NATIONAL RADIO INSTITUTE

Complete Course in PRACTICAL RADIO

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Radio-Trician
(Trade Mark Reg. U. S. Patent Office)

Lesson Text No. 22
(3rd Edition)

ELEMENTARY RADIO MEASUREMENTS

Originators of Radio Home Study Courses
••• Established 1914 •••
Washington, D. C.

WRITE AND ANSWER QUESTIONS

A Personal Message from J. E. Smith

When one has finished studying a book, it is worthwhile to go over the list of chapters and write a series of questions dealing with each chapter, and then, of course, answer these questions. The ability to ask pertinent questions about a subject is often an indication of clearer understanding of it than the mere statement of facts and theories about it.

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ELEMENTARY RADIO MEASUREMENTS

You have progressed far enough in your course in practical radio and now are undoubtedly interested in measuring some of the things we have been talking about in the previous lessons. You might think that this would be very difficult and would require extremely elaborate apparatus. While it is true that complicated apparatus is necessary for certain types of radio measurements, there are many interesting and valuable experiments which can be performed by the aid of inexpensive measuring apparatus. We will now discuss the construction and calibration of some measuring sets which you will find very valuable in connection with your work.

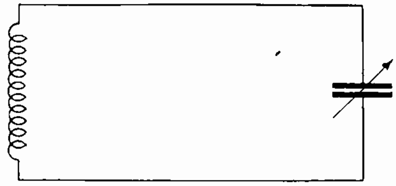


Fig. 1—Basic circuit for a frequency or wave meter.

THE MEASUREMENT OF FREQUENCY OR WAVE LENGTH

In the early days of radio communication, radio stations were designated by their wave lengths and the term frequency was but little used. Devices for measuring wave lengths were called **wave-meters.** The same devices when calibrated to measure in terms of frequency are now known as **frequency meters.** In general the apparatus involved in either case is the same. No matter what phase of radio communication you happen to be interested in, you will want to be able to measure the frequencies produced by radio stations or to calibrate receiving apparatus in terms of frequency or wave length. **In view of the recommended exclusive use of frequencies to designate stations, we suggest that you calibrate such circuits as you construct in terms of frequency and not in terms of wave length.**

You have already learned that if an inductance is connected to a condenser the resulting circuit is oscillatory if the resistance is low and the circuit responds best to a particular frequency. If the condenser is charged and allowed to discharge through the inductance the circuit will produce oscillations of this frequency. In Fig. 1 the inductance is shown as fixed in value while the condenser is shown as variable. This is the usual method of construction. The frequency to which such a circuit is resonant is as follows:

Frequency = 159,154 divided by a square root of the product obtained by multiplying the inductance of the coil in microhenries by the capacitance of the condenser in micro-microfarads.

If you like the algebraic method of presenting a formula of this type then the frequency in kilocycles is given by:

$$f = \frac{159{,}154}{\sqrt{LC}} \tag{1}$$

in which

f is frequency in kilocycles.

L is inductance in microhenries.

C is capacitance in micro-microfarads.

If, however, we desire to compute the wave length to which the circuit is resonant we use the following formula:

Wave length in meters equals 1.885 times the square root of the product obtained by multiplying the inductance of the coil in microhenries by the capacitance of the variable condenser in micro-micrafarads.

The algebraic expression for the above statement is:

$$\text{Wave Length} = 1.885\sqrt{LC} \tag{2}$$

Variable condensers of many types are on the market and can be purchased at very reasonable prices. The movable plates of some condensers are semi-circular while others are specially cut in different ways. Figure 2 shows the form of rotary condenser plates which are semi-circular. The capacitance of such a condenser will vary directly with the condenser reading. This will be explained shortly. Figure 3 shows the form of condenser rotary plates for which the capacitance varies as the square of the angular displacement, that is, as the square of the condenser dial reading.

