of times too big or too small, as may easily happen when hastily dealing with meaningless units of quite unsuitable size. To measure things in farads and henries when we want the dimensions of a coil in inches, or a wavelength in meters, is not practically convenient.

"Any open oscillating circuit transmits its energy to the ether, and so radiates it into space. If a circuit consisted of two capacity areas separated by a long wire or rod, it would be an exceedingly powerful radiator, and would radiate practically all its energy in two or three swings or alternations.

"However, a circuit of this type would be unsuitable for tuning or for any precisely resonant effects. To prolong the oscillations we must introduce electrical inertia in the form of inductance. The electrical oscillations will then alternate back and forth for a much longer time. It will conserve its energy to some extent; in other words, the damping coefficient will be diminished, so that if left to itself it would continue swinging twenty or thirty, or even more, times; or if connected to a continuous-wave generator it will be kept in vibration with but little applied power when tuned to the right frequency.

"When a current runs through a wire, it inevitably wastes some energy in the form of heat, especially if the wire is of small diameter. Any straight conductors should therefore be fairly large so as not to damp the vibrations out too much. But inductance which must be added to prolong the oscillations, and control the frequency of oscillation, has to be added in the form of a coil. For best operation, the resistance of this coil should be a minimum, and its inductance a maximum. It is obvious that if too great a length of wire is used, the resistance will be unnecessarily high, and the resistance and damping effect more than is needed. The question is whether thin wire will do for the coil, or whether it must be as large in cross-section as the lead-in wires.

"Let us now consider the resistance and inductance of a coil wound in a given channel, or on a specified size of tubing or other frame. The damping depends on the ratio of R to L (i.e., Resistance ÷ Inductance); and so long as this ratio is constant, the damping will be the same. It does not depend on R alone, nor on L alone, but on the ratio of the two. Suppose we fill the channel with a thick wire, its resistance will be small, but its inductance will be small also. Whereas, if we wind it with wire of small diameter, we shall have a large number of turns; so that the resistance will be high, but the inductance will also be high, and we must, therefore, consider whether the ratio remains the same. We shall find that it does, and that whether the coil is wound with a single thick wire, or whether it is wound with thousands of turns of fine wire, the ratio is not altered. For the resistance will depend on the square of the number of turns, since the length of wire will increase with n, and the cross section of the wire will diminish with n, Therefore, the resistance will depend on $n^2$. But the inductance also depends on $n^2$. Hence the ratio of R to L remains constant whatever wire is used.

"With extremely thin wires the space is largely occupied with insulation, and there is a tendency for the ratio of R to L to increase somewhat on this account as the thickness of the wire is diminished. But the increase is little, and for practical purposes is unimportant. Consequently, although the lead-in wires should be fairly substantial, or at least not too constricted in diameter, the wire on the coil may be reasonably thin. And any further details about the winding should be dealt with from the point of view of capacity as the resistance may be left to take care of itself.

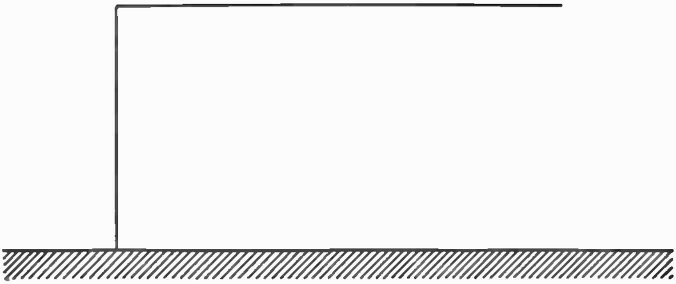
"The way to keep the capacity in the coil small is to wind it in a single layer, such as a number of turns wound on a cylinder. In that case we have only the capacity of each turn upon those on each side of it, unless the tube on which it is wound is of some conducting material, in which case the wire will form one coat of a cylindrical condenser, and the capacity will be far from insignificant. It is important, therefore, to use good insulating material for the cylinder on which wire is wound.

"Another plan, though more troublesome, is to wind the wire as a thin disc, in a large number of superposed layers of small breadth. By adopting this method of winding, and without using end pieces or metal frames of any kind, we reduce the capacity to a minimum. And we can, if we like, separate the turns, making a sort of basket winding, or else a spiral with interspaces, such as is often used for a loop antenna. Such methods of winding, however, are far from giving the maximum inductance possible with a given length of wire; so that the resistance may begin to be excessive, since that depends on the total length of wire used.

"If the wire is wound more compactly, say as compactly as possible, by filling a square section channel with layers of wire, one on top of the other, the inductance can be made a maximum by choosing a channel of the right dimensions, in proportion to the diameter of the coil; and the length of wire used will be a minimum, which is advantageous if the capacity effect is not troublesome.

"To calculate the capacity effect of a coil of many cylindrical layers, we can treat each layer as if it were one coat of a cylindrical condenser; and we shall find that we do not have to add these capacities together. The effective capacity of the whole coil will not be more than the capacity of a single layer, because the whole difference of potential between the terminals will not be applied to any one layer, but only a fraction of it. The whole difference of potential exists between the terminals of the coil, that is, between the inner and the outer layers. If there are six layers, only 1/6 of the difference of potential is applied to each, and to reckon the effective capacity we shall have, therefore, both to multiply and to divide by 6. Hence it is that the number of layers does not matter. All we want to know is the capacity of any one layer.

"Take the axial dimensions of the coil, or what may be called its breath; call that b. And take the radius of the coil, which we may call r. The layer forms a cylinder whose area is the



THIS CIRCUIT WOULD RADIATE ITS ENERGY QUICKLY

Figure U: If a circuit consists of two capacity areas such as the antenna and ground arranged as shown, it would radiate practically all its energy in two or three swings or alternations. Such a circuit could not be tuned properly.

circumference multiplied by the breadth; that is,

$$2\pi r b.$$

"It only remains to reckon the distance which separates one layer from the next, and this will be equal to the thickness of the covered wire minus the thickness of the uncovered wire. For an approximate estimate we can neglect the thickness of the uncovered wire, assuming that it is thin, and take the distance as the diameter of the wire, that is, twice the thickness of the covering.

Treating it in this way, we know that the capacity of a plate condenser is

$$\frac{A}{4\pi Z}$$

where A is the area of either coating, and z the distance between the coatings. So in the above case this quantity will be

$$\frac{2\pi r b}{4\pi T}$$

if T is the thickness of the insulation. We will consider the order of magnitude of this capacity for a given example.

"Let the breadth of the coil be 2 inches, and the mean radius of all the windings on it be 3 inches, and let the diameter of the covered wire with which it is wound be rather more than ½ millimeter, or say 1/40 of an inch. The capacity of each layer, with regard to the layers above and below, will then be

$$\frac{r b}{T} = 240 \text{ inches}$$

that is, 20 feet, which is comparable to the capacity of a single-wire antenna 400 feet high!

"The coils we advocate are wound with much thinner wire than that. And if the diameter of the covered wire is .006 of a centimeter, even though the breadth of the channel is only 1 centimeter, yet with the mean radius 3 centimeters, the effective capacity will be

$$\frac{3}{.006}$$

that is, 500 centimeters, or 5 meters, which is still very large—bigger than most amateur antennæ.

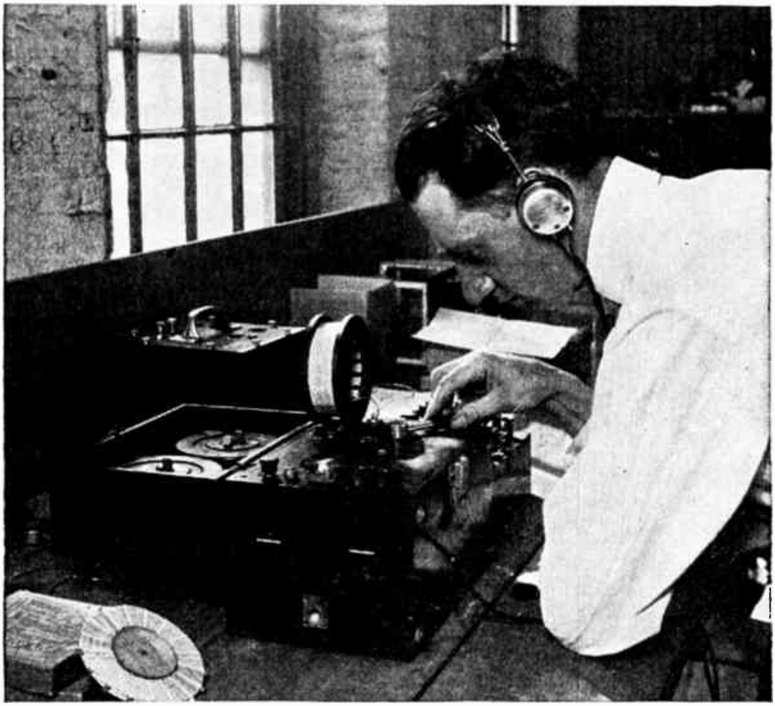
"To have that capacity, a single-wire antenna would have to be about 100 meters long and even a quadruple horizontal antenna with its four wires spaced a yard apart would have to be 40 meters in length.

"But we do not want the capacity of the coil to have any relation to the capacity of the antenna. The coil should be kept in its due insignificance so far as regards capacity. What we want in the coil is inductance. Distributed capacity along the coil only introduces confusion, spoils the sharpness of the tuning, and make precision impossible. It introduces the same kind of confusion as a submarine cable introduces into telephonic speech. The Leyden jar effect of a cable—that is, of a wire conductor separated by an insulator from an outside coating—prevents high-speed transmission and tends to smooth out the signals and make them indefinite.

"This effect in cables can be remedied by the introduction of coils at intervals, showing that coils are not in themselves deleterious. But they should always have as much inductance as possible in proportion to their resistance, so as not to introduce unnecessary damping."

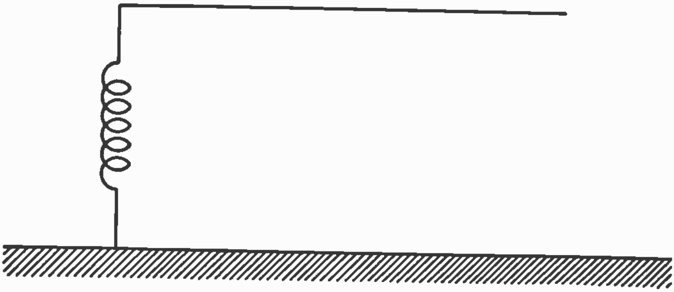
Prof. Morecroft, of Columbia University, has added a most understandable and helpful treatise to this discussion concerning coils:

"It would seem that such a simple thing as a coil could require but little analysis; that anyone could build a coil which would prove satisfactory when used in a radio circuit. Of course anyone *can* build a coil which will operate in



THE DAMPING QUALITIES OF A COIL CAN BE MEASURED

**Figure T: In order to determine the damping qualities of any coil it is only necessary to measure its resistance and inductance. Calculation of the damping effect of a coil will indicate how sharply it will tune in a radio circuit.**



THIS CIRCUIT WOULD TUNE SHARPLY

**Figure V:** The inductance added to the circuit between the antenna and ground serves as a balance wheel to the electrical oscillations and keeps them swinging much longer than would be the case with the antenna shown on page 204.

a radio circuit; the question is—how good is the coil and how well will it operate compared with the best coil which can be built for the purpose?

"It is the purpose of this contribution to point out some of the factors which determine just how good a coil is and how well it should function.

"There are three so-called electrical constants which enter into all of our calculations in radio work; not only enter into our calculations but which also determine completely how well a set may operate. They are:

The inductance;
The capacity;
The resistance.

"Resonance is, of course, the key-note of operation of all radio circuits; the product of the inductance and capacitance used in the circuit determine at what frequency resonance is obtained. The sharpness of this resonance (that is, the relative ease with which it lets through the desired frequency as compared with others of different frequencies not desired) is determined by the ratio of the resistance of the circuit to its inductance.

"It is evident that the characteristics of a coil, simple thing as it is, are well worth while studying; this study soon shows that resistance and inductance at radio frequencies are not the simple things taught in elementary physics, but are rather complicated—so much so that theory alone cannot predict what the constants of a coil will be at high frequencies, so that recourse must be had to experimental determination.

"The student of electricity learns that if the voltage (in volts) of a continuous current circuit is divided by the current (in amperes) which flows through a circuit, the quotient will be the resistance of the circuit (in ohms), and that this resistance is constant unless the temperature changes. In an alternating current circuit the same quotient yields the impedance of the circuit, the impedance being made up of two components, resistance and reactance. If the current lags behind the voltage, in phase, the reactance is inductive; if the current leads, it is capacitive. The resistance of the circuit is not the same value at all as would be determined by continuous current test, using Ohm's law for its calculation; in fact, a circuit which shows millions of ohms resistance to continuous current flow may have only a fraction of one ohm for a high-frequency alternating current.

"As Ohm's law does not suffice to determine resistance in an alternating current circuit we must get a new definition which does meet the situation. This definition, which is applicable to all circuits for continuous as well as for alternating current (that is, it includes Ohm's law as a special case) is

$$\text{Resistance} = \frac{\text{Power used in the circuit}}{\text{(current flowing in the circuit)}}$$

"If the power is given in watts,and the current in amperes, the resistance will come out in ohms.

"It might be questioned how this definition can be used in radio circuits—can we use a watt-meter to read the power used? The answer is "no"; the procedure indicated by the definition does determine the resistance but is not generally followed. We could put the circuit in a calorimeter, measuring the rate at which heat is developed, divide the amount of this heat by the square of the measured value of the current flowing, and so determine the resistance; but such a method is not suitable for rapid and accurate determinations.

"It is possible to so adjust the circuit that its reactance is zero, in which case the resistance is given by Ohm's law.

$$R = E/I$$

"In another method the alternating current Wheatstone bridge is used, by which the resistance and reactance of the coil are both determined at once when the bridge is balanced. The bridge is probably not accurate at more than a few hundred thousand cycles a second so that the resonance method (making the reactance equal to zero) is the only one available.

"If the frequency of the power supply is known (as it will be by wavemeter determination) and the capacity used in the circuit to establish resonance is accurately known, the inductance of the coil, as well as its resistance, is determined by the resonance test. So with a good wavemeter, and a well built and carefully calibrated condenser, with suitable thermocouples for current measurement, resistance and inductance measurements may be made with a fair degree of accuracy for frequencies as high as ten million or more.

"This contribution gives the results of a few measurements made by the writer in such a fashion; from these results certain conclusions may be drawn which are interesting to the radio enthusiast. By the radio enthusiast is meant the one who is interested in knowing *why* certain things are as they are, not the one who merely boasts that he furnishes the neighborhood with so much noise from his set that the police department have to censor him, or the one who hears so many distant stations that actually do not exist.

"Why should the resistance of a coil be different at radio frequencies than for continuous current?

"There are many things resulting in an increase in resistance for the high frequency alternating current which do not exist at all for continuous current or very low frequency alternating current. For continuous current all of the cross-sectional area of the conductor is useful in carrying current, whereas for high frequency, due to what is called the skin effect, but a small part of the copper may be useful in carrying current. The losses in bits of metal used in the construction of the coil (for terminals, for example) change the effective resistance of the coil, always making it greater than it is for continuous current. The material on which the coil is wound is in a high-frequency electric field, and even though it be a perfect insulator, permitting no current at all to leak from one turn of the coil to the next, it is subject to losses called 'dielectric losses,' or 'dielectric hysteresis.' This loss increases directly in proportion to the frequency and so may give a substantial increase in the effective resistance of the coil at the high frequencies used in radio.

"It might be thought that this change in effective resistance with increase of frequency is not worth bothering about —perhaps a few per cent. But such is not the case; the resistance for high-frequency alternating current may be many times as much as it is for continuous current. Thus one coil such as might be used in an ordinary receiving set had a continuous current resistance of 0.45 ohms; at 500 meters wavelength it had 3.5 ohms, and at 200 meters it had 18 ohms. In other words, the coil had forty times as much resistance as the

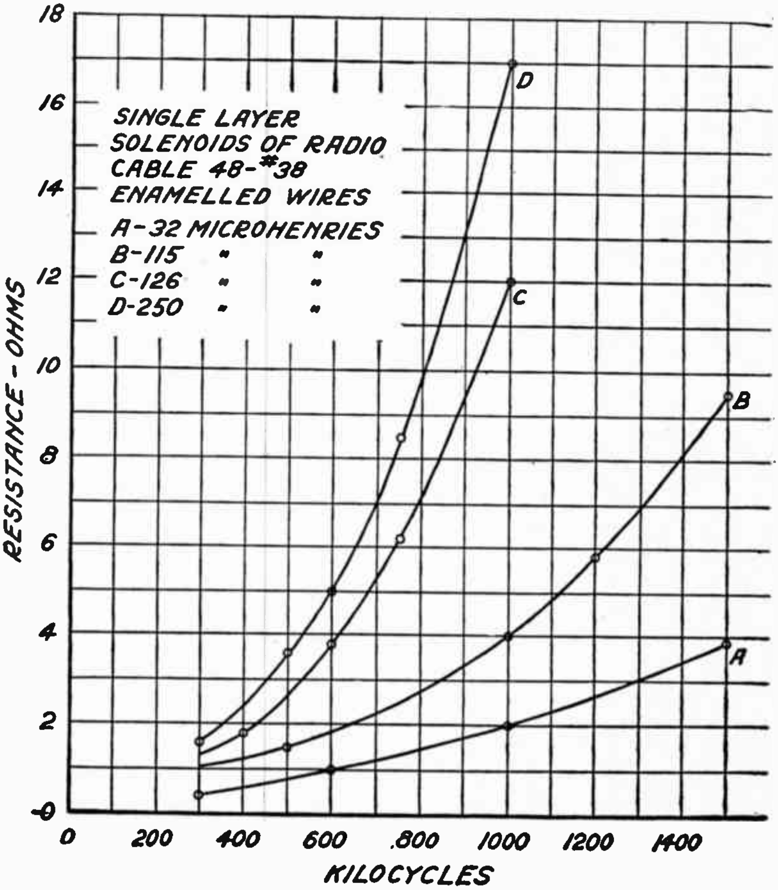


FIGURE W
A resistance-frequency chart of single layer solenoids of different values of inductance.

wire table for resistance of copper wires would predict. This was not a defective coil, but a good single layer solenoid of No. 20 solid copper wire.

"To show how the resistance of coils varies with frequency the curves of Fig. X are given; they are experimentally determined curves for ordinary solenoids such as are used in receiving sets of the better class. The wire of which the coils were made was of radio cable, made of 48 strands of No. 38 enameled copper wires properly bunched together. Up to frequencies above one million cycles a second the cable shows itself superior to solid wire, as the solid wire has not the same cross section as the cable but is of such a size that it winds the same number of turns to the inch. The continuous current resistance of the solid wire was only about one-half as much as that of the cable, showing there was more copper in it than there was in the cable. Above one million cycles, however, the solid wire actually becomes better than the much more expensive cable, or 'litzendraht,' as it is sometimes called.

"The superiority of the solid wire is well shown in Fig. Y, which gives the resistance of solid wire and cable coils of the proper number of turns to make them suitable for short wave sets. It will be seen that at the higher frequencies the solid wire has less resistance than the cable, although at the frequency used in broadcasting (about 833,000 cycles) the cable is considerably the better of the two. As to just where the solid wire becomes better than the cable will depend somewhat upon the form of coil; the conclusions reached from these curves holds only for coils of similar shape and method of winding. It is comforting for the amateur who 'builds his own' to know that the cable, costing about twenty times as much as the solid wire, and which is also troublesome to tap, is but little better than the cheap, easily worked solid wire.

"For a given type coil, wound of a given kind of wire at a specified frequency, there is one coil which gives a better performance than one with either more or less turns; that coil having the greatest ratio of reactance to resistance will tune best, be most selective; to get this highest ratio a coil with the proper number of turns must be used.

"Using two and three layer banked winding solenoids, made of radio cable (48-38's), the ratio of reactance to resistance was found for various coils as given in Fig. Y. The coils were all of the same diameter (about 4 inches), and the length varied with the number of turns used. These curves indicate that to get the best tuning (greatest selectivity) a proper coil should be used for a certain wavelength. Thus, for tuning to 500 meters we should use coil A in preference to any of the others, but for 800 meters practically all of the coils are equally good. It must be borne in mind that the conclusions drawn from these curves, while in general correct for any form or type of coil, hold specifically true only for coils of this size and wound with the kind of wire used here; also that the losses in the condenser used in conjunction with the coil for tuning must be considered. In general if two coils have the same ratio of reactance to resistance, that with the smaller inductance is preferable, as it will require a greater capacity for tuning and the effective resistance of a variable condenser always decreases with increase of capacity.

"The resistance of the loading coils used in transmitting sets is an extremely important factor in the efficiency of the station. Unfortunately the requirements for tuning, as at present carried out, practically require that a coil of heavy copper strip be used so that clips can be moved along them for adjusting the wavelength. The resistance of these coils is excessively high at radio frequencies. In one coil of heavy copper strip measured by the writer the resistance at 3000 meters was 350 times as much as its continuous current resistance; at 200 meters it would have been thousands of times as great as one would think, looking at the amount of copper used. In a certain one-kilowatt transmitting station the loading coil got so hot that it was uncomfortable to touch; it seems likely that two or three hundred watts were being used up in this coil, an amount of power which required an investment of perhaps $200 in tubes to generate. It seems advisable to build the loading coil of heavy radio cable, of the proper number of turns to tune the antenna to a slightly lower wavelength than it is desired to radiate, and bring the circuit up to the desired wavelength by putting a good variable condenser in parallel with the antenna. If the loading coil of your transmitter gets appreciably hot it is a safe guess that the coil has a very high resistance and is inefficient.

"The coefficient of self-induction of a coil may be easily calculated when the dimensions of the coil and number of turns are given. If the coil is measured at, say, 1000 cycles the calculated value of L will be found the same as the measured value, generally closer than 1 per cent. If, however, the coil is measured at radio frequency the inductance may be found either slightly less or considerably more than the measured value. And in the extreme case, what is evidently a coil measures up as a condenser!

"The reason that the measured value of L may come out smaller than the calculated value is because of the shift of the current from a more or less uniform distribution throughout the cross-section of the wire at the low frequency, to a crowding to that side of the wire which is closer to the axis of the coil at radio frequencies. As this shift in the current is equivalent to a decrease in the radius of the coil, of course the measured value of L is smaller than the calculated one, as the formula assumes a uniform distribution of current. If radio cable is used in constructing the coil this effect cannot occur, so the value of L does not show a decrease as the frequency is raised; the effect occurs to the greatest extent in the strip coils used for transmitting loading coils.

"The apparent increase in inductance with increase in frequency exists in all coils, no matter how they may be built, and does result in an increase in the measured value of L at the higher frequencies, no matter with what kind of wire the coil is wound. In the solid wire, or copper strip coil, therefore, we may expect the inductance to decrease slightly at first as the frequency is raised and then to increase, whereas with cable wound coils the measured value of L will show a continual increase in L as the frequency is raised. This increase is due to the distributed capacity of the coil itself. Each part of the coil acts with every other part to form a kind of complicated condenser, so that the coil really should be represented as a coil in parallel with a fixed condenser, the capacity of this condenser being equal to the distributed capacity of the coil. This representation is not complete because actually the capacity of the coil changes with frequency, an effect which is generally neglected in treating the theory of coils.

"The effect of this distributed capacity is, in general, not detrimental, but may be so if the capacity is comparable to that used with the coil for tuning purposes. In this case, as the capacity of the external condenser is only a part of the total effective capacity in the circuit, variation of its value does not accomplish tuning as sharply as if there were no capacity of the coil affecting the circuit.

"It might seem that distributed capacity in a coil is not objectionable, as we have to have a condenser connected to the coil anyway—for tuning purposes. But such is not the case. It is best to keep this capacity as small as possible because the dielectric used in that capacity is poor compared to the dielectric used in the external condenser. The distributed capacity of the coil has cotton, paper, shellac, or enamel, for its dielectric, whereas the regulation tuning condenser is a very well built air condenser, and air is far superior to any other substance as a dielectric; it has no losses at all.

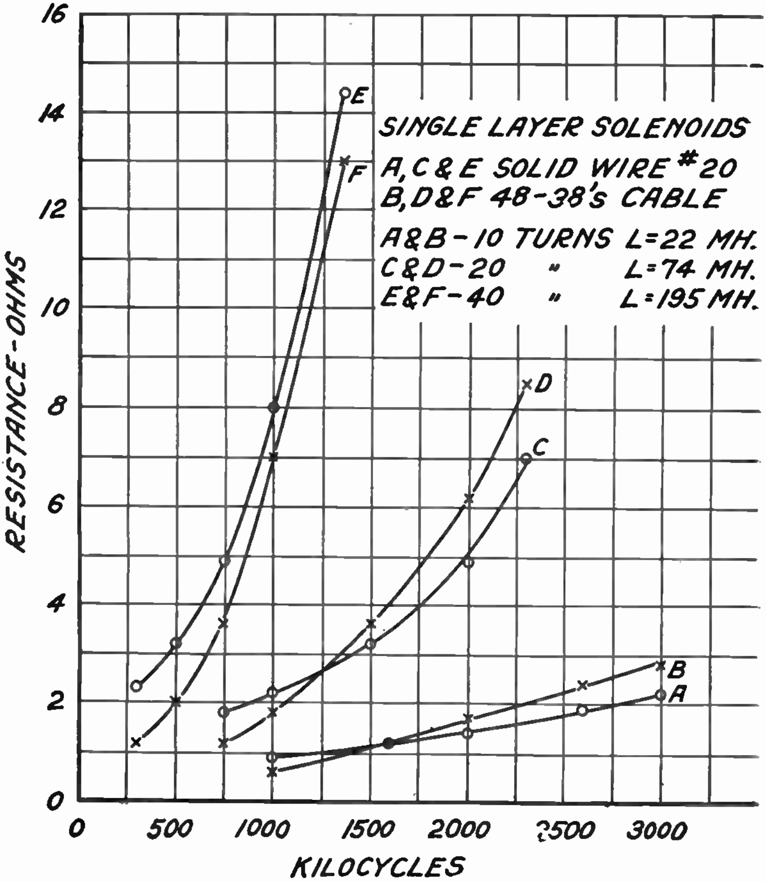


FIGURE X
Another resistance-frequency curve for coils wound with No. 20 wire.

"The various turns and layers of a coil should be kept reasonably far apart if the distributed capacity is to be kept low, and the dielectric between layers and turns should be air, if possible. Several years ago the writer showed how such a construction could be carried out without too much difficulty. Using air for the dielectric between layers has the double advantage of low specific inductive capacity and also prevents leakage of current in passing from one layer of the coil to another.

"Many times a solenoid is furnished with many taps and a multipoint switch for tuning purposes; although this is a convenience it does not give as good results as a single coil of the proper number of turns. This is especially true if but a small fraction of the coil is to be used, say a quarter or less. In such cases the coil acts as an auto-transformer, the used portion having comparatively high voltages induced in it and thus producing large unnecessary copper and dielectric losses in the unused portions. Also it is evident that the switch points mounted in the panel of bakelite or similar material constitute a condenser in parallel with the tuning condenser; in this connection it should be borne in mind that losses in the bakelite, or leakage across from one point to another, is, of course, just as detrimental as leakage in the coil itself.

"To prevent the losses in the unused portion of the coil it is best to build the coil in sections, an inch or more apart; many times it will be found advantageous to short-circuit that part of the coil which is not being used. This is especially true when but a small part of the

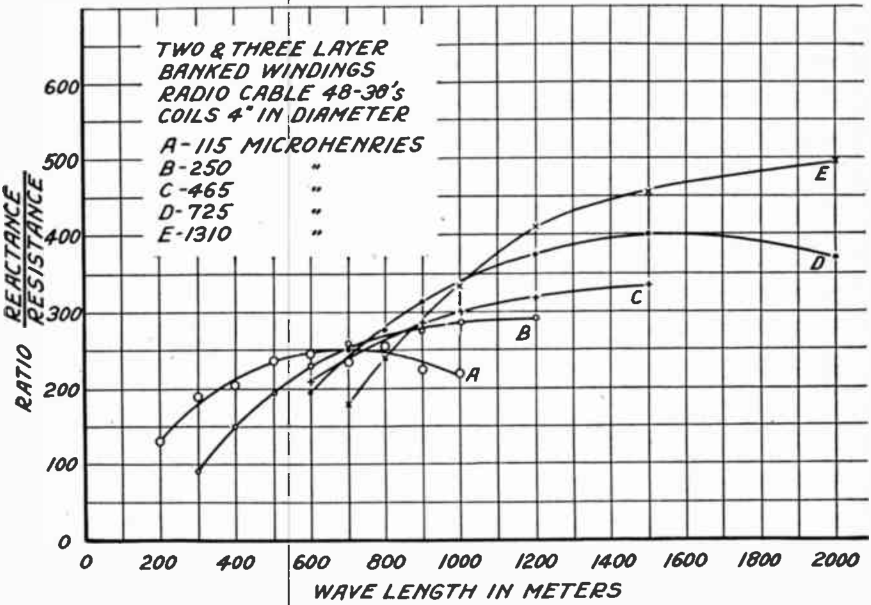


FIGURE Y

**This chart shows the ratio of reactance to resistance for two and three layer bank-wound coils at different wavelengths.**

coil is being used. Although there will be eddy current losses in the short-circuited part of the coil these losses may be less than if the coil were not shorted. There will be practically no dielectric losses in the unused parts of the coil, because the voltage in these parts will be low; and furthermore it is quite possible that there will be less current in the unused part than if it were not shorted, strange as this may sound. If there are several sections in the unused portion of the coil it will not be necessary to short all of the unused part; shorting the section directly next to that part of the coil which is being used is, in practically all cases, almost as satisfactory and as a matter of fact it is in general easier to accomplish. These rules of practice may be very easily followed."

## APPENDIX

## A PLEA FOR EASY SPECIFICATION

*By Sir Oliver Lodge*

When working with ordinary coils and condensers in the laboratory, the specification of capacity in microfarads is convenient enough, and so is the specification of inductance in terms of henries or secohms. But when working in radio wavelengths, it is convenient to have the antenna capacity, and the inductances associated with it, expressed in terms of length because the geometric mean of those two lengths—that is, the square root of their product—gives the wavelength direct when multiplied by $2\pi$, that is practically for rough estimate, by 6. Six times the square root of the inductance and capacity multiplied together is a close approximation to the wavelength; and in predetermining the inductance required for any given case this must surely be a handy rule.

Capacity in electrostatic measure is a length, and inductance in electormagnetic measure is also a length. The truth is that in all units—that is to say, in absolute measure—capacity is really $K$ times a length, while inductance is $\mu$ times a length. And it is natural to express the one in static measure, under the convention that $K = 1$, and the other in kinetic—that is, magnetic—measure, with the totally different convention that $\mu = 1$. For the one has to do with charge, and the other with current.

The capacity of an ordinary amateur antenna is some simple fraction of its height or linear dimensions: about one-twentieth of the length of an isolated thin single wire measures its capacity. But the fraction may vary for different antennas from a twentieth to about a twelfth, as will be shown later. A microfarad is far too big a unit for convenience. A millimicrofarad, or even a micromicrofarad, has to be employed, and they are by no means convenient. The length corresponding to a microfarad is 9 kilometers. So a millimicrofarad is 9 meters, and a micromicrfoarad is nine-tenths of a centimeter; that is to say, 10 micromicrofarads equals 9 centimeters. So that for a rough estimate, it may be taken as a centimeter, though it is a trifle smaller.

On the other hand, a henry is 10,000 kilometers. So a millimicrohenry—or what is sometimes called a billihenry—is exactly 1 centimeter. While a microhenry is 10 meters, and a millihenry 10 kilometers.

Conversion from one set of units to another is always a nuisance. But after all a henry and its sub-multiples have no particular meaning which the imagination can seize hold of; whereas the length of a meter or a kilometer is easily imagined. Hence it might be well to have the coils used in radio thus marked—that is, marked in terms of length—using any unit of length that is handy for the purpose and suitable to the coil. Thus, take an antenna with a capacity of 1 meter, and put a coil of 10,000 meters inductance in series with it. The geometric mean of the two is 100 meters, and the wavelength, therefore, 600 meters.

The meter as a rule is the most convenient unit of length under the circumstances, since wavelengths are commonly so specified. But some people prefer to work in centimeters; and it is easy enough to remember that a billihenry is 1 centimeter. The farad is not a convenient unit. It was always much too big; but it can be remembered that a microfarad is equivalent to a length of 9 kilometers. In radio work, however, it is certainly more convenient to express capacity as a length, whether it be agreed to specify inductance also in that way, or not.

It is curious to note that a farad coupled to a henry would have a slow oscillation period of six seconds; and so give a quite inappreciable wave, 1,800,000 kilometers long. A microfarad connected to a henry of inductance would oscillate a thousand times in six seconds, and so generate a wave 1,800 kilmoeters long. Whereas a microfarad coupled to a microhenry would have a frequency a thousand times as great, and so might give a strong wave 1,800 meters in length; the same wave being also generated by a millimicrofarad coupled to a millihenry; which may be expressed as a 9-meter capacity and a 10,000-meter inductance.

The intensity of radiation increases very fast as the wave is shortened.

### Nolte Coil Specifications

Type; special basket weave
Use; radio frequency coupling, etc.
Mounting; for Nolte coil mounting
Connectors; pigtails
Support; self supporting

### Acme Coil Specifications

Type; zig-zag weave
Use; radio frequency coupling, etc.
Mounting; no special facilities
Connectors; pigtails
Wire; green, silk-covered

### Acme Coil Specifications

Type; special zig-zag weave
Use; radio frequency coupling, etc.
Mounting; no special facilities
Connectors; pigtails

## Pfanstiehl Coupler Specifications

Type; low loss coupler
Coils; basket weave
Coil supports; self supporting
Insulation; bakelite
Frame; sheet metal
Tuning; adjustable for broadcasting range

## Precision Coil Specifications

Type; octagon solenoid
Form; moulded hard rubber with ribbed supports for wire
Wire; green silk covered
Use; radio-frequency coupling, etc.
Wavelength; broadcasting range
Mounting; base
Connectors; soldering lugs

## Ray Coil Specifications

Type; basket weave
Use; Reinartz ultra-audion tuned radio frequency, etc.
Wavelength; broadcasting range
Supports; wooden frame and pegs
Wire; cotton covered, tapped

## Bruno Coupler Specifications

Use; coupling
Frame; hard bakelite quartzite rods
Coils; Pancake and octagon
Mounting; Base
Connectors; binding posts
Wavelength; 200 to 575 meters with .0005 variable condenser

## General Radio Coil Specifications

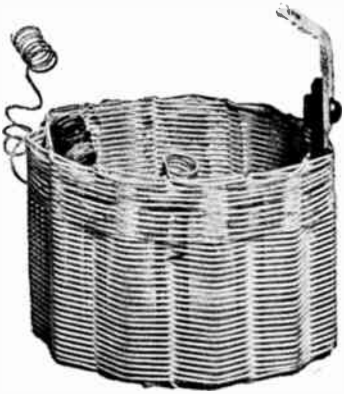
Use; inductance and coupling
Wavelength; may be had in 50 to 600 meter sizes
Frame; moulded bakelite
Winding; 2 sections
Frame; moulded bakelite
Connectors; soldering lugs and binding screws
Mounting; base or special support

## Langbein-Kaufman Vario Coupler Specifications

Use; inductive coupling
Wavelength; broadcasting range
Frame; moulded bakelite
Mounting; for panel
Connectors; binding posts

**Morris Coil**
**Specifications**

Type; torodial
Use; radio-frequency coupling
Mounting; for base
Connectors; soldering lugs



**All-Henry Coil**
**Specifications**

Type; basket weave solenoid
Use; radio-frequency coupling
Mounting; for base
Connectors; pigtails

END OF SECTION X

## SECTION XI

# The Improvement of Broadcast Reception

*THE elimination of disturbing noises requires something more than intelligent manipulation of the tuning knobs. The interference may be of a dozen different kinds and it may have a dozen different sources and it is only by treating the subject in its entirety that we can hope to meet all of the problems that arise in this particular and very important phase of the radiophone art.*

*John V. L. Hogan, who is one of the greatest authorities on the design of radio receivers in the United States, contributes the following matter to the course and the student may read and absorb it knowing that no more thorough or accurate contribution has been made to this kind of popular radio literature.*

There is really just one big problem facing those who listen to broadcast radio-telephone transmission—the attainment of perfect reception.

Already the technique of radio-receiver construction has progressed to the point that even the *average* set gives a reproduction of speech and music that compares favorably with the results obtained from the average phonograph. But there is no reason why even such progress should satisfy us, for the time is coming when radio reproduction will be much better than any phonograph can give.

Suppose we begin, then, by finding out what it is that is responsible for imperfect broadcast reception.

We may divide up the defects or difficulties into three main groups, *i.e.*, the effects that occur in the transmitting station, those that take place as the waves flash through space, and those that happen at the receiver.

We propose to go into more detail as to the matters concerned in receiving-apparatus design and use than as to the first and second classifications, for two reasons; in the first place, the receiver is in your own hands and you yourself can improve its operation; and in the second place, there is more room for improvement in the receiving system (as a general rule) than anywhere else. Nevertheless, we should understand something of the transmitting-station and wave-movement difficulties if we are to appraise properly the performance of our receivers.

Consider the transmitter for a moment. Here we must first produce a perfectly uniform and unvarying stream of radio waves of a single definite frequency. If the wave frequency varies during transmission the signals will appear to fade away and grow stronger again as the radio wave departs from and returns to the frequency that the

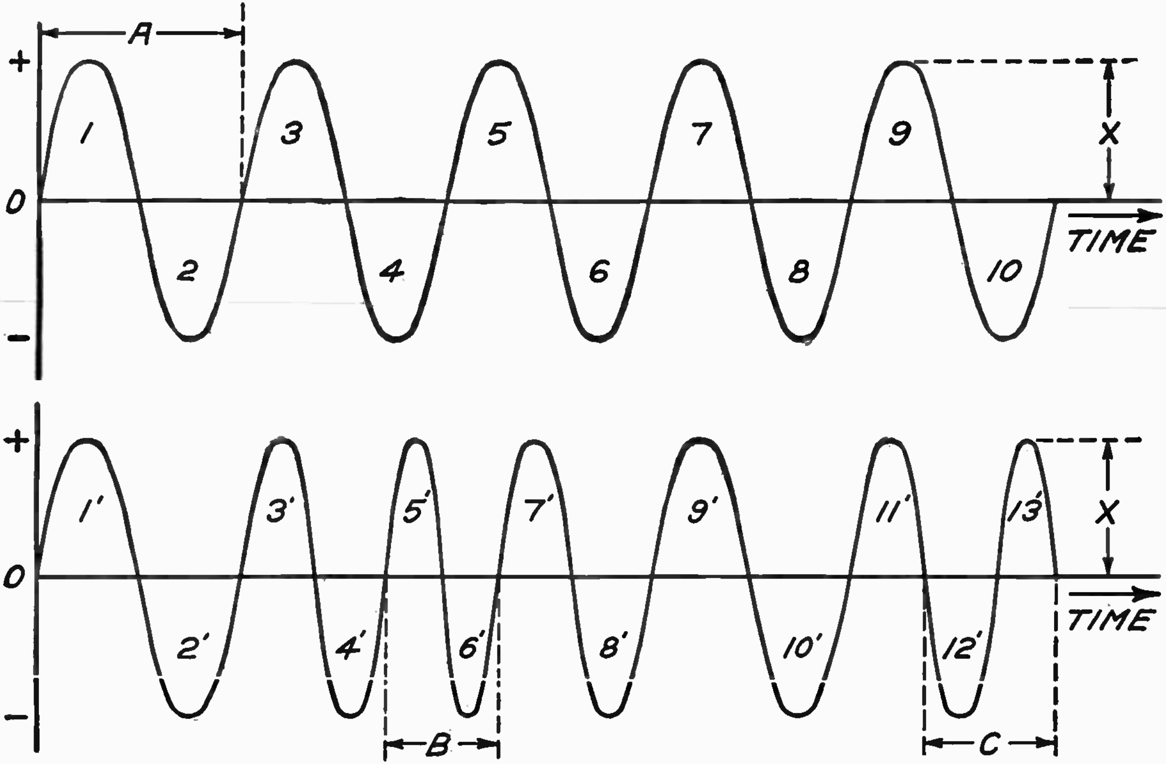
AN OLD-TIME "BROADCASTING STATION"

Figure A: The improvement made in radio transmission and reception since the days of the old "transmitting amateur" has been one of the outstanding accomplishments of the past three years. Until the advent of the present-day broadcasting station, amateur spark stations similar to the one pictured above and naval and commercial telegraph stations were the only transmitters that the radio fans could listen to.

listening receiving sets are adjusted to intercept. If the transmitted wave frequency remains constant during any one program, but varies from night to night or day to day, this sort of artificial "fading" will not be noticed, but signals from the station will be located at different receiving tuner settings at different times. Of course, such a variation in the wave frequency makes it difficult to receive from the station in question.

Keeping the transmitted wave steady is simply a matter of arranging the generating apparatus at the broadcasting station so that it will produce oscillations of uniform frequency, since the wave frequency must always be the same as that of the alternating currents that produce the waves. Fortunately the job of maintaining constant frequency of oscillations is no longer very difficult; most broadcast transmitters do very well on this score.

The fluctuations in wave frequency that cause apparent fading of signals are, of course, slow. It may require several minutes for the wave to change to a value only a few percent from its initial frequency. What would happen, then, if the variations in wave frequency occurred more rapidly? There are several general effects, and how much of each will be observed depends upon the rapidity and extent of the fluctuation. If the wave varies from its average value ten times a second, we would expect to hear a fluttering sound when listening to the station. The loudness



BROAD TUNING IS CAUSED BY CHANGES IN FREQUENCY

Figure B: The upper curve represents a perfect carrier wave. The lower curve shows how rapid changes in wave frequency spoil its uniformity and make close tuning impossible. Slow changes cause signal fading and the speeds in between make a warbling note in the receiver.

of the flutter would increase as the amount of wave-frequency change increased. If the rate of fluctuation were increased to twenty or thirty times a second the flutter would be changed to a low-pitched rumbling tone. Still more rapid fluctuations would result in higher-pitched musical tones in our receivers. All these noises, you should bear in mind, would be heard while listening to the unmodulated and supposedly quiet "carrier wave" of the transmitter in question. Further, they would be produced by the mere changes in wave frequency even though the amplitude or intensity of the emitted wave were absolutely uniform.

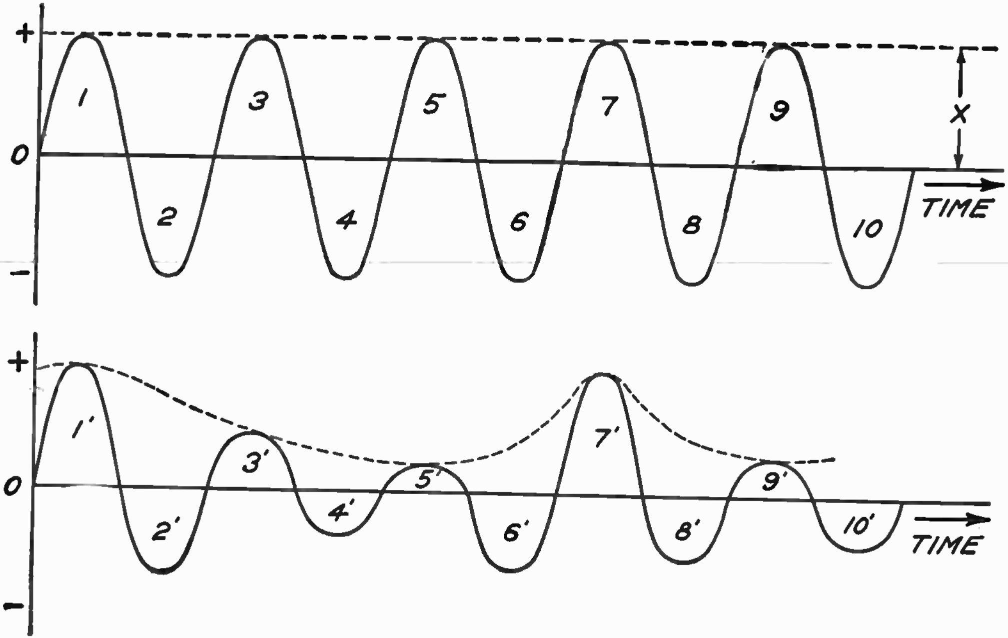
Now, let us suppose that the rate of frequency variation in the carrier wave is reduced to three or four times a second, and that the changes in value are not abrupt. The alterations in the carrier wave would not then produce a noise in the listening receiver, but we should be able to notice an effect that is quite different, namely, an apparent "broadness of tuning." It is not hard to see that, if instead of sending out a uniform carrier wave of 833,000 cycles a second frequency (corresponding to 360 meters wavelength), some particular station radiates at a frequency which slides up and down between 836,000 and 830,000 cycles, we cannot tune our receivers sharply to it at any single value between those limits.

Such fluctuations in carrier-wave frequency are undoubtedly responsible for some of the cases of broadness of tuning of broadcast transmitters that have been reported, and, even today, probably account for part of the poor quality of speech and tone consistently observed in listening to some broadcasters. Thus a loss of quality, or of fidelity in tone reproduction, that is generally blamed upon "poor modulation," may actually be caused by a very different thing. If you notice cases of wave-frequency fluctuation you can do a favor both to the broadcaster and to the radio listeners by writing to the station and telling its management in detail about your observations.

There is still another trouble that may be caused by the sending out of an incorrect wave frequency. Broadcasting stations are now licensed to radiate standard waves that have been chosen just 10,000 cycles apart in frequency. Waves so separated will not directly interfere with each other. But if, for example, station WRC in Washington, which broadcasts at 640,000 cycles (469 meters) were accidentally to increase its carrier frequency to 644,000 cycles, and if station WCAE in Pittsburg were to reduce its frequency from the assigned value of 650,000 cycles to a new figure of 646,000 cycles, the two station waves would obviously be only 2,000 cycles apart. With such small difference in frequency any two radio waves would directly interfere with each other. By the well-known beating or heterodyne action they would produce a whistling tone of 2,000 cycles pitch, about equal to that of the third C above middle C on the piano, in every radio receiver that was so tuned and so located as to receive both waves.

This whistling note might be only a faint sound in the background, if one of the two interfering stations were relatively far away, or it might be so loud as to ruin reception of either or both programs. This latter would be the case when the two stations were about equally distant from, or were received at about the same intensity on, the observing receiver.

There is no reason other than accident or carelessness for the occurrence of any such whistles caused by beating



NOISY RECEPTION IS CAUSED BY CHANGES IN INTENSITY

Figure C: The upper curve represents a perfect carrier wave. The lower curve shows how variations in the power supply affect the carrier wave. Generator hum or steady sizzling and frying noises—which you hear between features on the program—are nearly all due to changes in the strength of the carrier wave.

between the waves of broadcast stations in the United States, with the single exception of the "Class C" group that is licensed to use only 833,000-cycle waves (360 meters) Any two Class C stations are likely to interfere directly with each other, and the interference may be, and often is, so severe as to ruin their programs. If you like to listen to some particular Class C station and you find that it is continually being spoiled by a more or less steady whistling note, you should tell that fact to its management and urge them to ask for reassignment to a Class A or Class B wave frequency that will not be so disturbed.

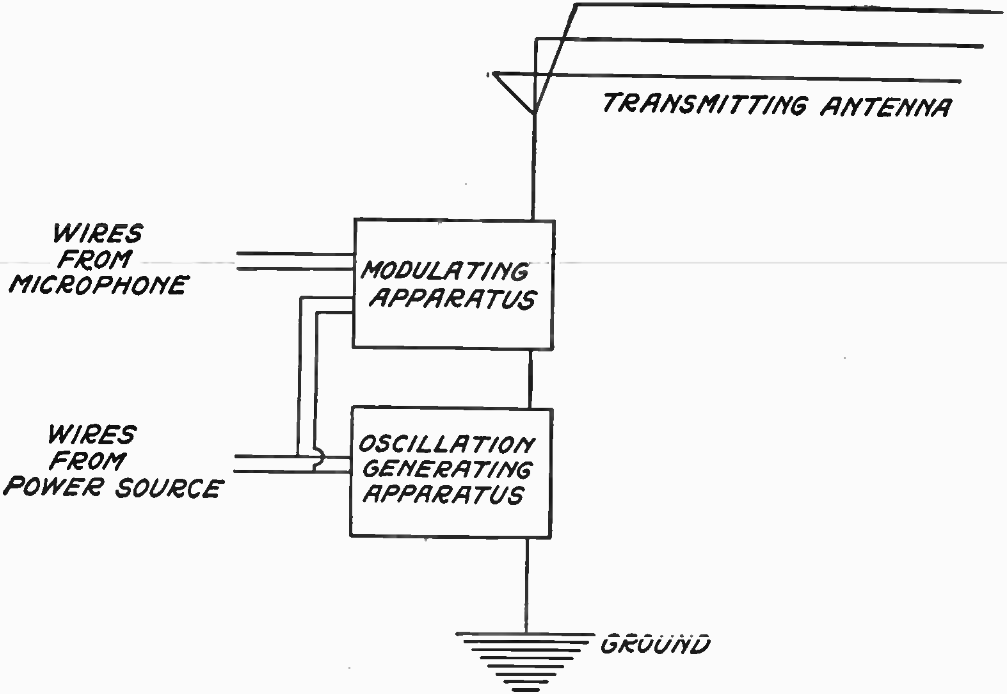
The great majority of high-grade broadcasting stations (and particularly those in Class B) have little or no difficulty with variations in their carrier-wave frequency. If we listen to such a station as heard in an oscillating receiver so that a beat note may be produced by the heterodyne interaction of the local oscillations and the carrier, we find that the beat tone is pure and constant in pitch. This means that the simple, unmodulated wave coming from that particular transmitter is uniform as to frequency and, consequently, that it is the ideal wave for bringing us radio-telephonic speech and music of high quality. If it is not so nearly perfect it will not serve so satisfactorily as a radio carrier wave.

Leaving the matter of frequency fluctuations, let us consider another possible defect in the radio wave as it is transmitted by a broadcasting station. This is a slow or rapid variation in the intensity of the carrier wave, which may occur even though the transmitter operates at a perfectly uniform frequency. The effects produced at a listening receiver by variations in the intensity or amplitude of the transmitted wave are in some ways like those caused by changes in frequency, which have just been discussed.