For the purposes of our experiment let us select a variable condenser in which the rotary plates are semi-circular. Figure 4 shows a calibration curve for such a condenser having a maximum capacitance slightly less than 500 micro-microfarads. Note that over a large portion of the graph we have a straight line. Where one variable varies directly as another then the resulting graph is always a straight line. In this case the capacitance varies directly as the angular displacement, that is, as the dial

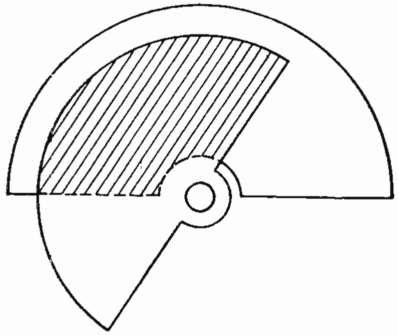


Fig. 2—Form for rotary condenser plates for which capacitance varies directly as the angular displacement.

reading. The curve slopes toward the horizontal at the top and bottom due to what is known as the "end effect" of the plates. This is a term used to account for the departure from the "straight" line characteristic due to the effect of the ends of the

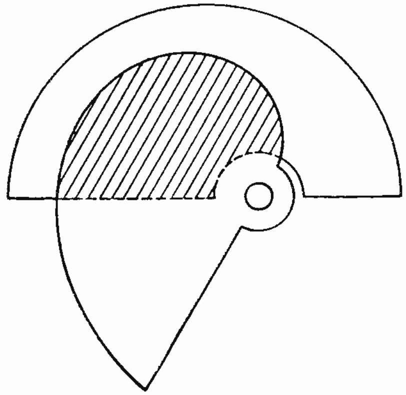


Fig. 3—Form of rotary condenser plates for which capacitance varies as the square of the angular displacement.

plates when the dial is set at 0 or at the maximum reading. Figure 4 is not meant to represent any particular condenser. As a matter of fact, the calibration curve has been so drawn as to permit the easy determination of the values of capacitance for particular dial settings.

DESIGN OF A COIL FOR USE WITH A FREQUENCY METER

Having selected a variable condenser for our frequency meter and having obtained the calibration curve given in Fig. 4, from the manufacturer or from some laboratory, our next problem is to choose a suitable inductance for use with this condenser. The value which this inductance must have will depend upon the frequency range we desire to cover with our frequency meter. If we are interested in a wave-meter, it will depend upon the wave length wave range we desire to cover. Let us assume that we are interested in obtaining a frequency meter which will cover as much of the broadcast band (that is the band lying between 550 kc. and 1,500 kc.) as it is possible to cover with a single coil and let us further assume that we are more interested in covering the frequencies nearer the lower end of the band than those toward the upper end. Our first step then is to calculate the value of inductance which with some capacitance near the maximum capacitance of the condenser will tune the circuit for a frequency of 550 kc. This is calculated as follows:

Inductance equals 25,330,000,000 divided by the product obtained by multpilying the capacitance in micro-microfarads by the square of the frequency in kc. or

$$L = \frac{25{,}330{,}000{,}000}{C \times f^2} \qquad (3)$$

The same notations apply to the algebraic letters as in Formula 1.

We desire that our frequency meter shall easily extend down to 550 kc. Referring to Fig. 4 we note that our condenser has a maximum capacitance slightly less than 500 micro-microfarads. Let us therefore design our inductance so that the frequency meter will tune down to 550 kc. with a capacitance of 460 micro-microfarads. Using Formula 3, we find that this requires a fixed inductance of 182.0 microhenries.

The proper value for inductance can also be obtained without the aid of formula 3, from Table 2 given in text-book No. 16 entitled "Inductance and Condenser Design" which you have already received. In Table 2 of Text No. 16 the L C product is shown for each frequency in the kc. column. You will note that opposite the frequency 550 kc. the figure .083734 is given as the L C product. In that table however capacitance is given in microfarads instead of in micro-microfarads. 460 micro-microfarads equal .00046 microfarads. Dividing .083734 by .00046 gives 182.0 microhenries, the same value we obtained from Formula 3.