For instance, if the wave intensity varies slowly, and by a considerable amount, it may produce at the receiver a corresponding variation in signal strength. If the intensity of the wave fluctuates rapidly, at a rate within the range of audible frequencies, it will make sounds in any ordinary listening apparatus and will be what is called a "noisy carrier wave." Such noises will, of course, be an obstacle to perfect reception of broadcast programs, and, at the transmitting station, they must be reduced to the practical minimum.

There are still other characteristics of the waves sent out by broadcast transmitters that may cause trouble in reception. One of these is the radiation of waves at more than one frequency, *i.e.*, at certain definite frequencies other than the single one that is authorized for the particular station. It is not uncommon for a transmitter to send out "second harmonic" waves at twice its normal frequency, and sometimes other waves go out at other and higher multiple or harmonic frequencies. As a rule this harmonic radiation is a good deal weaker than the main or fundamental wave, and consequently it does not carry so far. However, wherever it is heard, the program of the sending station will be received on the higher wave frequency, and this may cause substantial interference.

For example, let us imagine that the Memphis station, which uses a main wave of 600,000 cycles frequency or 500 meters length, were to radiate a strong second harmonic wave. This would necessarily be at 1,200,000 cycles (double the fundamental frequency), which corresponds to 250 meters wave-length. Such harmonic radiation would severely interfere with reception from



WHERE THE TRANSMITTING TROUBLES ORIGINATE

Figure D: Changes in frequency are due to the swinging of the antenna or local conditions within the transmitter. Uneven power supply or bad modulating apparatus cause a noisy carrier wave.

Class A stations using this 1,200,000 cycle frequency as their fundamental wave, as can easily be seen.

The extra radiation may not be at harmonic intervals, *i.e.*, at double, triple or quadruple frequencies, as in the above instances. Cases have been observed where a single station sent out several waves at relatively closely adjacent frequencies, and, consequently, set up strong interference that disturbed reception from a number of other broadcasting plants.

Generally speaking, there are four kinds of interfering noises that may come in with the radio waves you desire to receive.

The *first* of these is caused by variations in the carrier wave from the station to which you are listening, and we have already looked into the matter of frequency and intensity variations in these carrier waves.

The *second* kind of interfering noise is that caused by radio waves other than the one to which you are listening; interference of this kind may produce several quite different effects in your receiver.

The *third* kind of interference is that arising from natural or atmospheric electrical discharges, and is what we ordinarily call "static" or "strays."

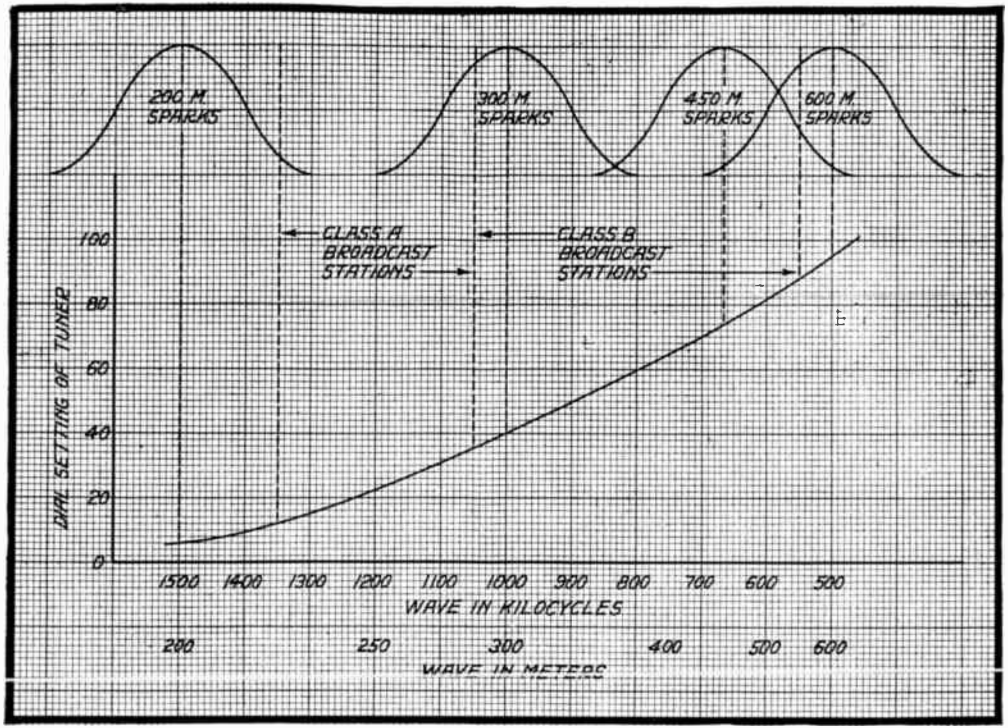
The *fourth* type of noise is produced by electric power or signalling lines or the apparatus connected to them, and is usually called induction.

Let us go back for a moment to the first type of interference.

Noises caused by frequency fluctuations in the carrier wave being received have been fairly well covered. We have also studied the matter of intensity variations to some extent, and we have pointed out that an uneven power supply at the transmitting station, or the use of bad modulating apparatus, would cause a noisy carrier wave. Before leaving the topic of "noisy carriers," as they are often called, it will be worth while to consider in a little more detail several of the ways in which they are set up. The ideal carrier wave for any radio telephone station would of course be absolutely uniform as to frequency and intensity. When no voice or musical signal is being sent out, the wave should not vary in any way. Such a uniform carrier wave, when received upon a non-oscillating receiving set, would produce no sound whatever in the telephones or loudspeaker. Consequently, when either music or speech was impressed upon this silent carrier wave it would be conveyed to the receiving station and there reproduced without any distrubing sound caused by wave fluctuations.

Now let us suppose that the transmitter which we are considering has a perfect carrier wave, within practical limits. That is to say, let us imagine that when we tune to the wave from this station we hear nothing except the telephonic voice or music. This will imply that the transmitter has a well-designed power source, so that no noises will arise from its irregularities. It also means that the modulating apparatus introduces no undesirable interference. If the modulator, in addition to quiet operation, has the ability to impress upon the carrier wave faithfully-copied variations corresponding almost exactly with the sound variations that strike the pick-up microphone, we have every reason to expect high grade transmission from the station.

But it often happens that a broadcasting transmitter has a carrier wave that is normally silent and free from frequency changes, together with a modulating system that is capable of high-quality tone production, yet that when we listen on some particular occasions



HOW THE SPARK SETS MAKE TROUBLE

Figure E: The curves at the top of the figure show how signals from spark transmitters of commercial radiotelegraph stations spread out over the broadcast wavebands. The reason for changing the spark-set wavebands is apparent from this illustration.

the signals are accompanied by noises and are not clearly reproduced by our receivers.

When this happens, many listeners are apt to say that the trouble is caused by "bad modulation."

As a matter of fact, the modulating operation of the radio transmitter may be perfect and the troubles may occur far away from the modulation apparatus of the broadcasting station. It is much more common, in well-planned broadcasting stations, for noises and distortion of this kind to develop in the pick-up microphone (and its amplifier and connecting line systems) than in the modulating apparatus itself.

If you know what to look for, it is not hard for you to pick out cases where noisy carrier waves are produced by the effects of the pick-up line that connects the microphone with the radio generating portion of the broadcast transmitter. Usually the short pick-up line that runs from oscillation generator and modulator equipment to a nearby studio is quite free from such influences, and thus when the station is broadcasting events from its studio there may be none of the interfering noise heard by radio listeners.

On the other hand, it is quite common for the longer pick-up lines that are used in transmitting "out-of-studio" programs (such as park concerts, sports, and so forth) to bring various kinds of noises into the radio sending apparatus. If the carrier wave, as heard between the announcements or the numbers of the program, is silent when transmission from the studio is going on, but noisy when outside events are being broadcast, you may be sure that the noise is a wave-intensity variation introduced by disturbances affecting the long pick-up lines.

Sometimes the sources of these noises may be identified by listening closely; electric motors, stock tickers and telephone ringers all have characteristic sounds. Any of them may induce disturbing currents (in a microphone pick-up line) which, when conveyed to the modulating apparatus, will be impressed upon the outgoing radio waves and thus carried to your loudspeaker.

In the same way you may note variations in the quality of reproduction when listening to different program items that are broadcast from some particular station. If the speech is clear and distinct when the speaker is at the studio, but muffled and hard to understand when he is talking over a long pick-up line, you may be sure that the faulty transmission is not caused by "poor modulation" but by poor transmission to the modulating apparatus. The defects introduced by poor pick-up lines, which often will convey telephone currents of some frequencies far better or far worse than a good average value, are particularly noticeable in musical transmission. Often a poorly adjusted pick-up line so distorts the currents that the tones of individual musical instruments cannot be identified with certainty.

¶*When you notice noisy carrier waves or distorted transmissions of the kinds we have just described, you will be doing a great favor to broadcast listeners generally if you will write to the management of the offending broadcasting station and tell them what you have observed.*

But when you write, don't say that the trouble is caused by "bad modulation" if in fact the modulator is doing its best and the noise is introduced by the pick-up lines!

Next let us take up the second general type of interfering noises that come in with the waves.

This second type is radio wave interference. To make improvements in your reception when it is disturbed by radio interference is not, as a rule, a matter of writing letters to the interfering stations. In the vast majority of cases the trouble can be completely remedied, or at any rate greatly reduced, by modification or careful adjustment of your receiver.

Radio wave interference is probably the greatest single cause of imperfect broadcast reception. It is, of course, true that there are many defective radio receivers in use, and that these sets reproduce noisily or with distortion, but so far as I can determine the great majority of receiving sets function correctly within the limits set by their design. We must now assume that your receiver is working as well as it can, and, in treating "outside" causes of receiving difficulties, limit ourselves to effects that occur in spite of a more or less approximate perfection in the individual parts and the assembly of the receiving set. If your set is not working well, and if you can locate the trouble within its circuits, you should repair it before giving any time to the matter of outside interference.

There are three main varieties of radio wave interference, and these have come to be known as "sparks," "whistles" and "cross-talk."

The division called "spark interference" should really include all types of telegraphic code distrubance, even though the interfering radio-telegraphic station is not of the spark type. Practically all interference of the code classification, however, comes from the old-fashioned spark transmitters that are still in use in so many radio-telegraph stations, and so all of it is generally blamed on sparks.

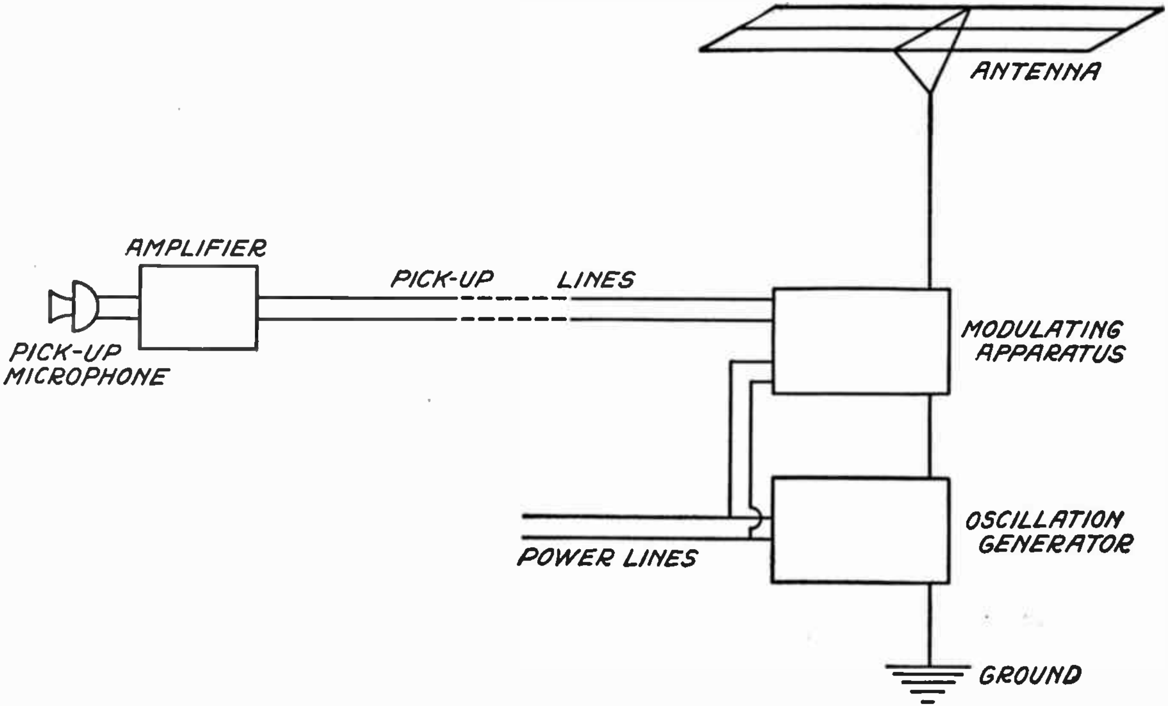
Interference from code transmitters is growing less as time goes on, because more and more spark sending stations are being re-equipped with modern transmitters that cause less disturbance. Further, there is in formulation a plan to reduce the trouble from the spark transmitters still remaining in service, by transferring their operations to wave-frequencies farther removed from the broadcasting range. Assistance along these lines will assuredly be welcomed by broadcast listeners everywhere, but as great progress in either direction will necessarily take some time it seems well worth while to see what can be done to make receiving sets themselves less susceptible to spark interference.

Let us see, then, just what the spark interference problem amounts to.

Suppose that you are listening to a broadcasting station of which the wave frequency is 610,000 cycles a second, corresponding to a wavelength of 492 meters.

Your receiver may be sufficiently well tuned to prevent your hearing any other broadcasting stations, but still the broadcast program may suddenly be interrupted by loud dots and dashes that come in from some unknown radio telegraph transmitter. Whether or not you are disturbed by such code interference will depend mainly upon four factors. The first of these is the difference between the frequencies of the desired wave and the interfering wave. The second is the width of wave-frequency band occupied by the interfering wave. The third is the excluding power (or sharpness of tuning) of your receiver; and the fourth is the intensity of the interfering signal compared to the broadcast signal you desire to receive.

We should examine these four factors separately if we are to understand the situation, and if we do not understand the problem we are trying to solve there will be only an exceedingly remote chance of our making any progress. From some viewpoints it is one of the



THE MODULATOR IS BLAMED FOR MOST FUZZY NOISES

Figure F: In reality the pick-up microphone, the amplifier and the pick-up lines shown in the diagram above are the sources from which many stray noises come to your loudspeaker.

A SWINGING ANTENNA LIKE THIS CHANGES THE TUNING

Figure G: Antennas rock when the bough bends or the tree sways in the wind. If the wind blows the tree toward the house, the antenna sags down to the position shown in the dotted line. This changes the capacity of the antenna and is often the cause of fading signals.

misfortunes of present-day radio that the practical development of broadcasting has come so rapidly, for the demand for apparatus and services of all kinds has been too great and too sudden to permit sound engineering to be the rule rather than the exception.

Considering, then, the effect of frequency difference upon interference, it is not hard to see that with other conditions remaining unchanged we will have least trouble from interfering waves that are widely different in frequency from the wave we desire to receive. This is simply because any receiving set that has any pretentions to selective ability, or the power to respond well to signals of some particular (tuned) frequency while excluding signals of other (untuned) frequencies, will discriminate to the greatest extent between waves of widely different frequency values.

What differences in wave frequency may we expect under today's conditions of broadcasting and marine radio-telegraph signalling?

The best and most concise answer to that question may be had from a tabulation of the various values of wave frequency in use, as shown below:

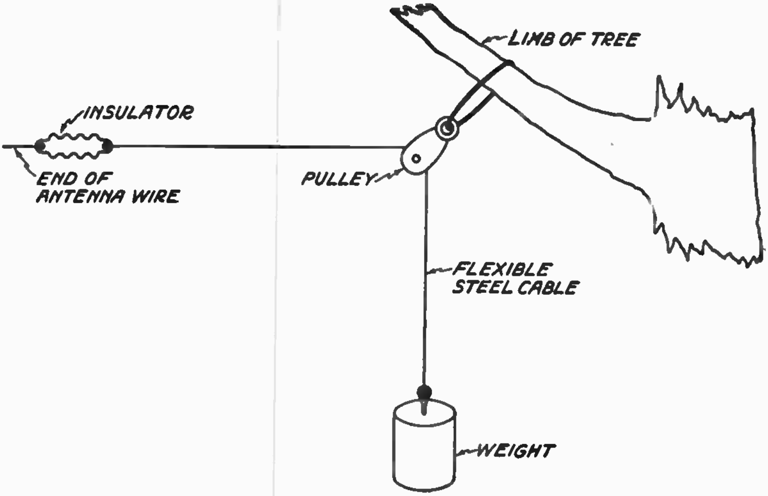
It is quite evident that amateur spark transmitters that use waves at or near the frequency of 1,500 kilocycles (1,500 thousand cycles or 1,500,000 cycles) will be likely to interfere with reception from broadcast stations that use the higher frequencies in class A, and that marine spark transmitters will often cause trouble in receiving from class B stations near the frequencies of 1,000 kc, 666 kc and 500 kc. There is little message traffic handled by ships at the high-frequency wave of 1,000 kc, and the Department of Commerce has assigned no broadcasting wave nearer to it then that of WSAI (Cincinnati) at 970 kc; consequently the 1,000 kc ship wave does not greatly trouble broadcast listeners. The 666 kc wave has been extremely bothersome, as it comes right in the middle of the broadcasting range:

| Frequency Cycles | Wave-length Meters | Service |
|---|---|---|
| 1,500,000 | 200 | Amateur Radio-telegraph Transmitters |
| 1,350,000<br>to<br>1,050,000 | 222<br>to<br>286 | Class A Broadcasting Stations |
| 1,040,000<br>to<br>1,000,000 | 288<br>to<br>300 | Class B Broadcasting Stations |
| 1,000,000 | 300 | Marine Radio-telegraph Transmitters |
| 1,000,000<br>to<br>670,000 | 300<br>to<br>448 | Class B Broadcasting Stations |
| 666,000 | 450 | Marine Radio-telegraph Transmitters |
| 660,000<br>to<br>550,000 | 455<br>to<br>546 | Class B Broadcasting Stations |
| 500,000 | 600 | Marine Radio-telegraph Transmitters |

| | |
|---|---|
| 640 kc | KFI, WCAP and WRC (Los Angeles and Washington) |
| 650 | WCAE (Pittsburgh) |
| 660 | KDZE and WJZ (Seattle and New York) |
| *666* | *Ship Interference* |
| 670 | WMAQ (Chicago) |
| 680 | WOS (Jefferson City) |
| 690 | NAA (Radio, Va.) |

Regulations have been put into effect by the Department of Commerce, however, which have had the effect of greatly reducing the marine traffic transmitted at 666 kc, and this has been of great help to broadcasting. The most important marine traffic wave, of 500 kc, is still largely used by spark transmitters and still causes much interference for listeners who are receiving from KSD (St. Louis, 550 kc), KYW (Chicago, 560 kc), WNYC and WOAW (New York and Omaha, 570 kc), and some others which use the lower-frequency waves.

When you experience spark interference with your broadcasting reception, it is a good plan to tune your receiver to the interfering station for a moment. If your set is of one of the types in which the scale readings are more or less proportionate to the wavelength to which it is tuned, you can get a very fair idea of the wave frequency of the station causing the trouble. For instance, if WNYC comes in at 80 on your tuning dial and the code interference becomes louder as the dial reading is increased to 95, for example, it is evident that the interfering wave is in the neighborhood of 500 kc. If the interference is loudest near the tuning point for WJZ or WCAE, the bothersome station is probably using the 666 kc wave. If the interference is far down the scale it may come from 1,000 kc ships or 1,500 kc amateur transmitters. The radio-telegraph transmitters occasionally send out incorrectly adjusted waves (and both commercial and amateur stations sometimes offend in this respect); a little experience in observing interference as suggested above will aid you to determine this fact, and



**THE RIGHT WAY TO FASTEN AN ANTENNA TO A TALL TREE**

Figure H: By using a pulley and weight fastened to the end of the antenna (as shown above) you can get rid of the trouble caused by the swaying of the tree in the wind. The weight takes up any slack in the wire and keeps the antenna always at the same tension and consequently always at the same distance from the ground.

you may be able to do some good by reporting your test to the Radio Supervisor in your particular district.

An odd thing about the transmitter defects is that their effects upon the receiver are in a number of respects like those of certain defects which may exist in the receiving set itself.

Where the difficulty in reception is caused by something that has gone wrong at the transmitting station, you have, of course, no direct cure available to you. You may write to the broadcasting station explaining the trouble and your observations upon it; and you should do that in every instance, for you will thus be helping not only yourself but thousands of other listeners. On the other hand, if the defective operation is to be blamed upon your own receiving apparatus, you have the opportunity of remedying it right before you. All you need is a little information as to what produces these possible troubles in radio receivers, and a few suggestions as to how they may be eliminated.

It is probably worth while, therefore, to interrupt our discussion of transmitter troubles at this point so that we may consider for a moment some of the things that can happen at a receiving station and which will produce similar effects.

Unless you are able to determine definitely whether some particular phenomenon is due to a cause existing at the radio sending station, you will naturally hesitate to write to the broadcaster about it. There would be the distinct possibility that the trouble really lay in your own receiver and that the broadcast station management could do nothing whatever to help you!

Let us first take up the effects produced by variations in the frequency of the carrier wave received from a radiotelephone transmitter, so that we may find out what things can happen within your receiving set and there produce similar effects.

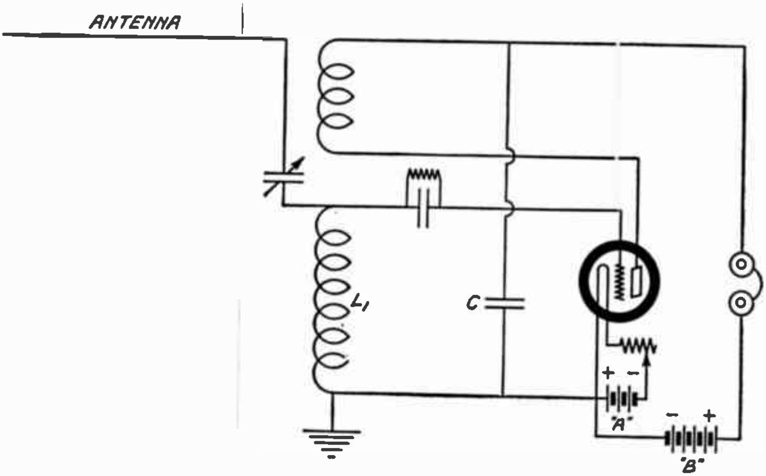
As we pointed out previously, fluctuations in the frequency of a carrier wave may occur slowly, or with moderate rapidity, or even at a high rate. The resulting effect will, of course, be different in each of these cases.

A slow change of carrier frequency will cause the signals heard in a sharply tuned receiver to vary slowly in strength as the wave swings in and out of resonance with the receiver. It is almost obvious that an identical effect would be produced if something caused the resonant frequency of the receiver to vary slowly, for then, assuming the carrier wave to remain fixed in frequency, the receiver itself would slowly swing in and out of tune. As the receiver's tuned frequency departed from the frequency of the carrier wave, the signals would necessarily weaken, only to become stronger again as the receiver returned to resonance with the wave frequency.

Possibly you are one of those listeners who has always thought that the frequency to which his receiver responded best was determined by the settings of the dials and by nothing else. An impression of that kind is certainly warranted by some of the discussions of tuning that have been written, but it is really far from the fact. Where we are considering only the closed tuned circuits of a receiver, that is to say, the circuits in which a coil is shunted directly by a condenser for tuning, it is safe to consider that the tuning depends mainly (if not entirely) upon the values of the coil and the condenser, and that some particular setting of the tuning condenser is invariably best for the reception of some single wave frequency (or wavelength). On the other hand, where the antenna circuit is to be taken into account the situation is very different.

It is probable that most of the receiving sets in use require reasonably accurate adjustment of the antenna circuit in order to give good signal strength from moderately distant stations. Such adjustment means that the natural electrostatic capacity of the antenna, in conjunction with its inductance, must be balanced against the inductance of the coils and the capacity of the condensers that are connected in the antenna-to-ground circuit within the receiving set. The resonant wavelength of such an antenna circuit, or (which is another way of saying the same thing) the wave frequency that will best be received at any time, is controlled by the values of *all* these inductances and capacities. Thus, even though you may leave the adjustable coils and condensers within the receiving set at any fixed value, the slightest change in the inductance or capacity of your receiving antenna will change the "tune" of your receiver. If the change in the antenna circuit is slight, the effect may not be serious; also, if your receiver uses a broadly tuned (or so-called "aperiodic") antenna circuit you may not notice the variations. On the other hand, (and this is the situation with most of the receivers in use), if your antenna circuit is sharply tuned you will find that fluctuations in your antenna constants will make themselves felt to a serious degree.

It is a fortunate thing there are only two general causes for such changes in antenna capacity and inductance. One of these is the actual movement of the receiving antenna with respect to other



THE SINGLE CIRCUIT IS SENSITIVE TO ANTENNA CHANGES

Figure I: The secondary circuit is the most sensitive part of any receiver and in the single circuit the antenna is directly connected to this part of the receiver. Three-circuit sets, especially those in which the antenna is left untuned, are affected very little by changes in the capacity of the antenna.

conducting bodies in its neighborhood, and the other is the variation of capacity of other wires or conductors located near the antenna under consideration.

Taking up the first of these, it is not hard to see that if your antenna is a long wire, hung loosely so that it may swing in the wind, it will have a larger capacity when it dips down toward the earth than when it is drawn high above the ground. This is simply because the antenna wire acts like one plate of a condenser, the other plate being the conducting surface of the ground; we all know that the nearer the two plates of a condenser are placed together, the higher will be the capacity of that condenser. The changes of capacity produced by a slight swinging of the antenna wire may be so small as not to affect tuning appreciably, but as a practical matter it is not uncommon for received signals to fade out and swing in again as the antenna drifts back and forth in the breezes.

In most instances such variations in signal strength, caused by changes in the receiving antenna, sound very much like the signal intensity variations that are caused by frequency fluctuations at the transmitter. Indeed, they also sound a good deal like the common "fading" effects that are due to the little-known changes in space between the transmitter and the receiver. Usually, however, when the soaring of signal strength is caused by movement of the receiving antenna wires it is of more or less regular or periodic occurrence; that is, the signals swing in and out a more or less definite number of times per minute, corresponding to the mechanical swings of the antenna wires.

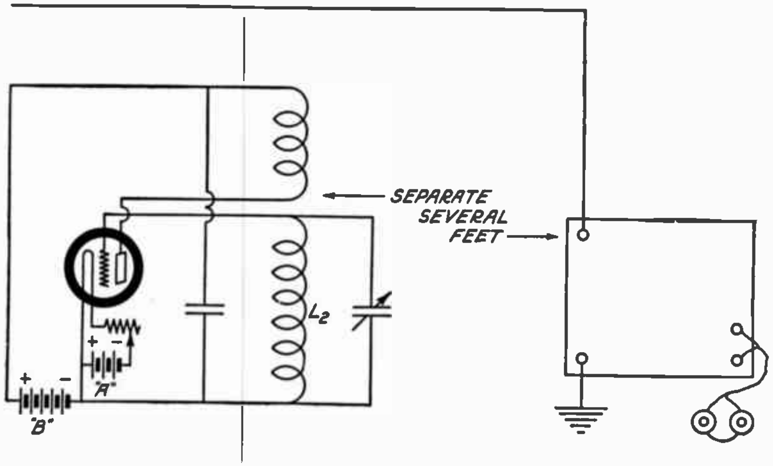
The obvious cure for this particular defect is to string your receiving antenna fairly taut, and if it is suspended from a tree or other support that can sway in the wind, to rig it with a weight and pulley so that it will not dip toward the ground. This alone may not be enough, however, for if there are telephone lines, power wires or in fact any conducting bodies near the antenna, and if they can swing or move toward and away from the antenna wire, its effective tuning will be changed by their motions. For best results, then, you must not only prevent your own antenna from swinging but you must locate it out of the vicinity of all other conducting bodies that *can* move.

There is one infallible test by which you can determine whether variations in signal strength are caused by fluctuations at the transmitter, by changes in your receiving antenna constants, or by a "fading" effect in space between the sending and receiving stations. By connecting a simple tuned-antenna (single-circuit) regenerator to your antenna and tuning it to a moderately distant broadcasting station *while allowing the receiving set to oscillate*, you can find out whether the fluctuations are of frequency or of intensity. To do this, you should adjust the receiver to oscillate at a frequency just the veriest trifle different from the frequency of the carrier wave. This can be done by setting the tuning condenser or inductance as closely as possible "between the two whistles" that are characteristic of oscillating-receiver or heterodyne reception, and carefully tuning to one side or the other so that a slow beat-flutter in the signal is heard. Such exact adjustments are difficult unless you use a vernier or geared condenser, but in this case are not hard to obtain.

With the regenerator so adjusted, listen carefully to this fluttering sound produced by the slow beats between the carrier wave and the oscillations of your own receiver. If the flutter swings in and out, or if it turns into a musical tone of varying pitch, you may be certain that frequency changes are taking place somewhere in the system. If the flutter or the low musical beat note remains practically constant, but the sounds increase and decrease in intensity, you may be sure that the carrier wave is constant in frequency, that your antenna does not swing enough to worry about, and that the fading is caused either by power variations at the transmitter or by fluctuations of the "carrying power" of the space between your receiver and the transmitting station.

Let us assume that this test shows, by the changes in pitch of the beat-note heard when you allow your regenerator to oscillate at a frequency very near to that of the carrier wave, that somewhere in the system there is a change of radio frequency going on. The next thing to find out is whether the frequency variation is at the transmitter or in your own receiver. This is easy. All you have to do is to set up a radio-frequency oscillating circuit (which may be another regenerative receiver) near, but not too near, to your own receiving set, and pick up the oscillations which it produces. Such an oscillator will generate radio-frequency currents of practically constant frequency for reasonably long periods of time and you should have no difficulty in producing a beat-note signal between its oscillations and those of your own receiver.

If this beat-tone is constant in pitch, even when the sound frequency is reduced to a very low note or flutter, you can assure yourself that your receiver's oscillation frequency is uniform and, therefore, that your antenna does not change appreciably in its constants under the conditions of your tests. It is a fair conclusion, having procured these results, that the frequency variation is occurring at the radio transmitting station upon which the observations were



HOW TO TEST FOR VARIATIONS IN THE RECEIVING SYSTEM

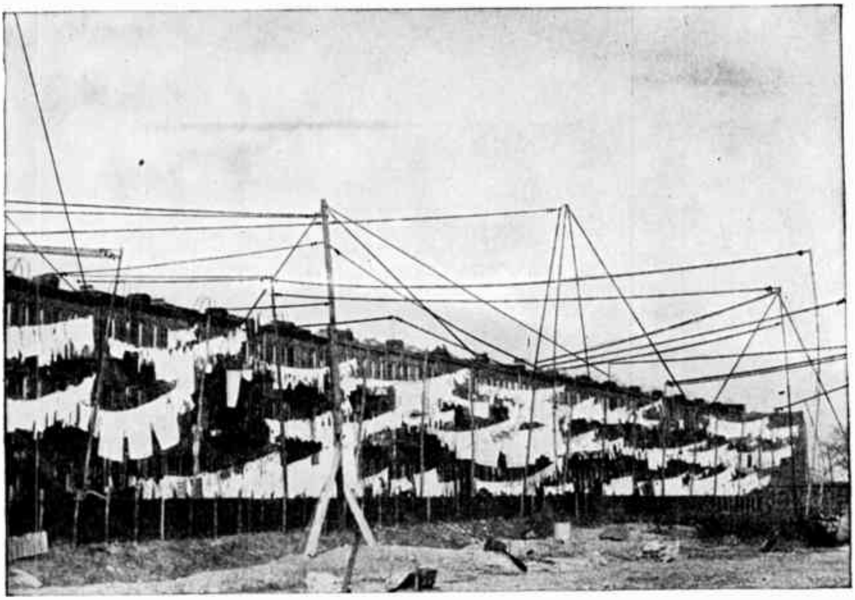
Figure J: On the right is the receiving set or any other set which is to be tested. On the left is shown a circuit for an oscillator capable of producing continuous and steady radio-frequency oscillations. By tuning the two sets to the same or "beat" note, variations in the receiver will produce periodic howling noises.

taken. This can be checked by stopping your receiver from oscillating, tuning it to the transmitter in question and then adjusting the second oscillator (which uses no antenna, of course) to make beats with the wave currents from the broadcasting station. If these beats are of variable pitch, that is, if the beat or note frequency changes while you are listening and without your touching the receiving set or oscillator, it is proof that the carrier wave is varying in frequency and you are entirely justified in writing to the broadcasting station to ask them to steady things up so as to permit improved reception.

The second general cause of changes in the inductance and capacity of receiving antennas is even more serious than the mechanical swinging discussed above, but fortunately it does not happen so frequently.

Where a large number of receiving sets are installed close together, however, as in the same apartment house, it often creates a great deal of annoyance. This second cause is the variation of capacity of conductors in the vicinity of the receiving antenna. For instance, if another receiving antenna is hung within fifteen or twenty feet of yours and is connected to ground through a receiving set, the operation of tuning that other instrument is likely to throw your receiver *out of adjustment.*

To illustrate this, let us assume that you have "tuned in" the signals that you desire to hear from some particular broadcasting station. This has been done, we will say, while your neighbor's antenna tuning condenser is set at 20° on the scale. If, now, he moves his condenser to 80° (for example) he may increase the effective capacity of his antenna, and, also, because your two antennas are close together, increase the



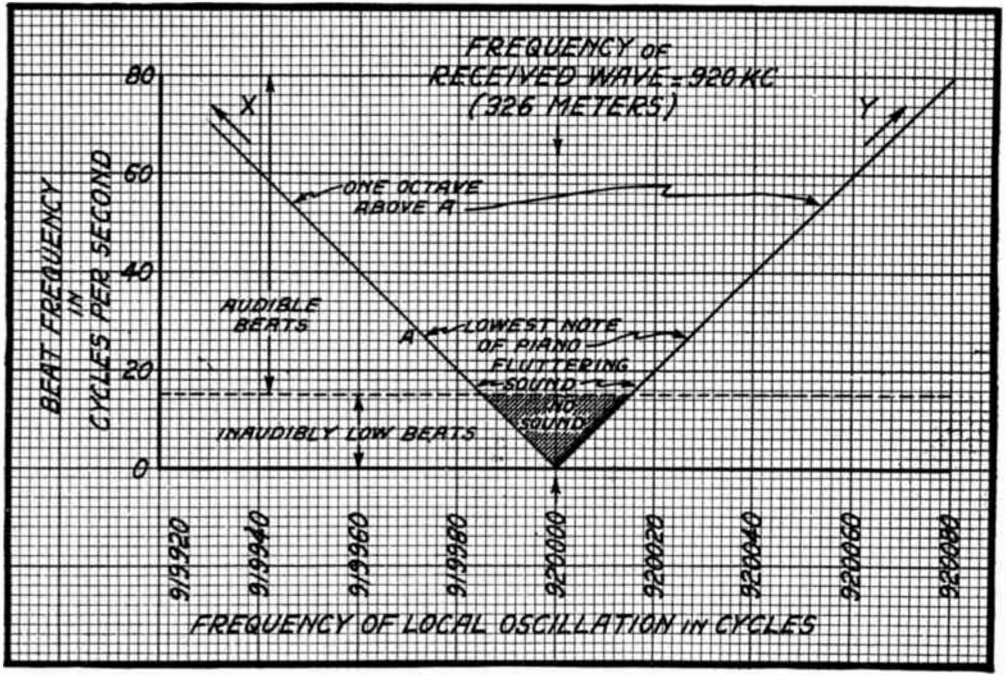
CARELESS TUNING CREATES RADIO CHAOS WHERE ANTENNÆ ARE PLENTIFUL

**Figure K:** In neighborhoods where antennæ are strung close together, great care must be used in tuning; otherwise the set will break into oscillation and spoil the reception of every other nearby receiver.

capacity of yours. That would be likely to throw your receiver so far out of tune that the signals to which you were listening would vanish quite without warning, and you would have to retune your set to bring them in again. Should it happen that the act of retuning your receiver similarly disturbed your neighbor's reception, he would be likely to adjust his once more and thus again disturb your balance. Thus an exceedingly aggravating condition may arise, and *you may neither be able to enjoy the operation of your outfits.*

If you notice tuning effects of this kind, which are evidenced by the sudden dropping out of signals, or by their irregular weakening, or by their appearance at various different settings on your antenna tuning scale, first see how far your receiving antenna is from other wires. If there is another antenna near it, get together with your radio neighbor and find out by experiment whether the adjustment of his set affects the tuning of yours and *vice versa.* If you interfere with each other in this way, try to work out a plan whereby your two antennas may be kept as far apart as possible, and after moving them to the new locations, try the test again.

Sometimes it happens that the two antennas cannot physically be separated far enough to prevent them from affecting each other; in such instances some improvement may be had by installing broad-tuned antenna circuits in both receivers, for the reactions caused by tuning coupled circuits will generally be less. Some loss in signal strength may



HOW A SILENT OR BEAT NOTE IS PRODUCED

Figure I.: When two high-frequency waves are near the same rate of oscillation, they reinforce each other and neutralize each other in regular sequence. If this sequence occurs at a rate above sixteen times a second, an audible note is produced in the telephones. The two sides of the V in the diagram show the plotting of this note as one of the radio frequencies changes wavelength. The darkly shaded section marked "no sound" is the "beat" note.

be experienced, but as a rule it will be more than compensated for by increased convenience in tuning.

Neighboring antennæ are not the only conductors that change in capacity and thus affect tuning conditions. If your antenna runs close to a power wire or a telephone circuit, you may find that certain broadcasting stations tune in best at one setting sometimes and at other settings at other times. Where a certain wavelength is best heard on your tuner may then depend upon whether somebody's telephone is idle or is in use, or whether a certain elevator is running, or whether the lights in some particular house are turned on or off. The remedy for troubles of this kind is to follow the good old rule of keeping your receiving antenna as far as you possibly can from all other conductors, including wire lines and your neighbors' antennæ.

Although it is not at all difficult to handle a simple regenerative receiver so as to secure from it really remarkable gains in radio reception, there exists a widespread impression that great skill is necessary for its proper manipulation. This is perhaps due to two prime causes:

*First*, because many poorly designed regenerators, which are almost impossible to control properly, have been made or sold and are in use;

*Second*, because well planned and built receivers are frequently supplied with incomplete or even misleading instructions for operation and so puzzle unskilled users.

Radio phenomena, understandable enough when the fundamental reasoning underlying them is explained, are indeed baffling to the uninstructed novice; when one adds to the simple tuning effects the interesting and varied actions which the feed-back circuits produce, it is something of a wonder that in the tremendous recent growth of radio receiving more trouble has not been experienced.

In order to fix our ideas about the operation of the Armstrong feed-back, let us concentrate upon a simple circuit arrangement which is now in wide use and which is capable of giving excellent results with only simple adjustments.

Figure M. is a diagrammatic representation of this layout, which may be called the "single-tuned circuit" with inductive feed-back. It shows a simple aerial-to-ground circuit including a variable tuning condenser and a tuning coil which is preferably adjustable in steps and to which is inductively (and variably) coupled another coil. The terminals of the tuning coil are connected to the detector tube grid, through condenser $C_1$ and leak resistance $R_1$, and to the negative side of the filament. The filament circuit includes the usual six-volt storage battery and a finely adjustable rheostat $R_2$ for controlling the temperature or brilliancy of the filament cathode and consequently its electronic emission. The plate circuit is completed through the second or feed-back coil above mentioned (frequently called the "tickler" coil), the telephone receivers and the "B" battery of about 20 volts potential—the telephones being shunted by a by-pass condenser $C_2$.

For best results on the 360 meter wave length, which is common in radio broadcasting, the aerial capacitance should be not greater than about 0.0005 microfarad, and its natural wavelength less than 220 meters or so. These conditions will be met by a single wire antenna from 120 to 150 feet long (including the down-lead to the instruments) and from 40 to 60 feet above the earth. The tuning condenser should be variable over at least the range from about 0.0001 microfarad minimum to 0.0007 maximum capacitance. The

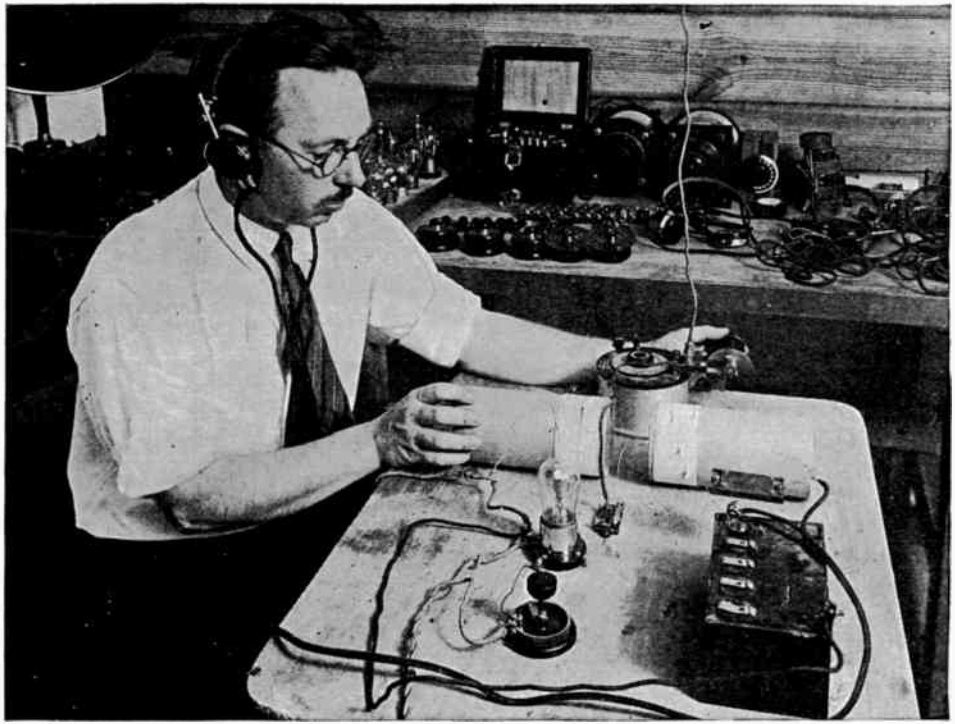


FIG. M1

How the single-circuit receiver should be connected. Mr. Hogan is here shown tuning the antenna circuit with the condenser (at his left), while controlling the amount of regeneration by moving the tickler coil nearer or farther away from the tuning coil.

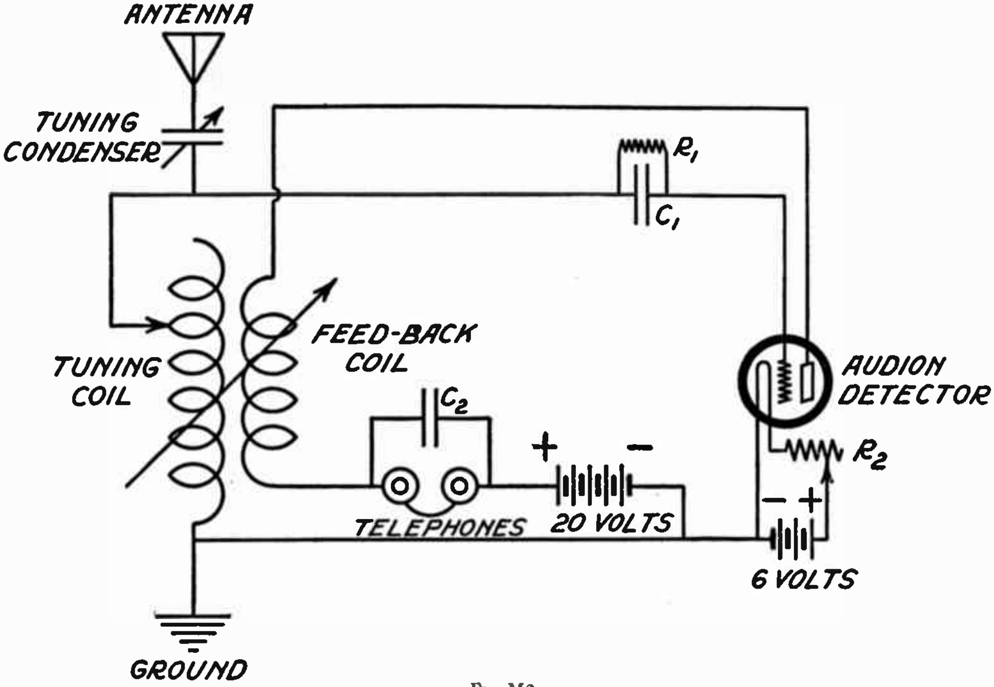


Fig. M2

The wiring diagram for the single-circuit oscillating receiver. This is the type of receiver that causes a great deal of radio interference because of the audio-frequency pulsations it transmits into the ether.

tuning coil should have an inductance in the general neighborhood of 50 to 100 microhenries, the exact value (which may in some cases be outside these limits) being determined largely by the particular antenna used. A coil of fifty turns of No. 22 B & S double cotton-covered magnet wire wound on a cylinder of 3½ inches diameter and provided with taps at 20, 30, 40 and 45 turns will give good results in most cases. A "hard" vacuum tube like the VT-1 or UV-201 should be used for the detector, as its vastly increased stability is ordinarily to be preferred over the delicately adjusted higher sensitiveness of a gassy tube in regenerative circuits. A grid condenser $C_1$ of about 0.0003 microfarad, grid leak of 1 megohn and by-pass condenser $C_2$ of 0.005 microfarad will usually give good results. The filament rheostat will be of about six ohms total resistance.

This leaves only the feed-back coil for consideration; a winding identical with that suggested for the tuning coil will work well under most conditions. The two coils should of course be arranged to be easily moved with respect to each other, so that the amount of feed-back coupling can be varied conveniently. In working with wavelengths as short as 360 meters and capacitance values of the order of 0.0005 microfarad and less, changes in tuning are frequently produced by the additional capacitance introduced when one's hand is brought near the circuit to adjust it. In an experimental outfit these bothersome effects can be avoided by fitting the tuning condenser and the coupling with insulating control handles some twelve inches in length, which will permit adjustment without close approach of the operator's hand. When a set is built up in panel form, a grounded copper shield plate between the control knobs and the instruments aids in securing compactness.

So much for the constructional fundamentals of a simple but effective regenerator.

It will be noted that there are only four variable elements in the entire system, namely: (1) the tuning condenser; (2) the tuning coil; (3) the coupling controlling the amount of feed-back, and (4) the filament rheostat. As the last-named item is not critical and as both the tuning controls produce the same general effect, it is fair to say that only two elements (the tuning condenser and the feed-back coupling) need be adjusted in the normal use of this outfit. The tuning condenser will ordinarily be of the semicircular multiple plate type having a total capacitance of about 0.001 microfarad; for easy adjustment in short wave working it is convenient to provide in addition a so-called "vernier" condenser, which has only two or three plates and which, when connected in parallel to the main tuning condenser, produces a change of tuned wavelength (for a motion through its entire scale of 180°) equivalent to only three or four degrees of the main condenser. The other adjustment—the feed-back coupling—may be controlled by turning a knob which varies the angular position of the "tickler" coil with respect to the tuning coil, or simply by moving the coils themselves nearer together or farther apart.

If you have purchased a regenerative receiver of the single circuit inductive feed-back type you will have no difficulty in these two adjustments; the handle usually marked "tickler" controls, from maximum to minimum, the amount of regeneration; and the resonant wavelength is varied by means of the "tuner" knob, supplemented, in some of the better instruments, by a closely adjustable condenser called the "vernier," as described above. In setting up an assembled or home-made outfit, however, it is necessary to determine the proper or additive direction of feed-back coupling. To do this, first be sure that the circuit is wired exactly as shown in Figure M2; put into circuit the full 50 turns of each of the two coils, and place them some distance (at least 8 to 12 inches) apart on the operating table. Listening in the telephones, test the detector circuits by turning on the filament to normal brilliancy and making and breaking a connection of the 20-volt plate battery; if everything is all right a strong click will be heard in the telephones at each completion and interruption of the circuit. By varying the tuning condenser it should now be possible to pick up (and tune to maximum strength) some radio telegraph or telephone signals; perhaps it will be necessary, if your aerial is relatively large, to reduce the number of turns used in the tuning coil. If signals can be "tuned in," the proper current direction in the feed-back coil can easily be determined by moving it nearer to the tuning coil, for if the signals increase in strength as the coils approach each other everything is all right. On the other hand, if bringing the two coils nearer together produces a weakening of the signals, either the tuning coil or the tickler coil must be reversed end for end. Once having the relative directions correct, the amount of regeneration is, of course, controllable from minimum to maximum by moving the coils from a relatively widely spaced to a closely adjacent position.

If signals cannot be picked up while the coils are far apart, try varying the tuning condenser as the coupling between the coils is increased, first with one relative direction and then with the other. Radiophone or wireless telegraph messages may be intercepted at some wavelength, with the help of regenerative amplification, so that the proper relation of the coils may be observed. If no signals whatever can be heard at the time the apparatus is being tried out, you will have to rely upon the oscillation test. Listening in the telephones as before, slowly bring the tickler coil near to the tuning coil; as they approach, if the relative directions are correct, you will hear a single "cluck" in the telephones. This marks the point of increased regeneration at which the whole receiver begins to generate radio-frequency oscillations. On moving the coils apart these local oscillations will cease; by increasing the coupling once more a repetition of the "cluck" will be heard, indicating the recommencement of oscillations. If the two coils are wrongly directed with respect to each other it will be found either that these oscillations cannot be produced at all or that the two coils must be nearly touching each other in order to do so. The remedy is, as before, to reverse one of the coils. Instead of turning one coil end for end, the wires connecting to it may be transposed.

Now let us look a little more closely at the adjustments necessary to get best results.

The set must be so assembled that the oscillation or "cluck" effect just described can be secured easily at the working wavelengths; when the feed-back coupling is increased to the point where oscillations are generated, their presence can be detected by tapping the grid connection of the detector tube; on each contact of the finger this same characteristic cluck will be heard in the telephones. If your set will not work in this way it is not regenerating properly, and you will not get the best results from it until it is fixed up.

FIGURE N

**In order to insure accuracy in his description of the way to tune a standard single-circuit regenerative receiver, Mr. Hogan actually performed the work in his laboratory—as these illustrations demonstrate. He especially warns the amateur against allowing the tube to oscillate, which causes interference to others in the neighborhood.**

To pick up a signal of unknown wavelength, or one for which the tuning condenser setting is not known, the tickler coupling should be set at a point sufficiently loose (toward the minimum) to prevent the set from oscillating as the condenser knob is swung back and forth throughout its range. If the desired signals are not heard at any point of the condenser scale with the full tuning coil inductance in circuit, change the number of turns and swing the condenser handle again; when the tuning coil is reduced in inductance by cutting out some of its turns, the tickler coil can ordinarily be moved up closer to the tuning coil without causing oscillations to begin.