Our next problem is to design a coil which will have an inductance of approximately 182.0 microhenries. This can be done by the aid of the graphs given on Pages 25, 26, 27 and 28 of the text-book entitled "Inductance and Condenser Design" already referred to. Let us assume that we have available a cylindrical form which has an outside diameter of two inches. Figure 15 on Page 26 of the text we have just mentioned gives the design data for coils two inches in diameter. Referring to the

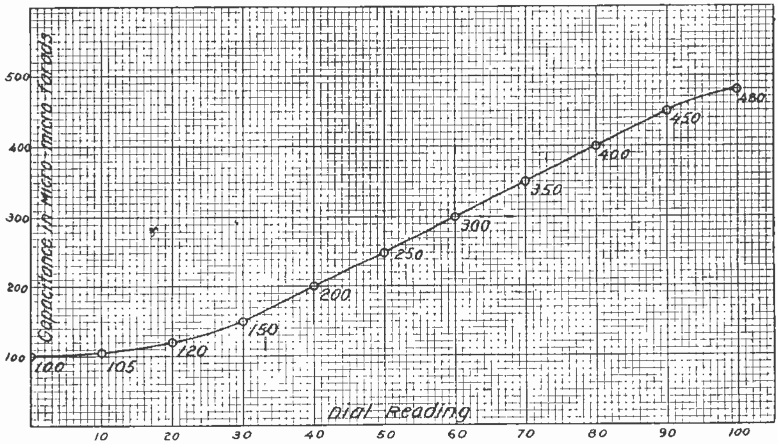


Fig. 4—Possible calibration curve for a variable condenser having a maximum capacitance slightly less than 500 micromicrofarads.

ordinates giving inductance in microhenries note the value corresponding to 180 microhenries. A line extended from this point to the right will intercept the curve for a coil 3 inches long where the abscissa is 27.5 turns per inch. The same line intercepts the curve for a coil two and one-half inches long where the abscissa is 31 per inch, and the curve for coils 2 inches long where the abscissa is 36 turns per inch. This means that (a) a three-inch coil on a 2-inch diameter forming 27.5 turns per inch will have an inductance of 182 microhenries (b) a 2½-inch long coil of wire wound on a 2-inch coil having 31 turns per inch will also have 182 microhenries and (c) a 2-inch long coil wound on a 2-inch diameter form having 36 turns per inch will also have an inductance of 182 microhenries.

Referring now to Table 3 given on Page 28 of Lesson

Text 16, you will note that 27 turns per inch can be obtained by using No. 20 B and S single cotton covered wire, that No. 22 B and S double cotton covered wire will give 30 turns per inch and No. 24 B and S double cotton covered wire will give 35.6 turns per inch. On the basis of the wire you have available you can therefore easily wind a coil having an inductance of approximately 182 microhenries. If you have available forms of 3 inches diameter or some other value you can easily determine the size of wire and the number of turns that will be necessary using the graphs given on pages 25, 26 and 27, Text-book No. 16.

We now have available a variable condenser having a maximum capacitance slightly less than 500 micro-microfarads, the calibration curve for which, is given in Fig. 4 and in addition a fixed inductance of 182 microhenries which can be used with this condenser. Inasmuch as we may desire to use other coils with the same condenser it may be found desirable to mount the condenser rigidly on a form and to provide single contact plugs and jacks so that the coils may be readily interchanged. If plugs and jacks are not available then binding posts may be connected in such a way as to permit rapid changing of coils.

CALCULATION OF FREQUENCY AND WAVE LENGTH CURVES

You will become most thoroughly acquainted with the action and calibration of frequency meters if we now calculate calibration curves for the condenser and coil combination we have been discussing. For practice we will not only calculate and plot a frequency curve but also a wave length curve. although it is recommended that only frequency curves be used in actual practice. Let us continue to assume that the curve given in Fig. 4 is the calibration curve for the variable condenser we are using and that upon measurement we find that the coil we have designed has an inductance of 180 microhenries, instead of 182 microhenries which we calculated would be the correct value. An inductance of 180 microhenries is entirely suitable for our purposes.

The information contained in Table No. 1 has been calculated from data obtained from the calibration curve for our condenser (Fig. 4) and the known inductance of our coil. From the condenser curve we determine the capacitance for readings ten degrees apart on the dial. Thus the figures appearing in Column 1 are 100, 90, 80, etc. Column II shows the capacitance of the condenser for each of these dial settings. Column III shows the

L C product obtained by multiplying each of the capacitances by the inductance we are to use which is 180 microhenries. Column IV is obtained by taking the square root of the figures shown in Column III. Column V shows the frequency for which the circuit will resonate for each dial setting as calculated by means of Formula 1. Column VI shows the wave length for each of the dial settings as calculated by the use of Formula 2.