After you have found the best number of tuning coil turns and the best condenser position for the desired signals, move the tickler coil slowly toward the maximum coupling position; as the coupling is increased nearer and nearer to the point where the receiver starts to generate oscillations, the signals will grow louder and louder. The tuning condenser should be readjusted slightly as the tickler coupling is increased, for the greater feed-back action makes the circuit more sharply tuned and a very exact setting becomes necessary in order to secure the loudest signals. It is for this final critical adjustment that the vernier condenser is so convenient.

The feed-back coupling cannot be increased indefinitely, for as the point where oscillations begin is closely approached the signals will not only increase in volume, but will show signs of distortion. This is particularly disadvantageous in receiving radiophone speech or music with amplifiers. When the oscillation point is reached or passed, the radio-frequency currents generated in the receiver react with those of the received wave to produce electrical beats which may entirely spoil the character and quality of the signals; hence the feed-back coupling should always remain on the side toward "minimum" from the oscillating point, for receiving radiophone, spark or other modulated wave signals.

There is another good reason, beyond the loss of signal clarity, for always keeping the tickler coupling below the oscillation-generating point; the radio-frequency currents set up in the receiving outfit by circuit reaction pass out of the receiver itself and into the aerial, there radiating electromagnetic waves of the frequency to which the set is tuned. Thus the receiver virtually becomes a continuous-wave transmitting outfit, which, although relatively feeble in power, is capable of creating severe interference for several miles around.

Every time you allow your regenerative receiver to break into the oscillating condition by increasing your tickler coupling too far, you send out radio waves from your antenna. Every time you hear in your telephones the loud heterodyne whistle caused by interaction between the received carrier-wave and the oscillations generated within your outfit, the waves your set radiates are producing similar interference whistles in sensitive receivers near you. Thus you not only spoil your own reception, but also that of your radio neighbors in a zone of several square miles. All of us have heard interference produced in this way and have learned how aggravating it is. As this disturbance is totally unnecessary and nothing more than a demonstration of ignorance or lack of consideration on the part of "transmitting" receiving set users, no one who understands its causes and effects will want to create such interference deliberately.

While there is no hardship in tuning to an unknown telephone or modulated wave while keeping the regenerative receiver slightly below the just-oscillating condition instead of slightly beyond it, sometimes one finds it convenient to pick up a continuous wave by setting the receiver into oscillation and swinging the condenser knob back and forth until the heterodyne whistle is heard. This should never be done at wavelengths near the broadcasting wave of 360 meters; even at other frequencies it may produce bad interference. However, by equipping the receiver with a single radio-frequency amplifier in advance of the detector tube, the local oscillations may be kept almost entirely out of the aerial and this source of interference practically eliminated. Figure O shows a circuit arrangement of this kind; further details of it will be given later.

The ordinary audion is so much more effective when used with a well-designed feed-back circuit than in a non-regenerative outfit that there are comparatively few grid-tube sets used in the latter fashion.

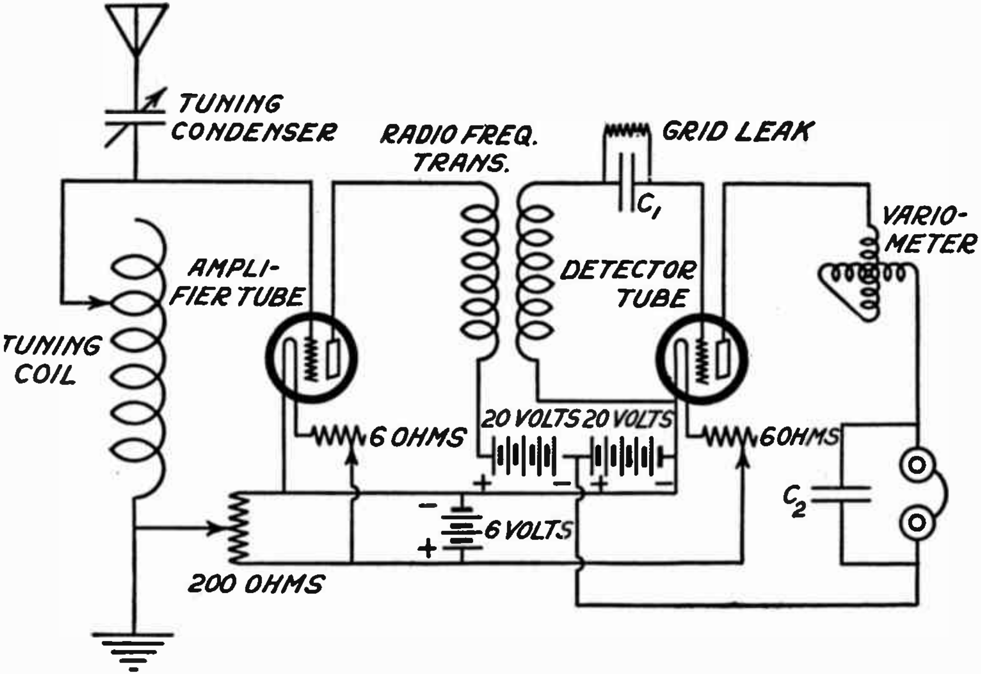


FIGURE O

The diagram gives the proper connections for including one stage of radio frequency amplification in the regenerative set. By this means the set is prevented from re-radiating high frequency oscillations, which cause so much interference in the hands of inexperienced operators. Static is also reduced by this addition.

Regeneration has two points of especial utility:

*First*, it neutralizes a large part of the wasteful resistance in the ordinary aerial and in the receiver circuits (thus giving louder signals and better selectivity).

*Second*, it provides a convenient means for receiving continuous wave telegraphy or for picking up telephone carrier waves by employing the self-heterodyne method.

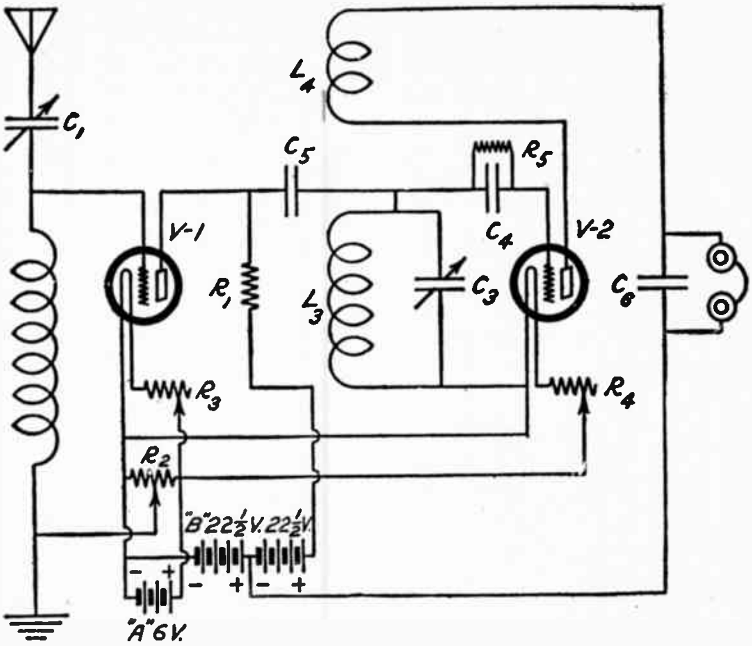
The first of these advantages is perhaps the more useful, especially when it is necessary to use rather poor aerials for receiving.

The second point represents a possibility that is of tremendous help to the individual user of a regenerator, but as it requires the set to be placed in the oscillating state, it may create a good deal of interference to reception by other listeners within a zone of several square miles.

This matter of interference caused by oscillating regenerators seems to be by no means as serious as it was some months ago. When radio novices were setting up feed-back circuits of all conceivable types and, in the absence of competent instruction, were allowing them to oscillate continuously and slightly off-tune from the broadcasting wavelengths, it was nearly impossible to receive a complete radiophone program. Of course these unskilled users themselves heard nothing but whistles, louder than the interfering tones they produced in their neighbors' outfits; largely as a result of this many of them have learned to use their receivers properly without allowing them to oscillate. Self-interest has thus brought about a great public benefit.

The ideal condition in which there will be no interference from regenerators has not yet been reached, however. Occasionally while listening to a broadcasting station one hears the swinging beat note or whistle which proves that someone in the vicinity is tuning his receiver by the "heterodyne search" plan. In the suburbs of New York such interference nowadays is often only momentary, but there is no need even for that. It is entirely feasible to pick up long distance radiophone signals by tuning one's receiver with the feed-back set somewhat *below* the oscillating point, and if this is done it will cause no inconvenience to other listeners. Some otherwise good regenerators are so designed, however, that it is practically impossible to tune over even a rather small band of wavelengths without either readjusting the amount of feed-back or losing the benefits of regeneration. This is especially true of many of the plate-variometer outfits, in which helpful amplification can be had (for a single setting of the plate circuit inductor) only over a small wavelength range. Tuning beyond such limits results either in negligible regenerative amplifications or in the production of oscillations that may greatly disturb nearby receivers.

There are several ways in which one may get most of the useful features of regeneration without causing the radiation of interfering waves from his receiving aerial. With these arrangements it is feasible to pick up signals from distant stations by the heterodyne or beat-note method, and to increase signal intensity by regenerative amplification resulting, in part, from neutralization of circuit resistance. As they depend, however, upon the use of a radio-frequency repeater between the antenna and the feed-back circuits they will not permit great reduction of aerial resistance; it is consequently desirable to use these circuits with an antenna which is itself of sufficiently good design to be an effective wave-absorbing system.



A SIMPLE CIRCUIT THAT INCLUDES A REPEATER TUBE

Figure P: A circuit with one stage of tuned radio frequency amplification with regenerative detector. This is the "hook-up" of the set pictured on the page following.

A simple circuit that includes such a repeater tube is shown in Figure P. Here the antenna is connected to the ground through a tuning condenser of about 0.0005 microfarad maximum capacitance and an inductor of some 50 or 100 microhenries. Across this coil is connected the input circuit of the repeater tube, as shown; the grid potential can be controlled, from 0 to 6 volts positive of the negative filament lead, by means of the potentiometer. The output circuit of the repeater tube contains the tuned primary of a short-wave inductive coupler; the balance of the circuit is the conventional transformer feed-back or "tickler" arrangement. In making the installation the only point that requires special care is the choice of the proper constants for the coils and condensers that will enable the circuits to tune to the wavelengths it is desired to receive.

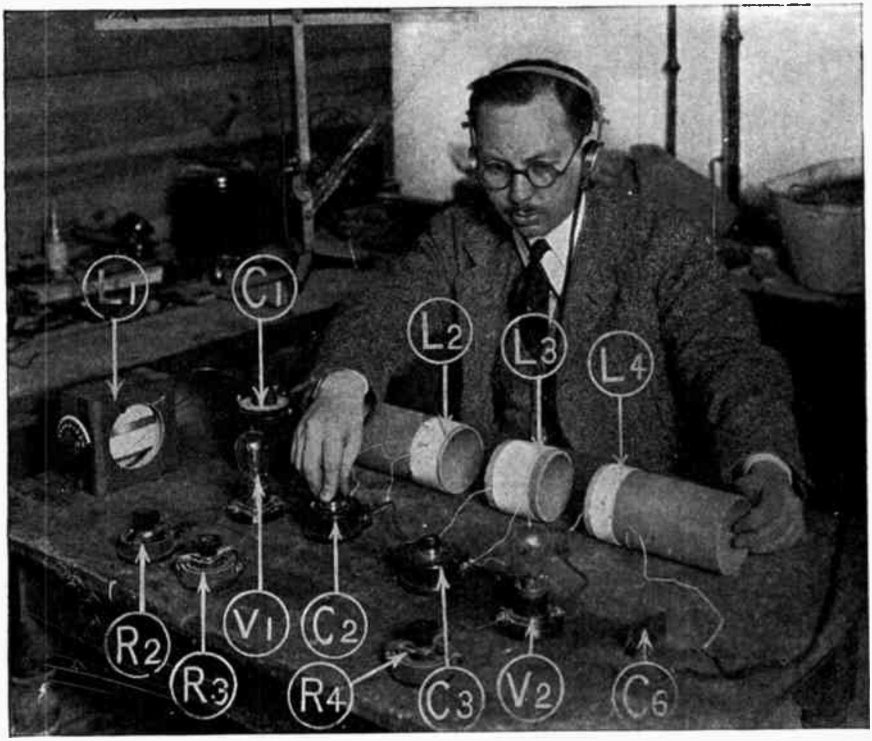
The operation of this circuit is a little more difficult than that of the ordinary single-circuit regenerator.

In the first place, there are two sets of circuits that can oscillate independently. The whole idea is to prevent the first tube (repeater) and the aerial from generating oscillations, and to confine this action to the second tube and its circuits (See Fig. Q).

In the second place, there are three tuned circuits ($C_1$-$L_1$; $C_2$-$L_2$; and $C_3$-$L_3$) and two couplings ($L_2$-$L_3$ and $L_3$-$L_4$) to adjust. But once the proper constants are chosen and the outfit is correctly set for reception of some particular wavelength, it will not be found difficult to tune to others.

Probably the best way to start using this receiver is to connect it up as shown, then to light only the detector tube, to set coil $L_2$ as far as possible from $L_3$ and to couple the aerial coil $L_1$ to secondary $L_3$. This makes the set a simple two-circuit regenerator with inductive feedback, and it may be tuned to a nearby broadcasting station in the ordinary way. Thus one can find fairly closely the best values for $C_1$, $L_1$, $C_3$, $L_3$ and $L_4$. Of course the final tuning should be done with quite weak coupling between $L_1$ and $L_3$, so that the inductance of each coil will not be too greatly influenced by the reaction of the other. There remains only the determination of proper values for $L_2$ and $C_2$, and the co-ordination of the adjustments throughout the set.

This will not be difficult if the operator now removes coil $L_1$ from the vicinity of $L_3$ and couples $L_2$ and $L_3$



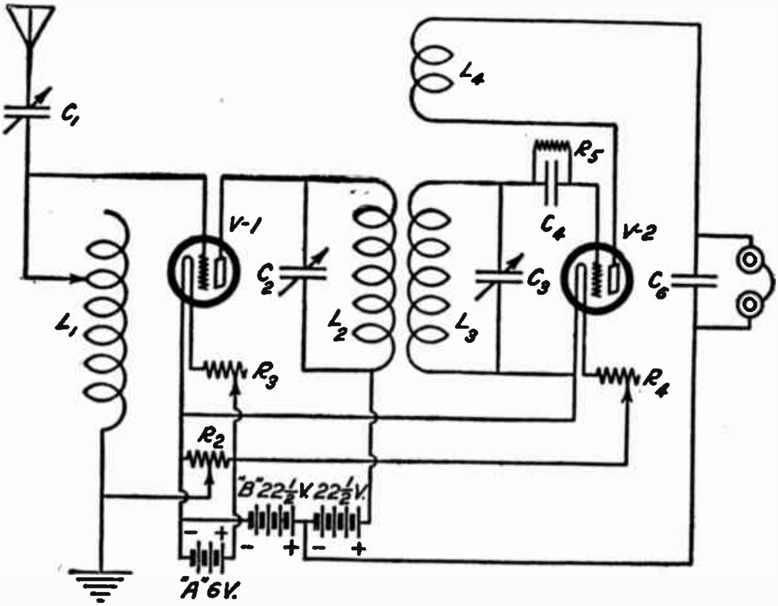
THE AUTHOR ILLUSTRATES THE "HETERODYNE-SEARCH" PLAN OF TUNING

Figure Q: Mr. John V. L. Hogan is seen adjusting the wavelength of the plate circuit of the amplifier tube with his right hand, while controlling the regeneration in the detector circuit with his left hand. The "heterodyne-search" plan of tuning may be used with this set, without causing interference to other sets in the neighborhood.

with moderate tightness—of course, turning on the filament of the repeater tube also. If the potentiometer contact is too near the *negative* end the repeater tube will be likely to oscillate as he adjusts $C_2$ and $L_2$, so it is well to turn it well over toward the positive end of the potentiometer winding while he is making his first adjustments.

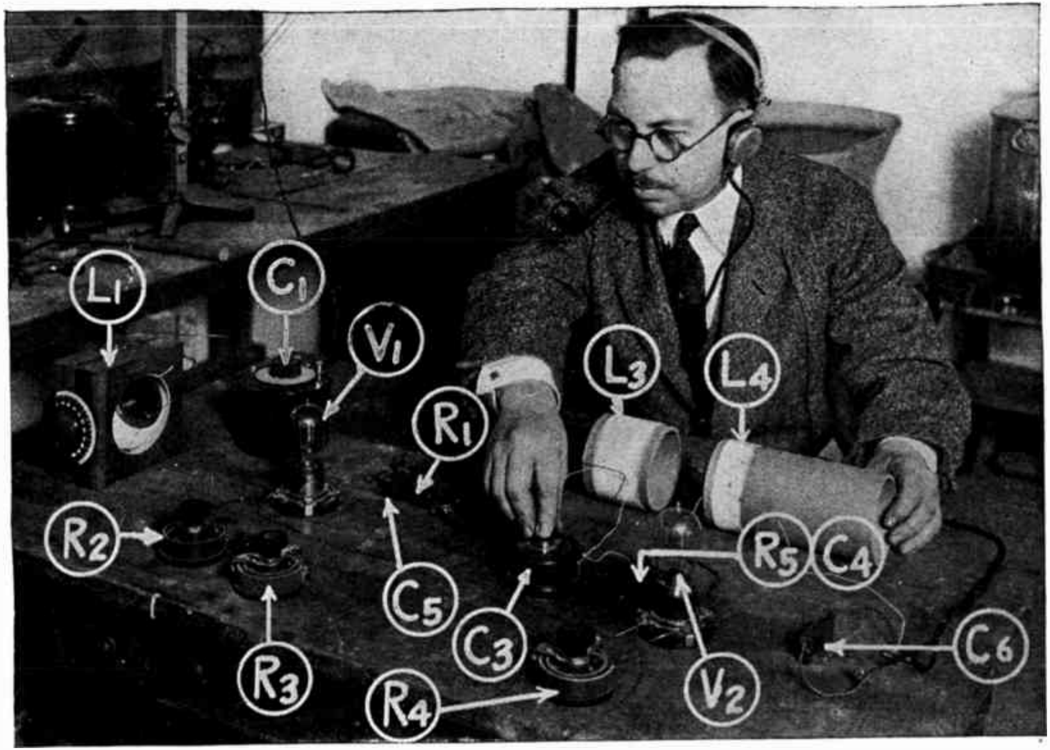
There is no reason why he should not use identical coils for $L_2$ and $L_3$ and the same kind of variable condensers for $C_2$ and $C_3$. If he does this, he may set $C_2$ and $L_2$ to the same values that have just been determined to the best for $C_3$ and $L_3$. Then the whole set can be tuned, simply by making comparatively small changes in the settings of the three condensers.

Once working, the antenna circuit may be left tuned to approximate resonance with the desired wave and the potentiometer set at a point well toward the positive end (so that the aerial circuit will not oscillate) and then forgotten, until the operator wants to make a substantial change in wavelength. For smaller variations the condensers $C_2$ and $C_3$ are handled just like the primary and secondary condensers of an ordinary two-circuit tuner, and the couplings $L_2$-$L_3$ and $L_3$-$L_4$ are handled like the primary-secondary and secondary-tickler couplings of such an outfit



A REPEATER TUBE SET THAT IS EASY TO TUNE

Figure R: This is a diagram of the set illustrated on the following page. It shows one stage of resistance-coupled radio frequency amplification, with a tuned regenerative detector circuit. This circuit will be found to be easier to tune than the circuit shown in Figure P.



TUNING THE RESISTANCE-COUPLED SET

Figure 8: The designations of the parts, shown in circles on the photograph, correspond with the designating letters in the text and diagrams. If you want to try out these circuits, you will be able to identify the right parts, and hook them up properly. Mr. Hogan not only explains how to tune these circuits but he gives explicit directions for adjusting each instrument.

used with regeneration. He can throw these circuits into oscillation by moving $L_4$ nearer $L_3$, in order to pick up carrier waves by means of the beat-tone method and he can thus get regenerative amplification and selectivity in these circuits. Yet the repeater tube will prevent the oscillations from feeding into the aerial circuit and radiating interfering waves.

The first tube is referred to as a radio frequency repeater rather than an amplifier because little amplification will be had at broadcasting wavelengths if the potentiometer contact is kept far enough toward the positive end to prevent the aerial system and the first tube from regenerating and thus tending to oscillate. By decreasing the positive potential thus applied to the grid the operator can take further advantage of regenerative amplification in this first tube and get considerably louder signals, but if he goes far in this direction he will be back where he started, for the repeater tube will begin oscillating if the coupling $L_2$-$L_3$ is slightly reduced and the oscillations will be radiated as interfering waves.

Proper operation of this outfit requires the first tube to remain in the non-oscillating condition regardless of changes in the circuits; the regeneration supplied in the detector tube circuits is used for selectivity, amplification and heterodyne pick-up.

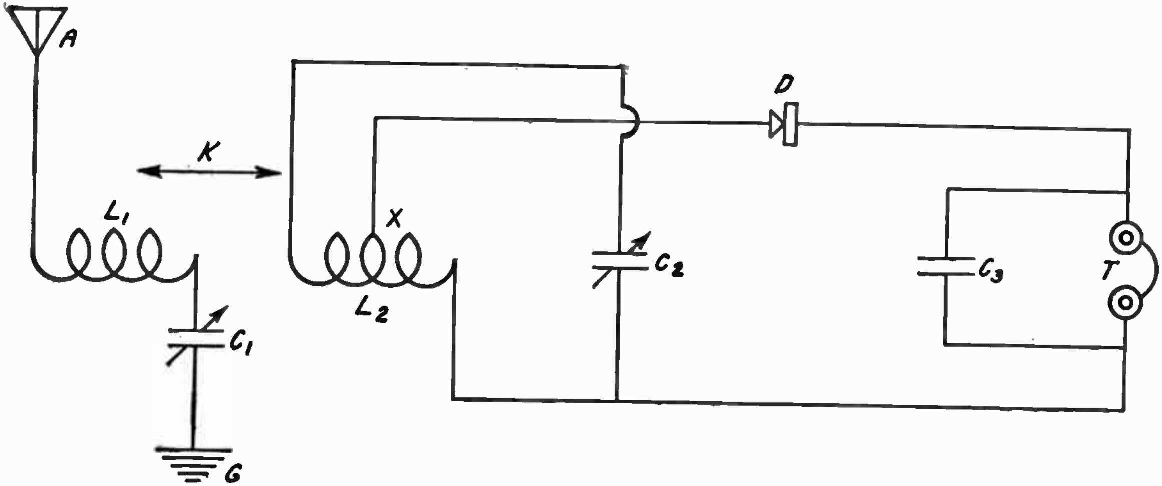
The constants for the instruments used in such receivers have been stated many times, but for the sake of completeness it may be well to repeat. There will be some deviation from normal, in a good many cases, to get best results; but a typical set of values of general utility is the following:

Condensers $C_1$, $C_2$ and $C_3$ of 0.0005 microfarad maximum capacity, preferably fitted with verniers; coils $L_1$, $L_2$, $L_3$ and $L_4$ each 50 turns of No. 22 B & S double-cotton-covered magnet wire wound on paper or bakelite tubes of 3½ inch diameter, with taps at 20, 30, 40 and 45 turns; potentiometer 200 ohms; filament rheostats 6 ohms; grid leak 2 megohms; grid condenser 0.00025 microfarad; by-pass condenser 0.005 microfarad; tubes UV-201 or VT-1; filament battery 6 volts (storage); plate battery two or three 22½ volt blocks. A good antenna would be a single wire from 100 to 150 feet long (including down-lead) with the horizontal portion some 40 feet or more above the earth. All of these values are stated for use on amateur and broadcasting wavelengths.

A little additional ease of adjustment may be had, at the cost of some selectivity, by using the circuit of Figure R. The elements are the same as before, except that $C_2$ and $L_2$ are omitted and $R_1$ and $C_5$ added. $R_1$ is a coupling resistor of about 50,000 ohms and $C_5$ a fixed condenser having about 0.0005 microfarad capacitance. With this arrangement the only important variables, once the set is adjusted to approximately the best condition, are $C_1$, $C_3$ and the coupling between $L_3$ and $L_4$.

It will be found that with the Figure R circuit there is much less tendency for the repeater tube to produce oscillations in the aerial circuit; and that the potentiometer contact can be moved much nearer its negative terminal. Further, the tuning is considerably simpler than that of Figure P. It will be noted that the plate circuit potential of the repeater should be increased to about 60 volts in order to offset in part the effect of the resistance unit R.

Either of these two circuits is capable of sharper tuning than the ordinary single-circuit regenerator and, on a good aerial, will give excellent results. With reasonable care in adjustment the user can do all the searching for long-distance stations he may desire, taking the full



A CIRCUIT THAT WILL IMPROVE THE CRYSTAL RECEIVER

Figure T: This hook-up with a crystal detector will give high selectivity because of the coupled circuits and the method of tapping the secondary coil.

advantage of the beat-note for locating weak signals, and yet be secure in the knowledge that he is not interfering with his neighbors.

We have considered spark or code interference most specifically, and we saw that, although some improvement may be expected as a result of the reduction of the number of radio code messages being sent on waves that lie within the broadcasting range, we must go farther than this to get the desired relief. The situation will be greatly aided by the installation and operation of higher-powered broadcasting transmitters. But, it will take time to get these stations into operation. Meantime, we should improve our receivers so that they will better discriminate between the music and the speech and the undesirable code interference. This improvement must naturally be sought through increasing the selective power of our receiving sets.

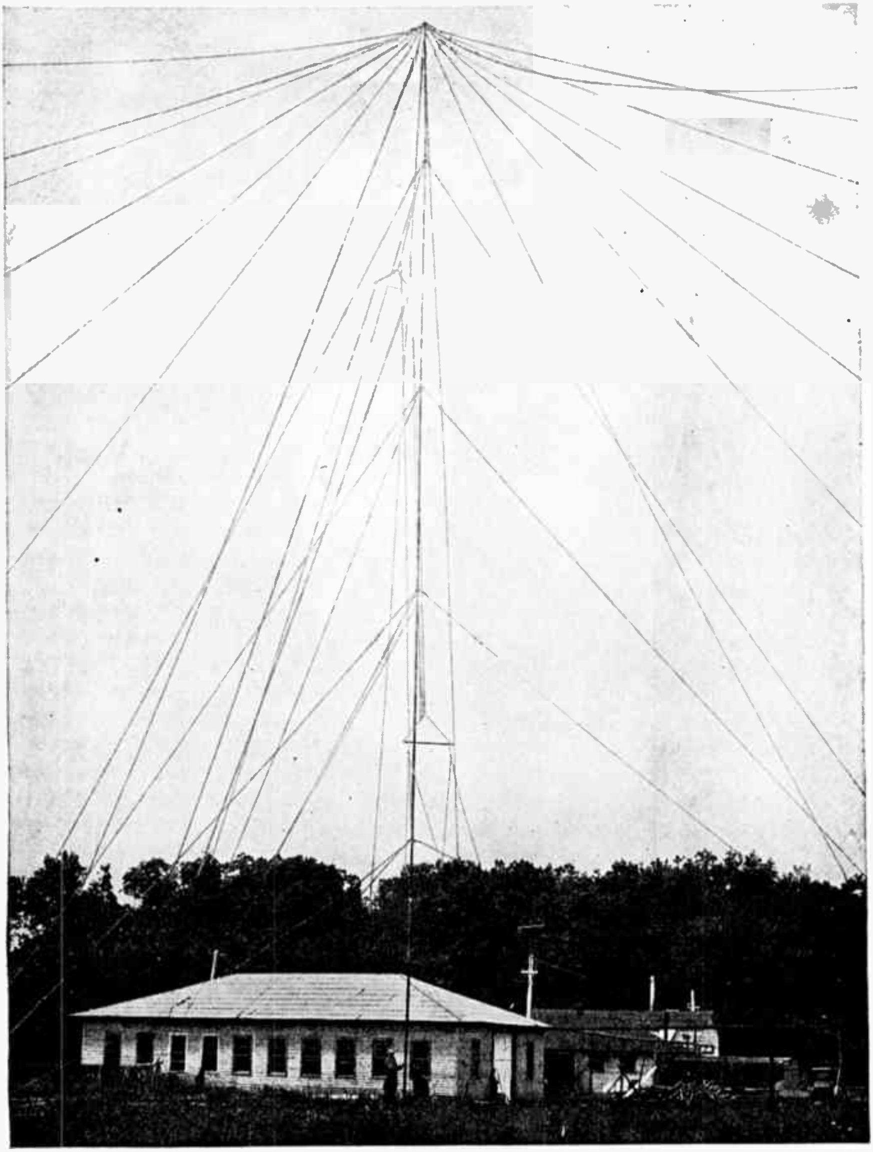
It is well to remember that even the most nearly ideal radio receiver, from the point of view of selectiveness, will not entirely exclude interfering signals sent out by powerful and nearby spark transmitters. Nevertheless, most of the radio receivers in use are of types that can be substantially improved in their capacity to cut out spark signals, and, what makes the improvement of added value, they will at the same time become better able to choose between the signals of different broadcasting stations that operate on adjacent waves. Thus, while we are attempting to get more satisfactory conditions for listening to broadcast programs without interruption from ship or shore spark transmitters, we will simultaneously be reducing our troubles from "cross talk" or direct program interference between broadcasting stations.

We should consider next the way in which two-tuned circuits may be used with crystal receivers.

The most satisfactory arrangement is to tune the antenna-to-ground circuit separately and to couple it transformer-fashion with a second tuned circuit to which the detector is directly connected. Such a receiver is shown in Figure T. in which the first or antenna-to-ground circuit is shown at the left extending from the antenna A through the primary coil $L_1$ and the primary tuning condenser $C_1$ to the ground connection G. The size of the coil and condenser to give best results, will depend up on the size of the antenna to be used. As a general rule, the larger the antenna is, the smaller the coil may be and the larger the tuning condenser that may be used.

For this sort of circuit it is desirable to use an antenna that is not too long and which is large or has great capacity through its umbrella-rib or parallel wire formation. If you have a single tall flag-pole or similar support, an umbrella antenna constructed on it is very effective. The individual wires should not be over 75 or 100 feet long, and all of them should be of the same length, including the down-lead to the receiver. If you have available two masts or points of support you will get good results from four parallel wires, each of which should be not more than 50 or 60 feet long, and hung at least three feet apart between spreaders.

With a fair-sized antenna of the sort just described, the primary condenser $C_1$ may be of .0005 or even of .001 mfd. capacity, and the coil $L_1$ may be chosen by trial so that the broadcasting waves come at intervals that spread well over the scale of the condenser. A good coil to begin with would have 100 turns of No. 22 DCC copper wire wound on a tube three and a half or four inches in



Signal Corps, U. S. A.

THE UMBRELLA ANTENNA HAS NO DIRECTIONAL EFFECT

Figure U: This type of aerial has a large electrostatic capacity on account of its numerous wires. The individual wires should be not more than 100 feet, and all of them should be as near the same length as possible. The down-lead should not be longer than the antenna wires.

diameter. If the antenna is of fairly high capacity, it may be found that the long-wave broadcasters "tune in" too far down the condenser scale. If, for instance, WEAF (610 kc or 492 meters) tunes at less than 70 or 80 divisions on a 100-part scale, it is an indication that the number of turns on the coil may be reduced to advantage. The same indication may, of course, be obtained by noting the tuning point of any of the lower-frequency (longer-wave) stations such as KSD, KYW, WNYC, WCX or WIP. What is sought is to make the coil of such size that the lower frequencies tune at the maximum-capacity end of the condenser scale, because then the tuning adjustment will be most effective over a large part of broadcast wavelengths.

If the coil $L_1$ has too few turns for the antenna you are using, or, in other words, if the antenna is too small for the coil, you have the option of adding more wires to the antenna (it is not so good to increase its length) or of increasing the coil.

As a general rule, it is better to enlarge the antenna than to use more than 100 turns on the coil. You can, of course, tell whether the coil or the antenna is to small, because the medium-wave stations such as WJY, WGY or WFI will tune at the high-capacity end of the condenser scale instead of near the middle. Thus, if you cannot reach the longer-wave stations on your condenser dial, you will have to add turns to your coil or else increase the size of the antenna. Sometimes the use of a larger tuning condenser will do the trick. However, because the effective capacity of the whole circuit is limited by the capacity of the antenna, this does not help as directly as an increase in the coil would.

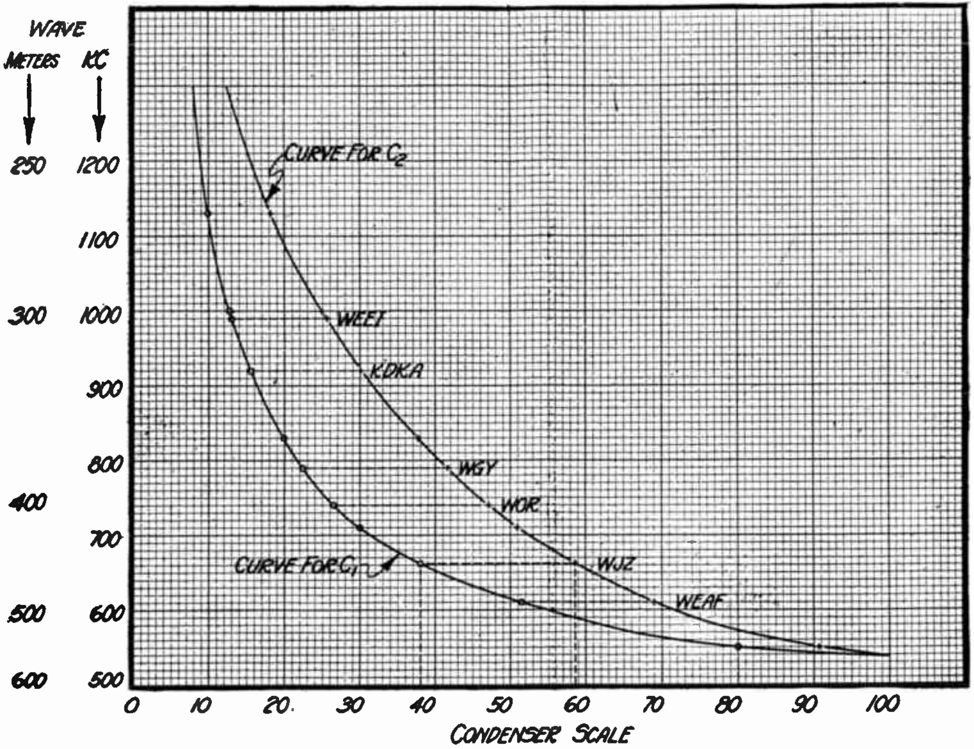
The tuned, secondary circuit consists of the secondary coil $L_2$ and the secondary tuning condenser $C_2$.

This is a simple closed circuit the tuning range of which depends almost entirely upon the size of the coil and the condenser. Forty turns of No. 22 DCC on a three-and-a-half-inch tube as the coil will ordinarily work quite well in connection with a variable condenser of .0005 mfd. maximum for $C_2$. In making this coil you should tap it at the tenth, twentieth (midpoint) and thirtieth turns so that the detector connection may be attached, as will be described later. It may be that your present receiver contains the parts necessary for this secondary circuit. Some sets have a coil and a variable condenser in series with it for tuning the antenna circuit; and, if yours is one of these, you need only connect the antenna and ground binding posts together by a short piece of wire. Then, if the detector is connected across the coil within the set, your outfit will be like the secondary circuit of Fig. T, except that the lead from the detector will be connected to the left-hand end of the secondary coil instead of to the tap X.

Of course, your antenna and ground are to be disconnected from the set and connected to a separately tuned primary coil and condenser as described in the preceding paragraphs.

The detector circuit of Fig. T consists simply of the crystal detector itself, at D, an accumulating condenser of .001 or .002 mfd. (the size of this condenser is not particularly important) and the headphones.

The detector is not connected across the entire secondary coil, but instead its upper lead-wire runs to a tap on that coil as indicated at X. Ordinarily about half-way down the coil there will be the best average position for this tap, but, if still greater selectivity is desired in tun-



TUNING CHART FOR A SIMPLE-COUPLED RECEIVER

Figure V: The settings for any station may be found from this curve. For instance: WJZ at 660 kilocycles (455 meters) will tune at 39 on the primary and at 58 on the secondary. It is most convenient to plot these curves in kilocycles, as they are expressed in tens.

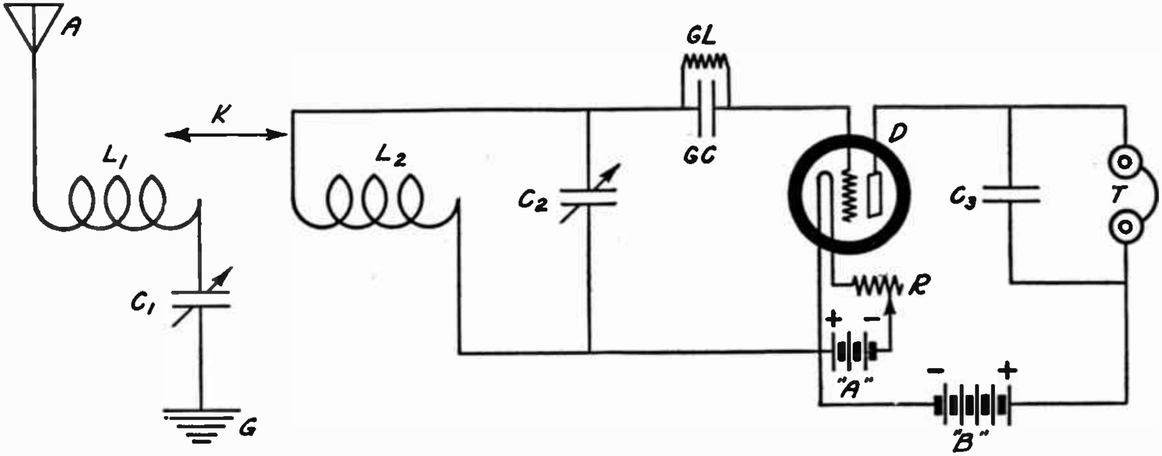
ing to strong signals, less than half the turns may be included between X and the right-hand end of the coil leading to $C_3$. The greater the number of turns you place between X and the right-hand end, the louder the signals may be, but you will obtain less selectivity. Under some conditions the use of the midpoint tap will give not only greater selective power but also louder signals than a position for X including more turns in the branch circuit containing the detector. This, however, is a matter that must be determined by trial under your particular working conditions.

The only factor that remains to be considered is the coupling between the primary and secondary coils, which is indicated by the double-ended arrow marked K. This shows that the coils are intended to be relatively movable along the line of their common axis; you may fix $L_2$ in position and arrange $L_1$ so that you may slide it back and forth. It should be possible to move the coils together into the abutting or end-to-end position, or to separate them so that two or three inches of free space will separate their nearer ends. It is not necessary to make one coil slide within the other, as has been done in many old designs of couplers. Ordinarily the circuit will show very poor selective qualities with the coils in this position.

Having set up the circuit in accordance with the above suggestions, you will find it rather different in behavior from (and far superior to) the usual crystal receiver. To learn to use this improved receiver, it is well to begin with the two coils abutting and at a time when you are certain that several broadcasting stations in your neighborhood are transmitting. Also, you will need a test buzzer to make sure that your crystal is adjusted to a sensitive point. With the ordinary crystal set you will hear something as soon as you start to adjust your detector, and, thereafter, turned adjustments will merely improve or hinder matters a little. With this outfit you should hear nothing unless your crystal is a sensitive condition and both your tuning condensers are properly set.

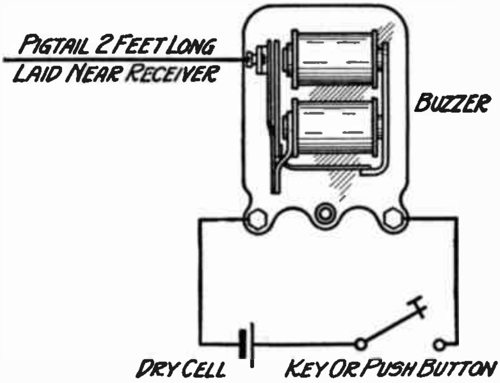
Therefore, begin by making your crystal respond strongly to the test buzzer, and slide the two coils close together. Listen in the headphones carefully, set the antenna or primary tuning condenser at 100 and then swing the secondary condenser slowly back and forth between, say, 60 and 100. If you hear nothing, set the primary condenser at 95 and search again with the secondary condenser. Continue to reduce the primary condenser in five scale-reading steps and swing the secondary condenser more widely through its scale as the primary setting becomes smaller. If your set is working and if there is any station that is transmitting within your range, you should "pick it up" without difficulty. Once you hear a station, find the best positions for both condensers and *write them down*. Try to get similar records for a number of stations throughout the wavelength range that your set covers. It may help you the first time you attempt to pick up these stations if you connect the detector across the entire secondary coil. If you have to do so, you should then tune for the same stations again and record the tuning settings when the midpoint tap X is used. You will be surprised by the improvement in tuning sharpness that the use of this X tap produces.

Having prepared a list of stations and their best tuning settings as above, mark it "K maximum" (indicating that it applies when the coils are as close together as possible—i.e., with the maximum coupling) and then go through the pro-



**A SIMPLE VACUUM-TUBE HOOK-UP**

Figure W: This is a type of selective circuit that employs tuned antenna and secondary circuits. If a WD-11 or WD-12 tube is used, the "A" battery need be only a single dry-cell and the "B" battery a small 22½-volt block.



THE TEST BUZZER ARRANGEMENT

Figure X: An old electric door bell will perform the necessary work if the clapper is cut off and wired up, as shown above. When the buzzer is operated, an electromagnetic field around the pigtail will affect the receiving circuit; this effect will be heard in the headphones if the crystal detector is properly adjusted.

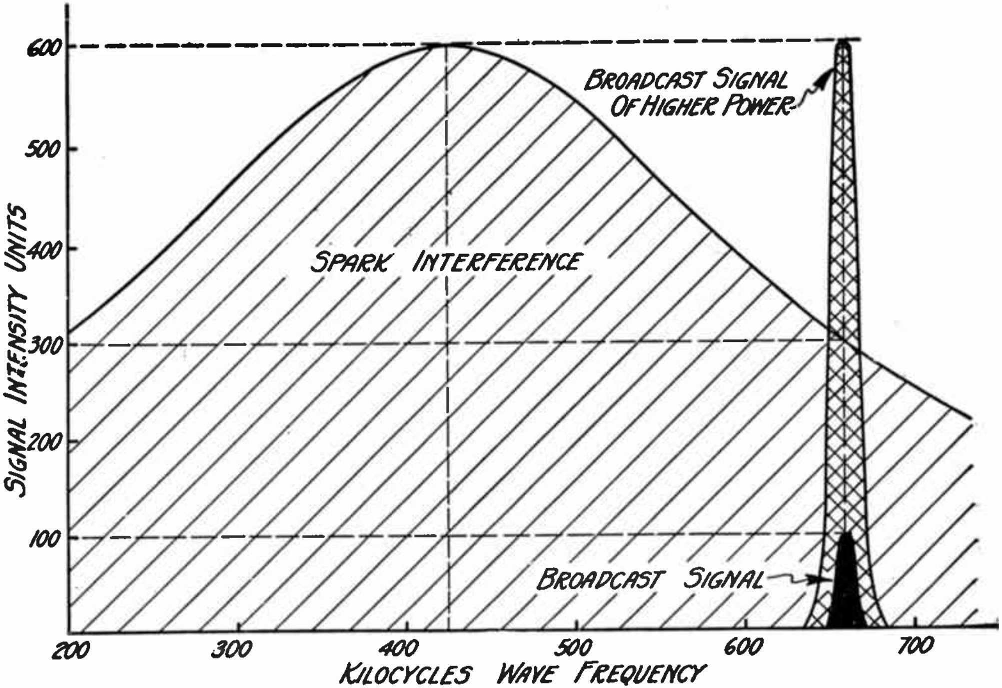
cess again with the ends of the two coils one inch apart. This will shift the tuning positions on both condensers somewhat, but the earlier records should be of considerable help to you in locating the stations under this new condition of looser coupling.

You will observe that the tuning will have sharpened up a good deal, and the signals in some cases may be a little weaker. Make a list of the settings for the several stations with "K one inch," for future reference. If this separation of the coils gives you adequate freedom from interference, you need experiment no further. You may find it worth while, nevertheless, to try a coupling distance of two inches or even more, and to reduce the number of turns in the detector portion of the secondary coil.

For your antenna and detector you will find some coupling and X tap position that give the best all around results; and that is where you should conclude your tests. If you "log" the tuning settings for a number of stations under these conditions you can draw a tuning curve such as is shown in Fig. V, which will be of great assistance to you in locating the adjustments for other stations of which you know the wave-frequencies or wavelengths.

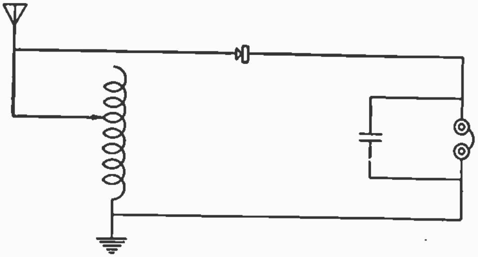
You will see at once that the foregoing instructions for operating a two-tuned-circuit receiver apply when you have built up the secondary circuit with a coil such as that described or when you are using the circuit of your old receiver as a secondary. You may have to use some ingenuity in mounting the antenna-circuit coil if you have utilized the old receiver, but this should present no real difficulty if you remember that it is to be arranged next to the secondary coil and with a common center line or axis.

It is perhaps not so obvious that the same general arrangement may be used



HOW HIGH POWER STATIONS CAN AVOID SPARK TRANSMITTERS

Figure Y: As long as the signal intensity of the broadcasting station is less than that of the spark set, interference will exist as shown graphically in the diagram. However, by increasing the intensity of transmitted signals as indicated above the broadcaster will break through spark "jamming."



THE OLD-STYLE SINGLE-SLIDE TUNER HOOK-UP

**Figure Z: Crystal sets wired in the manner shown in this diagram tune too broadly for satisfactory radio-telephone reception.**

with a simple or non-regenerative vacuum-tube detector. The vacuum tube is two or three times as sensitive as the crystal, and requires no adjustment of contact points; consequently its use is often well worth while, even though it is more expensive and requires two sets of batteries.

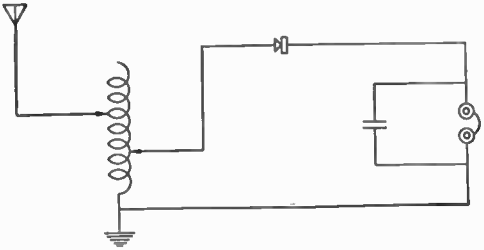
Fig. W shows a very simple single-tube receiver circuit corresponding to Fig. T except for the change in the detector. The tap X has been left out, because the vacuum tube ordinarily does not affect sharpness of tuning in the secondary circuit as much as the crystal does; thus it becomes possible to connect its grid-filament circuit across the entire coil without much if any loss.

The principle of tuning and loosely coupling the antenna circuit may be applied to practically any receiver from the simplest crystal set, such as that described, to the most complicated superheterodyne. In most cases the change is well worth while, because of the freedom from spark interference and cross-talk that it gives, even though, as ordinarily applied, it requires the tuning of an additional condenser. With the large number of broadcasting stations now in operation, and with the coming of higher powered transmitters, increased selectivity is particularly valuable.

It is feasible, moreover, to tune the antenna circuit at the same time and with the same motion that tunes the secondary or closed circuit by using equalized and simultaneously variable, double condensers. That invention (which I described some ten or twelve years ago in connection with commercial radio receivers) provides the ease of tuning that is characteristic of single circuits and besides the high selectivity of multiple-tuned circuits.

Interference with broadcast reception caused by spark transmitters was one of the topics that the Department of Commerce Conferences have studied with a good deal of care, and a number of recommendations have been made that should be directly helpful in improving the situation.

In increasing the number of wavebands or channels to be used for broadcasting, so as to allow the broadcast stations to operate with less mutual interference, the Conferences suggested a new grouping of wave frequencies and



THE DOUBLE-SLIDE TUNER

Figure AA: The re-arrangement indicated in this diagram of a single-circuit tuner shows how selectivity may be improved whereby closer tuning for broadcasting can be accomplished.

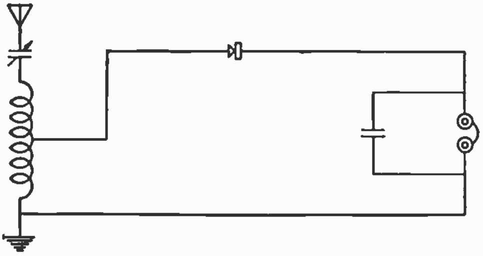
a new classification of broadcasters, as shown in the table on this page.

Outstanding features shown by this tabulation, and features that are bound to help out our recent troubles from spark and other wave-interference, are the following:

| Frequency Cycles | Wave length Meters | Service |
|---|---|---|
| 2,000,000 to 1,764,000 | 150 to 170 | Amateur CW and ICW Radio Telegraph |
| 1,764,000 to 1,666,000 | 170 to 180 | Amateur Radio Telegraph |
| 1,666,000 to 1,500,000 | 180 to 200 | Amateur CW and ICW Radio Telegraph |
| 1,460,000 to 1,420,000 | 205 to 211 | Class 3 Broadcasters (less than 100 watts power) |
| 1,400,000 to 1,090,000 | 214 to 275 | Class 2 Broadcasters (corresponding to old Class A) |
| 1,070,000 to 550,000 | 280 to 545 | Class 1 Broadcasters (corresponding to old Class B) |
| 500,000 | 600 | Marine calling and distress signals |

1. The amateurs have agreed to eliminate spark transmission, thus freeing the high-frequency end of the broadcasting range of waves from this interruption.
2. The amateurs have agreed to restrict their radiotelephone experiments to the band between 1,666 and 1,764 kilocycles (170 to 180 meters) to aid in removing this sort of interference from the broadcast range.
3. The marine interests have agreed to stop the use of the old 1,000 kc (300 meter) and 666 kc (450 meter) waves, which caused so much trouble in broadcast reception.
4. The marine interests have agreed to use the 500 kc (600 meter) wave, adjacent the broadcast band, for calling and distress purposes only. Ship-and-shore message traffic will thus be handled upon the new lower-frequency channels more remote from the broadcasting waves.

It is only natural for all of us to hope that these various recommendations and agreements of the Conference can be put into practical operation at the earliest possible date. They are likely to



A VARIABLE CONDENSER USED WITH THE ELEMENTARY SET WILL HELP FIGHT THE SPARK

Figure BB: Introducing capacity in the antenna circuit as shown above will enable you to improve tuning with a single-circuit crystal set.

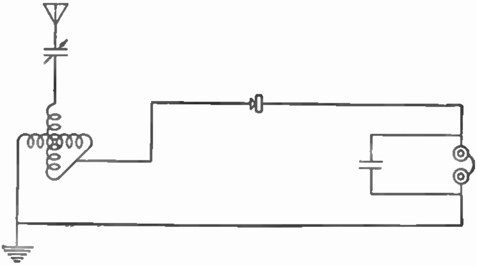
produce an immediate improvement in broadcast reception, though of course no one expects any or all of them to prove itself a perfect panacea that can overcome all difficulties. It still remains for us to do everything we can to improve the selection or discrimination power of our radio receivers, for unless we do our utmost in that direction we may expect to suffer interference from spark transmitters even under the new wave assignments.

You may wonder why the changes in working wave frequencies will not be sufficient to prevent the occurrence of such interference. It seems entirely unreasonable to many people that they should be disturbed, in receiving broadcast speech or music, by dots and dashes sent out at what appear to be widely different wave frequencies. For instance, even a reasonably selective receiver can take programs from WJZ (New York) on the 660 kilocycle wave without interference from WEAF at 610 kc or WNYC at 570 kc. The frequency-differences are 50 and 110 kc respectively. Yet this same receiving set, while tuned to WJZ, may be badly interfered with by a ship at sea operating at the nominal wave of 425 kc (706 meters), differing from WJZ's wave by 215 kilocycles!

Whereas a modern continuous-wave (CW) or interrupted-continuous-wave (ICW) radio-telegraph transmitter will work within a waveband less than one or two kilocycles wide, and produce little or no interference in receivers sharply tuned outside of that band, the old spark transmitter may spread out its signal splashes over all wave frequencies within a few hundred kilocycles!

Thus, a CW transmitter working at 405 kc can hardly be heard, if at all, in a good receiver tuned below 404 kc or above 406 kc, even though the receiving point is located relatively near to the sending station. On the other hand, a spark station having high damping might be heard, in the same receiver, on all settings from 200 to 700 kilocycles.

Some of you are perhaps now wondering why the radio art tolerates such inefficient use of the "ether" as is necessary when spark transmitters are permitted to operate. The answer is that the spark installations were in existence and were doing fairly satisfactory work long before the demand for more and more radio



THE ADDITION OF A VARIOMETER WILL GIVE GREATER REFINEMENT FOR TUNING

Figure CC: The crystal set that is used with a variable condenser and variometer wired as in this diagram will meet ordinary needs for reception from superpower stations.

channels became as acute as it is today. All of these old sets on shipboard represent a substantial investment, and the amount of money involved in replacing or converting them is no small sum. They are gradually being changed-over or scrapped, however, and some day we may expect to see them only in museums.

But in the meantime, as has aptly been pointed out, traffic in the radio channels can be no more effectively regulated or utilized than could traffic on a boulevard where huge juggernauts fifty or a hundred feet in width were allowed to plunge along at will. We shall have spark transmitters with us for years, however, unless somebody loses patience with their propensity to tear through the radio channels, and, over the protests of their owners, legislates them out of existence.

What can we do in these spark-ridden years, then, to make the interference as little as possible? Is there anything that will help us to receive broadcast programs free from dot-and-dash interruptions?

Fortunately there is. We may take advantage of the third and fourth factors of the problem (as outlined on a previous page of this Part). We may improve the excluding-power (or sharpness of tuning) of our receivers; and we may improve the intensity of the broadcast signal we desire to receive, as compared to the intensity of the interference.

The first of these items—the improvement of receiver selectivity—cannot cure the spark evil.

That is true because the spark station distributes its power all over a vast number of wave-frequencies, and, if you are at all near to the spark transmitter you will be likely to pick up some interference on any broadcasting wave no matter how sharply you tune to it. Nevertheless, there are some features of this interference problem that appear to have been overlooked in many quarters and yet which offer some hope to us.

Most broadcast receivers do not exclude interference from powerful, nearby stations even though they are capable of discriminating sharply between waves from distant stations. There is vast room for a general improvement along these lines, and it is this type of improvement that will be helpful in cutting out spark interference. Incidentally, gains in this direction will also be valuable in reducing interference from "static" or strays, and from nearby radio telephone stations.

The second point of attack on the spark interference problem is one which the listeners can help only indirectly. It consists simply of increasing the power of broadcasting stations.

This is by far the most certain way to overcome all kinds of interference, as has been demonstrated again and again in all branches of the radio field. Years ago transatlantic radio telegraphy was attempted with transmitter powers as small as five kilowatts. Even with such small power signals were received at great distances, but only under the quietest and most favorable conditions. By increasing the power of the transmitters to as much as two hundred kilowatts the received signal was made six or seven times as loud, so that it could be distinguished through whatever part of the interfering noises could not be filtered out in the receiving apparatus.

The best broadcasting stations are using, on the average, something over one-half kilowatt of power. At distances of even fifty or one hundred miles the signals from such stations are often too faint to be heard clearly through interfering noises. To be sure, conditions are sometimes so good that the stations are heard over thousands of miles, but we must all admit that such long distances represent exceptional and not average day-and-night, summer-and-winter, performance.

Let us suppose that some particular evening you are receiving from a moderately distant half-kilowatt broadcaster whose signal may be said to have a strength of 100 units in your receiver. Now imagine that an interfering spark "breaks through" with a received intensity of 300 units. Of course your reception will be spoiled. If, now, the broadcast station could quadruple its power, making it two kilowatts, the signal would be doubled to 200 units. This would still be too weak to be heard above the interference of even a few local spark transmitters.

But if the broadcast plant could be increased to twenty kilowatts, the received signal would rise to over 600 units in strength and would dominate the interference.

This is such a simple and positive way of overcoming many interference troubles that one wonders that it has not been more generally applied. The reason is probably that twenty kilowatt radio-telephone stations cost more than half-kilowatt plants, just as the big electric stoves used in some hotels cost more than household electric toasters. The hotel stove may use twenty kilowatts of power; the toaster uses about half a kilowatt. It is certainly high time that radio broadcast stations got out of the toaster class, so that their signals might override much of our present-day interference. It is profoundly to be hoped that more powerful broadcast stations will soon come into operation, and you can do a part toward advancing the art by encouraging such larger plants.

Having reviewed the possibilities in this direction, let us return to the matter of receiver selectivity and see what can be done to gain some freedom from interference by that means.

Of course there are all kinds of radio receivers in use for listening to broadcasting, and the various kinds have varying degrees of selectivity. Lowest on the list is probably the single-tuned-circuit crystal set, and since this is doubtless the least selective outfit in common use, let us first find out what can be done to improve it.

If the receiver consists simply of a coil of wire connected in variable amounts (by a multiple-point switch or a sliding contact) between antenna and ground, and having the crystal, telephones and accumulating condenser shunted across the entire portion of the coil that is in circuit, we can do a good deal to improve matters. Probably the most effective step would be to connect the side-circuit containing the crystal and condenser across only *half* or even less of the active part of the coil.

Further improvement would be had, though probably less in amount, by cutting out the switch or sliding contact and putting a variable condenser in series between the entire coil and the antenna. This variable condenser would then be used for tuning. A still better arrangement would be a condenser and a variometer in series between antenna and ground, with the crystal side-circuit tapped across only half of the variometer.

This marks about the limit of what can be done with a single-tuned-circuit and crystal detector, though in any event it is a good plan to be sure that there are no insulation leaks or high-resistance joints in the antenna-to-ground circuit. Signal strengths in a receiver have often been doubled or trebled by the simple plan of scraping bright and re-splicing every connection in the circuit.

A considerably greater degree of freedom from spark interference can be had by converting the single-tuned receiver into one using two tuned circuits.

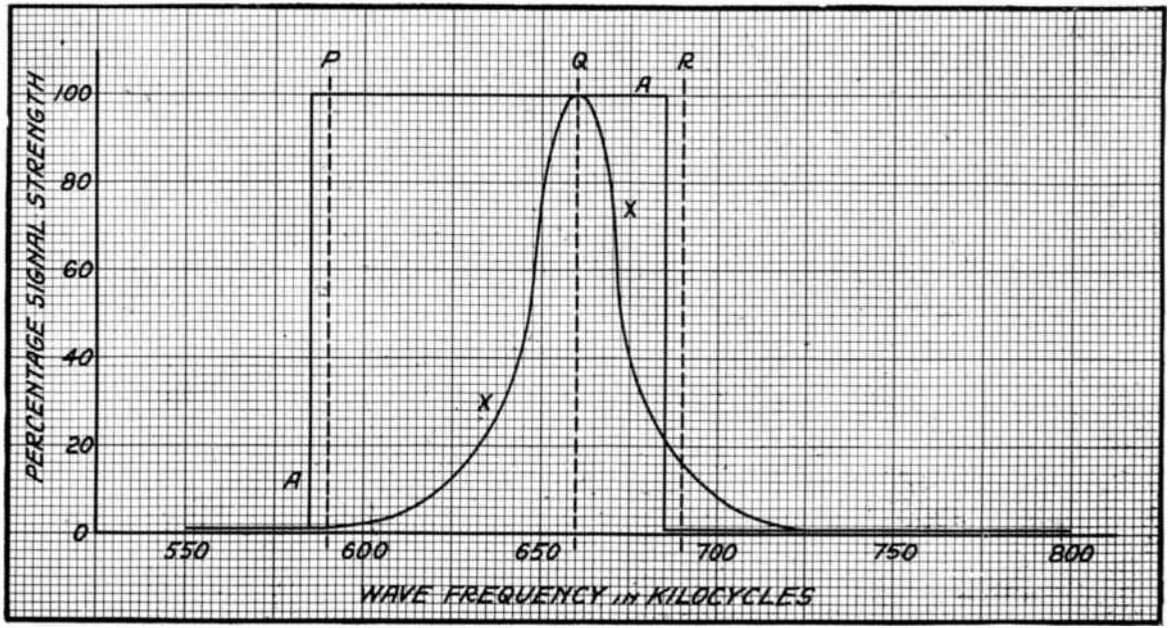
Since the adoption of the new wave-frequency (or, in the old phrase, wave-length) allocations for broadcasting, the number of transmitters that can be heard by any receiving station has been substantially increased.

Under the former plan the transmitters were licensed to work at only two wave-frequencies—833 and 750 kilocycles a second (corresponding to 360 and 400 meters wavelength). If the broadcasters had lived up to the regulations no one would have been able to receive from more than two stations, one on each wave, at any one time. As a matter of fact it was found that so much interference developed when only the two waves were used that the station managements gradually tuned their transmitters to waves a few kilocycles either side of the specified frequencies. This practice, together with the division of operating hours among the numerous senders that desired to transmit in each locality, helped out the situation a good deal. Despite the fact that it resulted in two groups of stations, the larger group operating in the neighborhood of 833 kc and the other clustering about 750 kc and even though the waves were chosen more or less at random, the shifting away from the authorized wave-frequencies made possible what little choice of broadcast programs was enjoyed by radio listeners in the past.

Some novice listeners have complained that the wave-frequencies of the various stations are too close together and that it is not possible to hear programs from one station without simultaneously picking up music or a speech from other broadcasting plants.

These complaints have come only from listeners whose receiving sets are poorly designed or poorly manipulated.

It has been proved that receivers of only average selectivity, adjusted with only normal care, are fully capable of discriminating between various broadcasting waves that are said to interfere



A WAVELENGTH-SIGNAL-STRENGTH CHART

Figure DD: The author's frequency-signal-strength chart which he uses to explain how a selective receiver and a broadly tuned receiver would act in regard to interference elimination.

with each other. If you are having trouble in picking out the station you want to hear, and in listening to that station alone, don't blame the wave assignments. Bear in mind that thousands of other people are having no trouble at all, and get busy on your receiver. Make it as highly selective as you can and enjoy the choice of programs that you will be able to get in that way.

Some of your neighbors (and probably a good many of them) have found that by sharp tuning they can hear any one of twenty or more stations at a time of "good nights" this season; last winter they were lucky to be able to choose more than five or six.

Let us look more closely into this matter of receiver selectivity.

The term is almost self-explanatory, it means the ability of a radio receiving outfit to select signals transmitted on one frequency of carrier wave from other signals that are simultaneously being sent out on waves of other frequencies.

Suppose we made a chart of some of the broadcasting wave-frequencies as in Fig. DD, where the different values are arranged along a vertical scale. In this figure, the localities to which the various wave-frequencies have been assigned are indicated, as well as the corresponding wavelengths in meters.

Toward the right-hand side Figure DD is drawn a heavy vertical line, marked AA, with an opening equivalent in width to 100 kilocycles. Imagine that this line represents the barrier set up by your receiving tuner; that no wave energy can get through at the frequencies opposite the line, but that the wave-frequencies opposite the opening *can* get through to operate your telephones. From the diagram it is quite clear that a receiving set which admits a 100-kc. band (or continuous group) of wave-frequencies could simultaneously pick up signals from two of the New York stations, from Philadelphia, from Washington at 640 kc. and (if the signals were strong enough) from Pittsburgh, Chicago and a few others. This assumes that the particular set be located in the east; if it were on the west coast, it would simultaneously admit signals from San Francisco, Los Angeles and Portland.

Following the diagram's teachings a little farther we see that even a receiver so non-selective as this could choose between three New York stations at 610, 660 and 740 kc. Although in the position shown it admits both 610 and 660 kc. by turning the tuner controls to give resonance to the lower frequencies (which would have the effect of lowering the opening in the line AA) the 660-kc. wave could be cut out. By raising the admitted frequencies 40 kc. above the illustrated values, 610 kc. would be cut out but 740 kc. not yet admitted. On the other hand, so broad a tuner could not be effectively used with a very sensitive detector and amplifier, for the increased responsiveness of the receiver would bring in interference from the more distant stations.

Here we have the crux of the whole tuning situation. Your receiving tuner *must be more and more selective* the *more sensitive your detector and amplifiers*, or the *farther you desire to receive*.

If you are in the vicinity of two or three broadcasting stations that use well separated wavelengths, and if you are satisfied to limit your reception to those stations, a relatively dull detector (such as a crystal) and a tuner with 100 kc. selectivity may be all you need

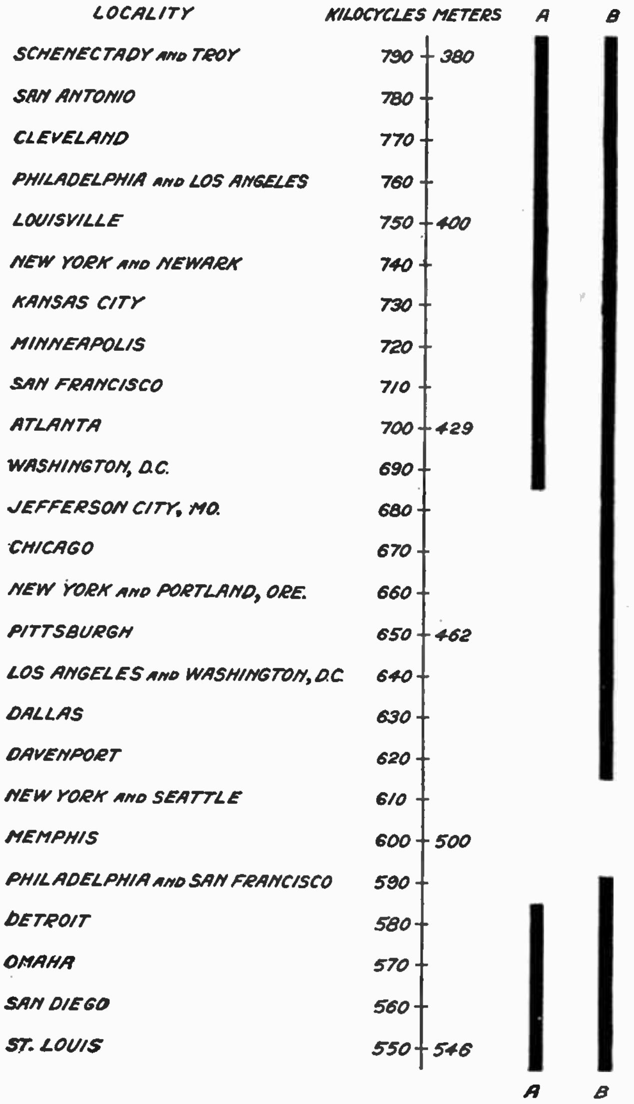


**Figure EE:** This chart shows how a broad-tuning set would include the signals of a number of stations at one time while the sharp-tuning set would get only one or two. The small gap in the dark heavy line at the extreme right of the chart would include only New York, Memphis and Seattle. This line is for a sharp tuner. The large gap in the second heavy line includes everything from Jefferson City to Philadelphia and San Francisco; this line is for a broad tuner and considerable interference would be experienced.

If, however, you want to reach out with amplifiers so as to hear Omaha, Detroit, Philadelphia or other stations whose wave-frequencies are not very different from each other, you will have to match your sensitive detecting system with a highly selective tuner.

You can see at once that the narrowness of the opening in the line AA (Fig. DD) is a measure of the receiver's selectivity. If this opening is made more narrow, say to a width admitting only a 20-kc. range at one time, as in BB, the receiver sensitivity may be greatly increased without bringing in interference, because the selectivity of the tuner has been much increased. With a tuner that would exclude all but 10 kc. at a time, one might use a sufficiently sensitive amplifying system to pick up any of the broadcasting stations in the United States without experiencing interference from any of the others. It is feasible to build receivers having even more than this extreme degree of selectivity.

The chart of Fig. DD is based on the assumption that the receiving tuner will admit freely, and with equal facility, energy received on any of the wave-frequencies that fall opposite the opening in the line AA but that at the end frequencies of this admitted band the tuner will cut off sharply so as not to admit any energy from waves outside the frequency limits marked by the opening. It is possible to build receivers that have practically this sharp cut-off characteristic, but the ordinary tuners that depend upon simple circuit resonance for their selectivity have a gradual or tapered cut-off on each side of a single frequency that they receive best.

Fig. EE compares these two characteristics, here the frequency scale is drawn horizontally and the vertical scale represents the percentage response that the receiver would give to a signal of some definite intensity at all of the wave-frequencies illustrated.

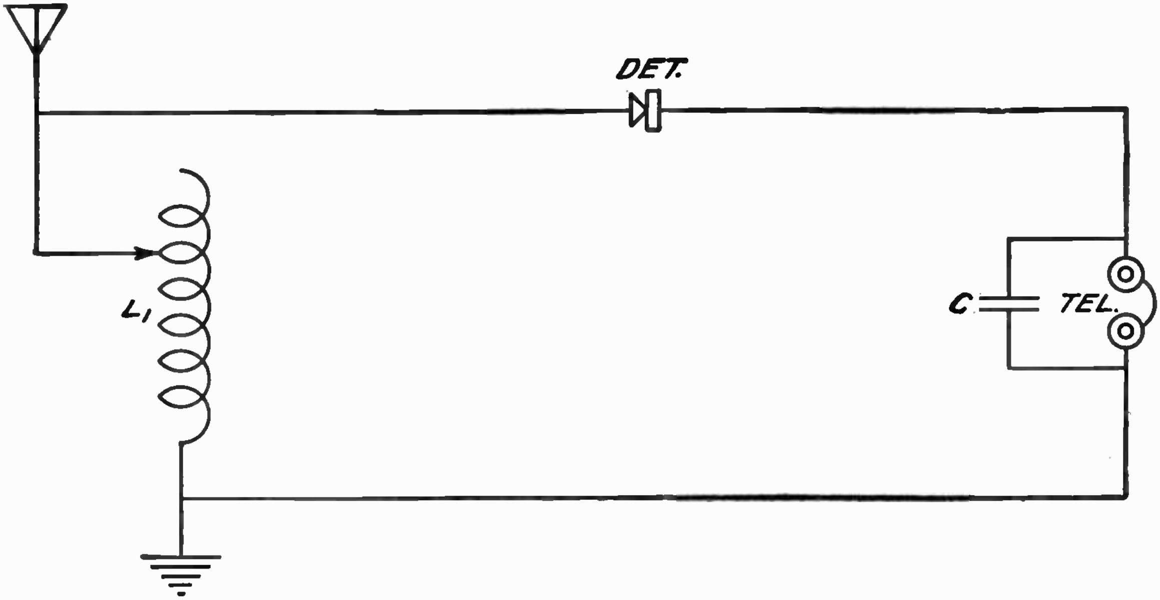
In Fig. EE the square-shaped line marked AA corresponds to the barrier line and opening similarly designated in Fig. DD and represents a receiver that admits a 100-kc. wave-band with sharp cut-off at each end. It is easy to see that, at the setting illustrated, a wave of frequency 590 kc. (as used by some of the Philadelphia stations and indicated by the vertical dash line P) will produce 100-percent signals. A wave of frequency less than 585 would produce no response on account of the sharp lower cut-off. A wave of 660 kc. (used by WJZ in New York and shown at line Q) would give 100-percent response, but 690 kc. (Washington; line R); would be above the upper cut-off and give no signals.

Now look at the curve XX in Fig. DD, which shows the selection characteristic of an ordinary but reasonably good receiver. When set to give a maximum response to 660 kc. (line Q, as shown) signals on carrier frequency 690 kc. (line R) would give only about 15 percent full response, while other signals of 590 kc. (line P) would produce practically no sound in the telephones.

We might make a table showing the best signal strength that would be received by such a tuner for various differences of wave-frequency, using this resonance curve as a basis:

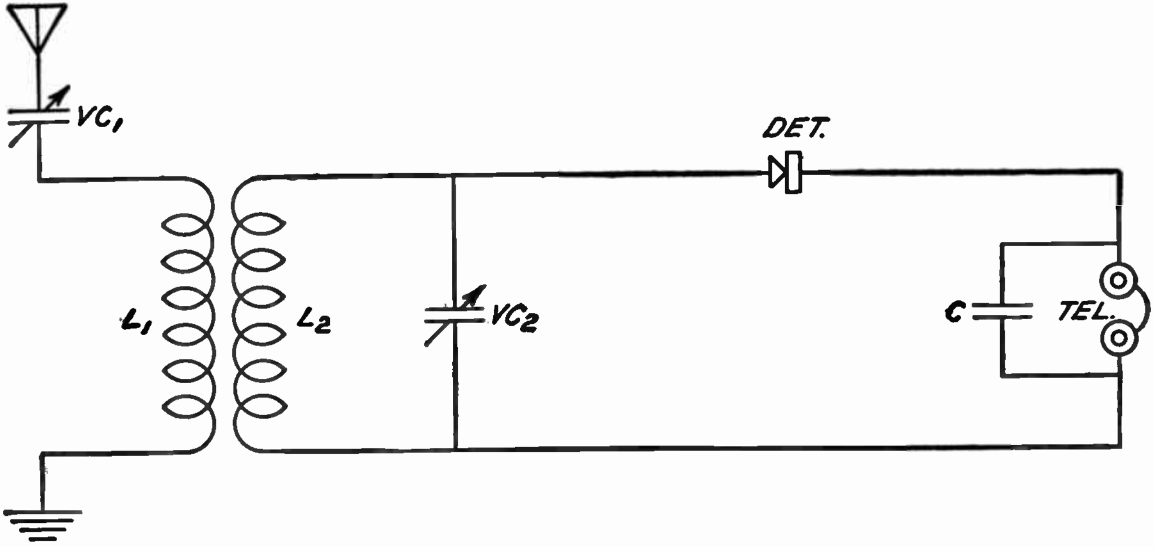
| Difference from Resonant Frequency | Percentage of Resonant Signal |
|---|---|
| 0 | 100 |
| 10 | 80 |
| 20 | 25 |
| 30 | 15 |
| 40 | 10 |
| 50 | 5 |
| 60 | 3 |
| 70 | 0 |

From such a table we can see just



THE CONVENTIONAL SINGLE-CIRCUIT CRYSTAL RECEIVER

Figure FF: Many beginners who have this type of simple set are experiencing trouble with interference. The author tells us that the trouble may be lessened if not eliminated by changing over this circuit to the circuit shown in Figure HH.



THE INDUCTIVELY COUPLED CRYSTAL CIRCUIT

Figure GG: This is the best crystal circuit to use from a standpoint of selectivity. It is even better than the hook-up shown in Figure CC.

what to expect in the way of freedom from interference. For instance, if instead of tuning to 660 kc. as shown, you adjusted to New York (WEAF) at 610 kc., the energies of signals from other stations would be as follows (New York being rated 100 percent because tuned to its maximum):

Memphis and Davenport—80 percent of their maxima.
Dallas and Philadelphia—25 percent of their maxima.
Washington and Detroit—15 percent of their maxima.
Pittsburgh and Omaha—10 percent of their maxima.
New York (WJZ) and San Diego—5 percent of their maxima.
Chicago and St. Louis—3 percent of their maxima.
Jefferson City and others—0.

Note that these relative signal strengths are given as percentages of the loudest possible signal your set could receive from any particular station, and that each percentage refers to the signal from the station in question and that only. In other words, this above table will not show the relative signal strengths in comparison with the signal from some one stations, such as the one to which the set is tuned. To get this information we must combine with the above figures another tabulation giving the *relative* signal strengths of the station in question. One or two examples will show how this can easily be learned and applied in the practical operation and control of radio receivers.

Suppose that with your receiver, under some particular condition, you can hear New York (WEAF) with intensity 100, New York (WJZ) with intensity 60 and Philadelphia (WIP) with intensity 20. If your tuner has the selectivity characteristic of curve XX in Fig. DD, can you expect to hear Philadelphia without even the faintest interfering signals from either New York station?

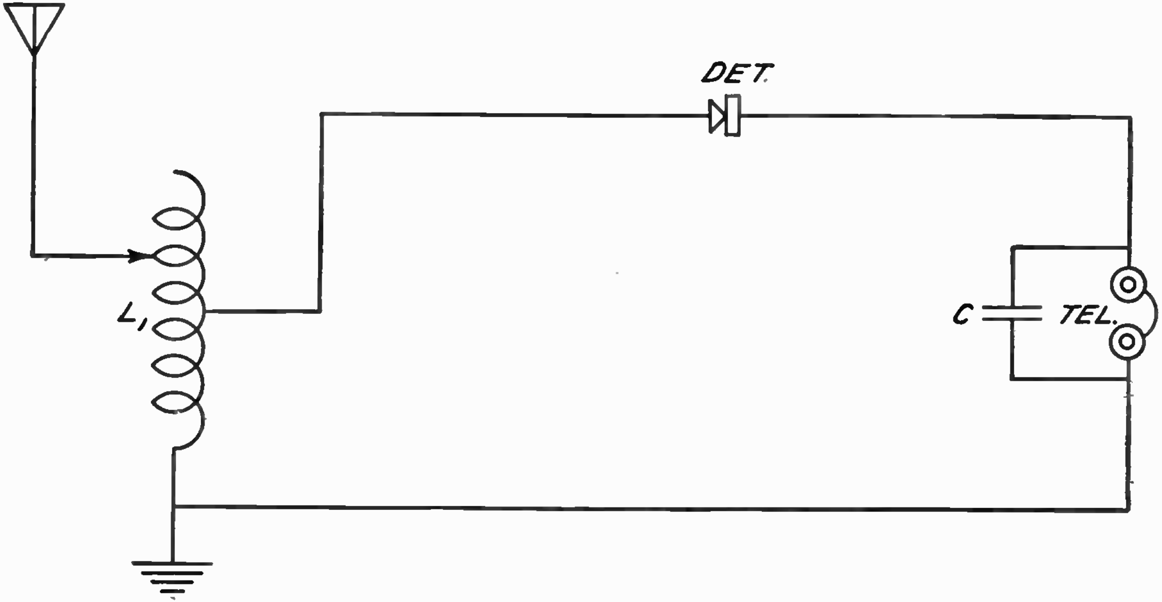
To find out the answer we need only note that Philadelphia's wave-frequency is 590 kc and those of the New York stations 610 kc. for WEAF and 660 kc. for WJZ. The differences are 20 kc. and 70 kc.; if the receiver is tuned to WIP, the desired signals will be received at full 100-percent intensity or 20; WEAF's signals, being 70 kc. removed, would not be heard. But WJZ's signals, only 20 kc. away from WFI's would come in at 25 percent of their full strength of 60, or at 15 which is three-quarters as loud as WIP. Consequently WJZ would interfere with WIP under these conditions, and a more highly selective tuner would be required to receive signals from this particular Philadelphia station without interference.

What can one do to increase selectivity so that such interference can be prevented? The details of all the answers to that question would be enough to fill the space of several articles such as this, but we can at least set down some of the high spots:

1. If you are using a crystal detector with single-circuit receiver (the ordinary form of which is shown in Fig. FF), change over to the double-circuit receiver of Fig. GG. If you cannot do this, at least tap the detector circuit across only a *part* of the inductance coil as in Fig. HH.

2. If you are using an ordinary vacuum-tube detector, in a non-regenerative circuit, change to a good regenerative circuit, and preferably one which is coupled inductively to the antenna (as in Fig. II).

3. If your interference conditions are too severe to be overcome by a circuit of the type represented by Fig. II (a very unusual state of affairs), use a loop



A DOUBLE-CIRCUIT CONDUCTIVELY COUPLED CRYSTAL SET

Figure HH: By using only a small part of the coil L1 for the secondary circuit which contains the detector and the telephones, the selectivity is increased to a considerable extent over that obtained by the circuit in Fig. FF.

antenna with *tuned* radio-frequency amplifiers and regeneration, or, perhaps still better, with a super-heterodyne receiver.

Above all things, bear in mind that as much skill is required to operate a highly selective tuner as to drive a car through the heavy traffic encountered in a big city.

Don't expect to become expert in handling the tuner any sooner than the car. It is easy to pick up and enjoy programs from the local stations—as easy as it is to run a phonograph —but practice and patience are required to learn to hear all the available distant points through the local interference. But don't let that fact discourage you; you can do what others are doing, with a little perseverance, in really learning the facts about tuning.

If your object (or one of your objects) in radio receiving is to "get distance," get the most highly selective tuner and the most sensitive detecting and amplifying system that you can handle effectively, and work with it until you learn the tricks of manipulation. Your effort will be well repaid, and you will find that the new schedule of wavelengths makes these great results possible.

You may remember that when alterations that occur in the wave frequency are of substantial amount and that when they occur at a rate that is in the low audible range (say from fifteen to thirty times a second), you will hear a fluttering noise in your receiver, from the carrier wave of the broadcasting station.

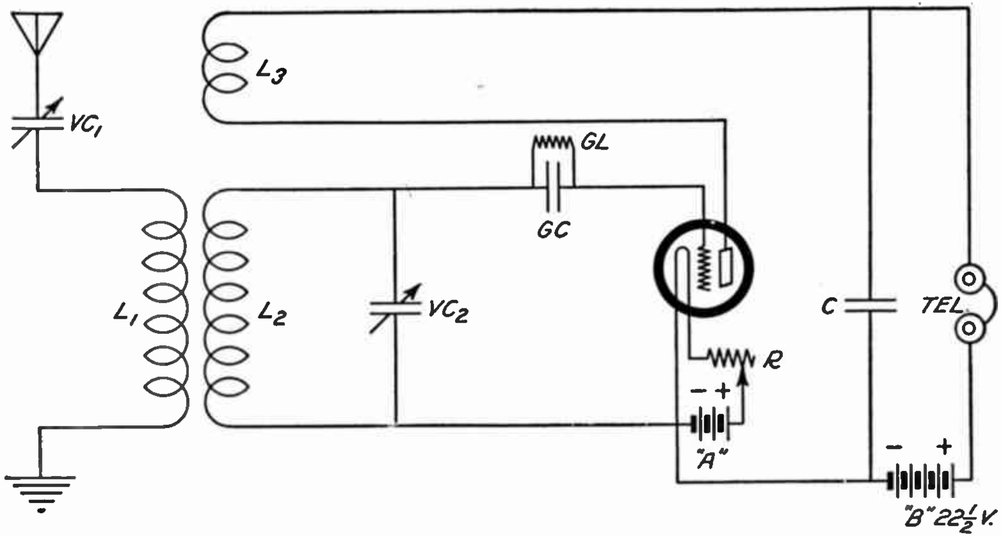
A nearly identical noise may, however, be caused by variations in the *intensity* of the radiated wave, as was pointed out previously. If, when you are listening to some particular station, you hear such a noise between the "numbers" on the program, your natural question will be: How can I tell whether this flutter is explained by frequency variations or by intensity changes in the radio waves?

You may also ask yourself whether or not the sound is the result of something going on in your own receiver, and therefore, whether it marks a defect for which you are yourself responsible.

Fortunately there are not many things that can happen in a radio receiver that will cause a fluttering sound in the telephones or loudspeaker. Furthermore, anything that does tend to make such a sound will probably have the same effect on all the signals you hear and is likely to keep on going even if no signals are being received. The logical thing to do, then, is to distinguish first between the home-made noises that may be produced by your receiver, and the transmitter-made noises that come in with the waves.

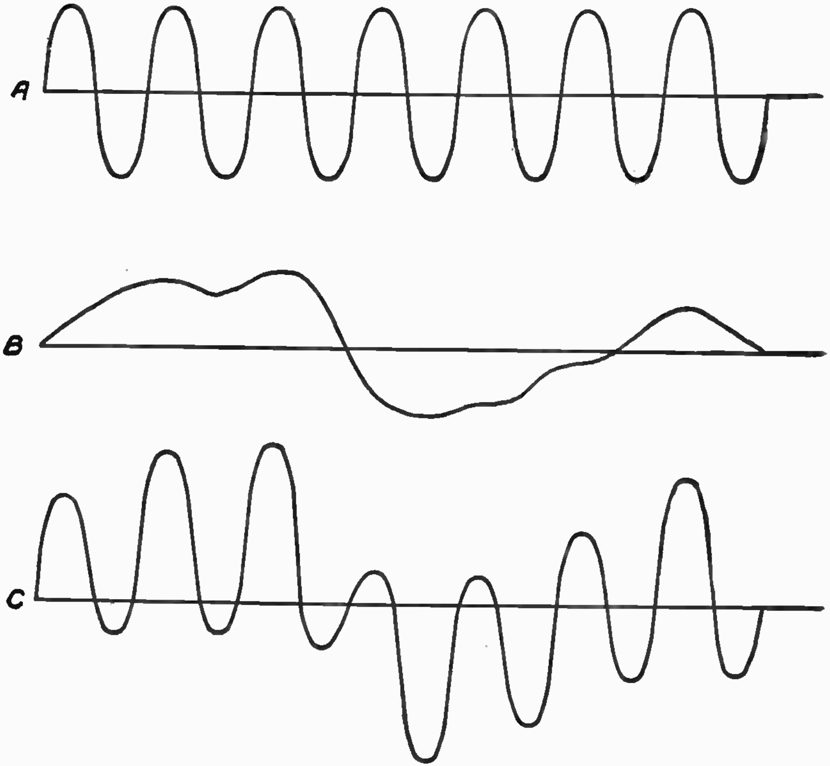
Let us suppose that when you are listening to some certain broadcasting station you hear a fluttering sound whenever the carrier wave is being received. It may be heard above and along with the speech and music that is sent out, or it may be so much weaker that you do not hear it except between the successive items of the program.

The first thing to do it to try detuning your receiver; that is to say, turning your tuning knobs (or one of them) a little away from the position where the signals are heard loudest. If the noise continues, you would be justified in concluding that it originated within the receiving set. To make sure, however, it is a good plan to disconnect the antenna so as to cut out the signals altogether; if the flutter is still heard you may be reasonably sure that something in the audio-frequency system is



THE TRIPLE-CIRCUIT, VACUUM-TUBE, REGENERATIVE CIRCUIT

Figure II: By adding one more coil to your present single-circuit tuner you may greatly increase the selectivity and at the same time cut down re-radiation which is the most objectionable feature of the single-circuit hook-up.



WHAT HAPPENS WHEN THE POWER SUPPLY IS NOT STEADY

Figure JJ: The upper curve A, shows the form of a perfectly oscillating wave. Curve B shows graphically the variations that sometimes take place in the voltage of the current supplied to the plates of the tubes. The lower curve shows the effect of this variation on the oscillating carrier wave.

wrong. Likely places for such trouble are in the amplifier circuit and sometimes in the grid-leak and condenser used on the detector tube.

On the other hand, the flutter may "tune out" with the signal, but change in pitch from a low note (or even a rattle) up to a high whistle, which gradually disappears as the pitch increases, while you detune. This is proof positive that your receiver is generating radio oscillations within its own circuits. It is very difficult to receive broadcast telephony satisfactorily under such conditions, and you should arrange matters so that the oscillations are prevented. To do this may require merely the change of position of one of the adjusing knobs, such as a "stabilizer," "intensity" control or "tickler," or it may be necessary for you to provide an additional adjustment.

Many home-made receivers (and a good many that are put out by the factories) insist upon oscillating at certain wavelengths and so prevent, or at least make very difficult, the proper reception of broadcasting.

One of the simplest and most effective cures for this trouble is to connect a variable and moderately high resistance directly in series with the ground lead, and then to "cut in" enough of this resistance to overcome the set's tendency to oscillate. A standard potentiometer of 200 or 300 ohms is often useful for this purpose (see Fig. KK). The trouble is most likely to occur in receivers that have radio frequency amplifier tubes, and is particularly common in reflex sets.

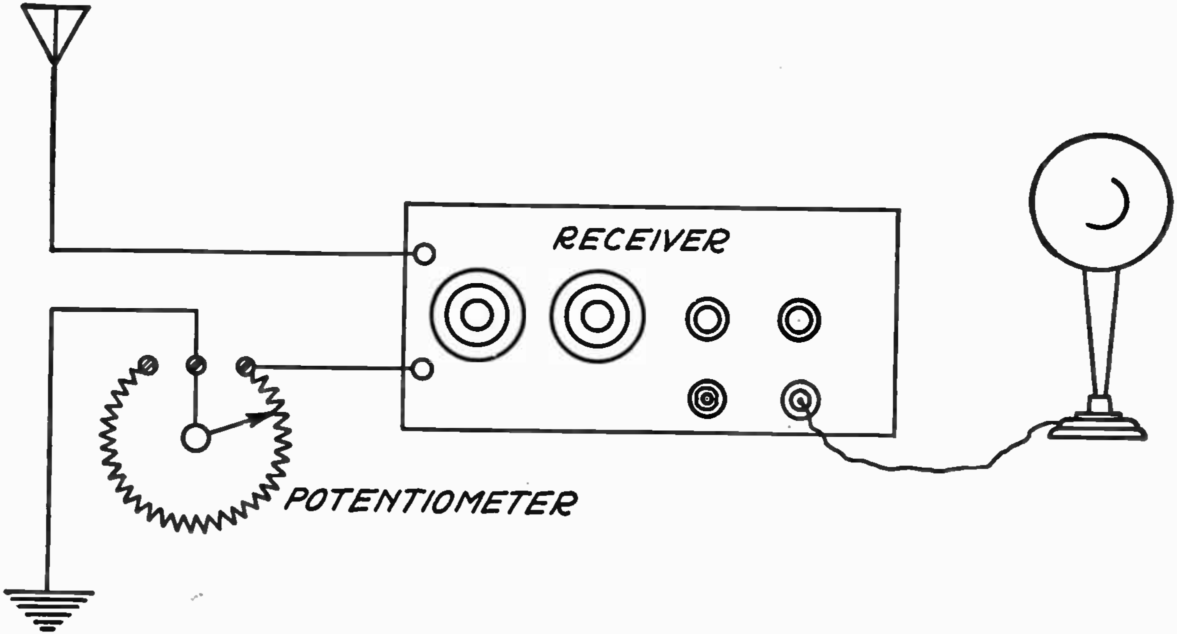
There is a third possibility which also indicates that the trouble is in your receiver. This is, that although the flutter vanishes when you tune out the station to which you began to listen, it comes in again in exactly the same way whenever you tune to any other station. If the coming and going of the fluttering sound is accompanied by changes in pitch, as just described, it means that your receiver is oscillating. If the flutter does not change in character or sound, but merely in intensity, and if it appears whenever you listen to any broadcasting station, there is something wrong with your receiver. Whatever causes this kind of flutter will probably be in the radio-frequency circuits, as your tests will have proved that it requires the presence of radio currents to produce the sound. However, such effects are both rare and obscure, and no diagnosis that could be given without inspecting the receiving set would be likely to be helpful. I mention the phenomenon with the idea of eliminating all the things that may occur in the receiver, so that you may have confidence in your observations if they point to a defect in the arriving wave.

And, so, we come to the situation where (1) the flutter tunes out when the wave from the particular broadcasting station you are investigating is tuned out, (2) the flutter does not turn into a whistle as it is tuned out, and (3) it does not reappear as you tune to the waves from other stations.

Under these conditions it is a fair conclusion that the irregularity that produces the sound exists in the carrier wave, and that it has its origin outside of your receiving station.

Your next problem, if you really want to know what is wrong, is to find out whether the noise is caused by frequency changes or by intensity changes in the wave. If the fluctuations are small there may be some difficulty in doing this, but the test is so simple that it is worth trying in any event.

If the frequency of the incoming wave changes from instant to instant, it



HERE IS A WAY TO STOP YOUR RECEIVER FROM SQUEALING

Figure KK: A variable resistance of 200 or 300 ohms (an ordinary "A" battery potentiometer) connected in series with the ground lead can be adjusted to prevent the tendency of the receiver to oscillate on certain wavelengths.

is evident that a sharply-tuned receiver will not hear all of the wave all of the time, so to speak, at any one tuning adjustment. To hear the station at full intensity at every instant, it would be necessary to change the tuner settings continuously so as to follow the variations in wave frequency. The general effect of such fluctuations is, then, to broaden the range on the tuner throughout which the signals are heard.

By comparing the broadness of tuning, or the number of degrees you may turn the tuning dial away from the loudest position without completely cutting out the station, you can get some information as to the constancy of the wave frequency.

If you take as a standard some other station whose carrier wave does not flutter, and which you hear at approximately the same intensity as the plant you are studying (and which preferably has approximately the same wave frequency) you may find, for example, that the signals tune out when you move the dial about three degrees away from the maximum setting. If, then, you find that equally loud signals from the station having the fluttering wave persist when you move the tuning dial six or eight degrees from the best setting, it is a good indication that the wave frequency of that transmitter is varying.

On the other hand, if both the standard and the fluttering waves tune out in the same way, the probabilities are that the noise is caused by intensity variations. In either case you should write to the manager of the broadcasting station that is sending out the noisy wave and tell him of your observations; he can check them up himself, and thus determine the possibility of improving his transmitter.

There are two other possible causes of flutters in the received carrier wave, and as neither of them can be blamed upon your receiver or upon the broadcasting station, they should be mentioned here. If a second broadcasting transmitter, perhaps more than a thousand miles away, happens to be sending out a wave that is within a few cycles of the wave to which you are listening, the two will beat together. The beat will not produce a musical tone if the two frequencies differ by less than about 16 cycles a second, but it may cause exactly the sort of flutter we have been discussing. Such conditions are rare in practice, and should never occur except at the 833 kc. (360 meter) waves of the class C stations, for the Department of Commerce is doing its utmost to prevent undue duplication of wave frequencies among broadcasters. Occasionally a transmitter may get so far out of adjustment as to cause this effect, but the chance of striking so closely the frequency of another station is exceedingly remote. If you should hear two stations making low-frequency beats of this kind it is likely that you would find the wave frequency of either or both changing gradually while you listened, so that the flutter would drop out at one instant, come in again, change to a low musical note of varying pitch, return once more to a flutter, and so on. A condition of this kind should be reported to the broadcasting station whose signals are affected.

The second way that beat flutters may be made is by the reception, along with the signals you want, of waves sent out by an oscillating receiving set. The final effect is almost exactly the same as when you receive an interfering wave of the same frequency and intensity from a distant broadcasting station.

If one of your neighbors has a radiating receiver, and if, while it is in the oscillating condition, he tunes to the

HOW TO SEARCH FOR POOR CONNECTIONS

Figure LL: With the antenna and ground disconnected, but the batteries hooked up and the phones on, it's easy to find a faulty connection. Press against each wire with the end of a hard rubber fountain pen or other piece of insulation and a grating or rasping sound will be heard in the phones when the poor connection is touched.

same station that you are listening to, radiation from his set will probably interfere with your reception. This is because, as has often been explained, any receiver that is so adjusted as to generate radio oscillations in its antenna circuit will act for the time being like a small transmitter.

Should your interfering neighbor tune his oscillating set to *exactly* the same frequency as the wave you desire to receive, you will *not* hear a beat flutter or note, but if he deviates from this exact frequency (or if the broadcasting station itself swings in frequency by even a few cycles), you will hear the fluttering sound that has been described.

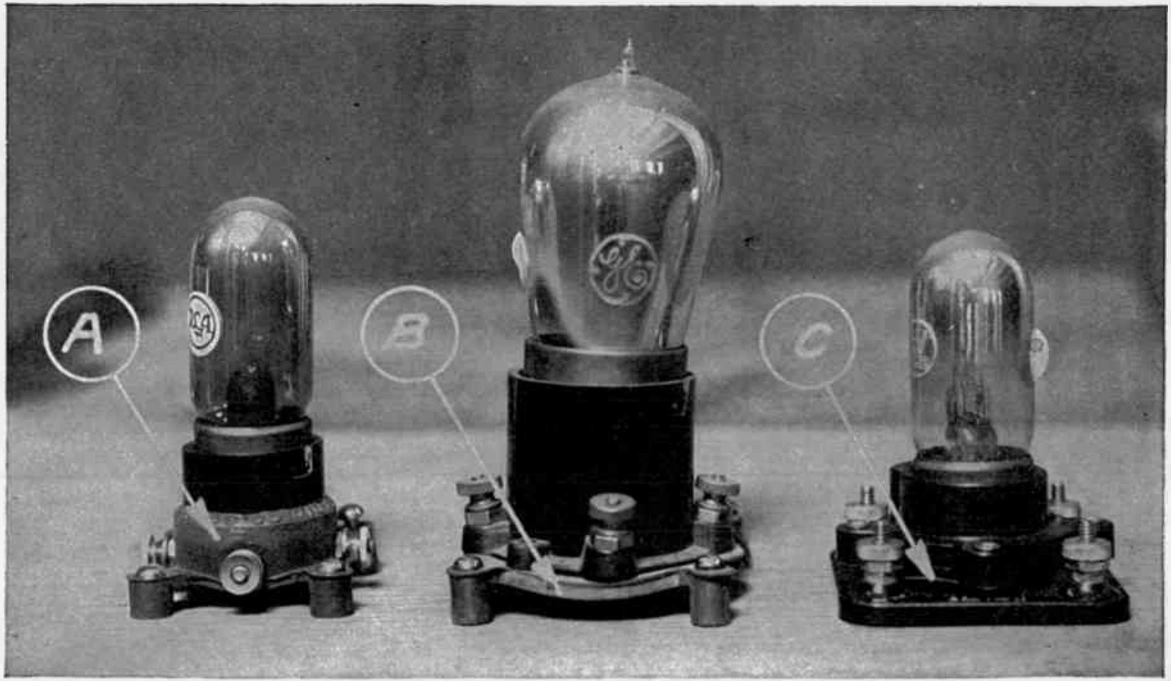
Ordinarily you can tell whether such receiving interference is produced by a neighborhood "squealer" or by a distant broadcasting station, by observing the constancy of the beat note or flutter. It is unusual for a listener who uses a whistling receiver to leave his adjustments alone for more than a few seconds or at most a few minutes at a time. When he changes his tuner settings the beat noise will change correspondingly, usually turning into a musical note of gradually increasing frequency. When you hear such changes in the flutter you can be reasonably sure that the interference arises in your own vicinity, and that you will be repaid for making a tour among the radio listeners who operate sets near your home. Most of the people who allow their sets to give this sort of trouble do so through inexperience or lack of appreciation that they are interfering with other people's reception, and it is ordinarily not difficult to build up a co-operative spirit among a group of closely adjacent listeners that will permit all to receive without such bothersome interruptions.

We have now considered most of the phenomena that are likely to occur as a result of frequency variations, either slow or rapid, in either the transmitters or the receivers; we have also looked into the possibilities of distinguishing between these various effects, so that any listener can find out whether the source of his disturbance lies in his own receiver or at a more distant point.

The next topic is that of noises produced by intensity variations either in the wave or in the response to the received signals.

If you hear unwanted noises while you are listening, the first thing to find out is whether they are produced by a defect in your own set or whether they come in with the waves. Much the same plan as suggested above for detecting frequency variations should be followed; if you hear the noises at all settings of your tuner, or if they continue when you disconnect your antenna, it is almost certain that something is wrong in your apparatus. Bothersome sounds of this sort, which persist even when no signals are coming in, can often be traced to poor connections in the set. If you bump your receiver with your hand while listening in the telephones, you should hear nothing but the ringing noise produced by the vibration of the tubes. If the tubes are well mounted on a cushioned base, you may not hear even that. If the jar causes a rattling sound in the telephones, or if the noises that you have been hearing are more violent, you should hunt for a loose contact in some of your instruments or wiring.

Of course, this crude "bump" test will not be helpful if your receiver is of the crystal type, without tubes; in such a set the chances of internally produced noises are fairly remote, though sometimes a shaking contact will cause them and, in any event, a bad connection will make the received signals



CUSHIONED SOCKETS HELP TO MAKE YOUR RECEIVER QUIET

Figure MM: Socket A is made with the lower portion of soft rubber. At B is a soft rubber platform on which a standard socket can be mounted. The socket on the right is made in two pieces held apart by springs at point C. With such sockets and with all connections tight, there will be no noises unless they come from outside.

weaker than they should be. The best way to test the contacts in a crystal set is to try to shake each of them with an insulating rod (like a closed fountain pen) while listening to signals; a bad connection will usually show up by making a noise or by stopping the signals when you move it.

If there are no loose contacts in your receiver, and you still hear irregular noises while the antenna is disconnected, you should look for the trouble in your "B" batteries (which may have become run down and noisy) or in your detector grid-leak (which may have become microphonic or may not be of the correct value for the tube you are using). Should the noises not appear when you allow the set to remain untouched, but if they show up when you adjust some particular element such as a tuning condenser, a coupler or a potentiometer, you may expect to find a "floating" or irregular bad contact in that instrument.

END OF SECTION XI