TABLE NO. 1
Calculations for Data for Drawing Calibration Curves for Frequency and Wave-meters.

Using 180 Microhenry Coil, with Condenser Having Calibration Curves Shown in Fig. 4.

I Condenser Dial Reading	II Capacitance in Micro-microfarads	III L X C	IV $\sqrt{LC}$	V Frequency in KC= $\frac{159,154}{\sqrt{LC}}$	VI Wave Length in Meters= 1,885 $\sqrt{LC}$
100	480	86,400	293.94	541.45	554.07
90	450	81,000	284.60	560	535.47
80	400	72,000	268.32	593.15	505.78
70	350	63,000	250.99	634.10	473.11
60	300	54,000	232.37	684.92	438.02
50	250	45,000	212.32	749.59	400.22
40	200	36,000	189.73	838.84	357.64
30	150	27,000	164.31	968.62	309.72
20	120	21,600	146.99	1082.75	277.08
10	105	18,900	137.47	1157.73	259.13
0	100	18,000	134.16	1186.30	252.89

Let us now plot a curve which will give us frequencies for all possible dial settings of the condenser. We consider a dial setting as the independent variable and the corresponding frequency of our combination the dependent variable. Dial settings will therefore be plotted along the X axis while frequencies will be plotted along the Y axis. Referring to Columns I and V (Table No. 1) you will note that the frequency corresponding to a dial setting of 100 is 541.45 kc. We cannot, of course, plot this figure more accurately than if it were 541 kc. unless we used a very large sheet of paper. We first read out the X axis to the point marked 100 and then read vertically 541 division and there make a circle as is shown in Fig. 5. The circle corresponding to the setting we have just described is at the extreme right end of the curve. Referring again to Columns I and V we note that a dial setting of 90 corresponds to a frequency of 560 kc. We then read out the X axis to 90 and then up 560 division and make another circle. This is the circle to the left of the one just mentioned. In a similar manner the other figures shown in Column V are plotted as functions of the figures shown in Column I, Table No. 1. A curve is then drawn joining all of the circles and the result is Fig. 5. Should we desire to use our condenser coil combination as a wave-meter we obtain a curve as is shown in Fig. 6 by plotting the data shown in Column VI of Table 1 as a function of the corresponding dial settings shown in Column 1. We can then use either Figs. 5 or 6 depending upon whether we are interested in frequencies or wave lengths.

Assume now that we desire to set our frequency meter so that it will resonate to a frequency of 900 kc. We first read vertically up the Y axis until we reach the 900 kc. line. We extend this line to the right until it strikes the curve as is shown in Fig. 5. We then turn our line at right angles and extend it down parallel to the Y axis until it strikes the X axis where we note the reading. In this case the reading on the X axis is 35. If we now set the dial on the condenser incorporated in our frequency meter at 35 degrees the circuit will be resonant to 900 kc.

Suppose, however, that we have adjusted our frequency meter to some source, the frequency of which is unknown to us and find that resonance occurs when the condenser dial is set at 66.5 degrees. To find the frequency corresponding to this we project a line up from the 66.5 mark on the X axis until it strikes the curve and then to the left until it strikes the Y axis where we read the correct frequency. In this case we find that our unknown source possesses a frequency of 650 kc. The wave length curve shown in Fig. 6 can, of course, be used in the same way if we are interested in wave lengths rather than frequency. Bear in mind that we have as yet not discussed any method of detecting resonance in our frequency meter. This will be discussed shortly.

You will note that the frequency meter we have made, using a 180 microhenry coil with the condenser having a calibration curve such as shown in Fig. 4, will not cover the entire broadcast band lying between 550 and 1,500 kc. It will not tune to frequencies above 1,186 kc. We can, however, easily extend the range of our frequency meter by designing and building a coil of somewhat lower inductance than our 180 microhenry coil.

The maximum capacitance we can obtain from our condenser is obtained by setting the condenser dial at 100, when the capacitance will be 480 micro-microfarads. Since it is desirable to have a certain amount of overlapping of the ranges covered by a frequency meter using more than one coil, let us determine the inductance of a coil which, when connected across a condenser having a capacitance of 480 micro-microfarads, will give a circuit resonant to 1,100 kc. The frequency range between 1,100 and 1,185 kc. can then be covered either with our 180 microhenry

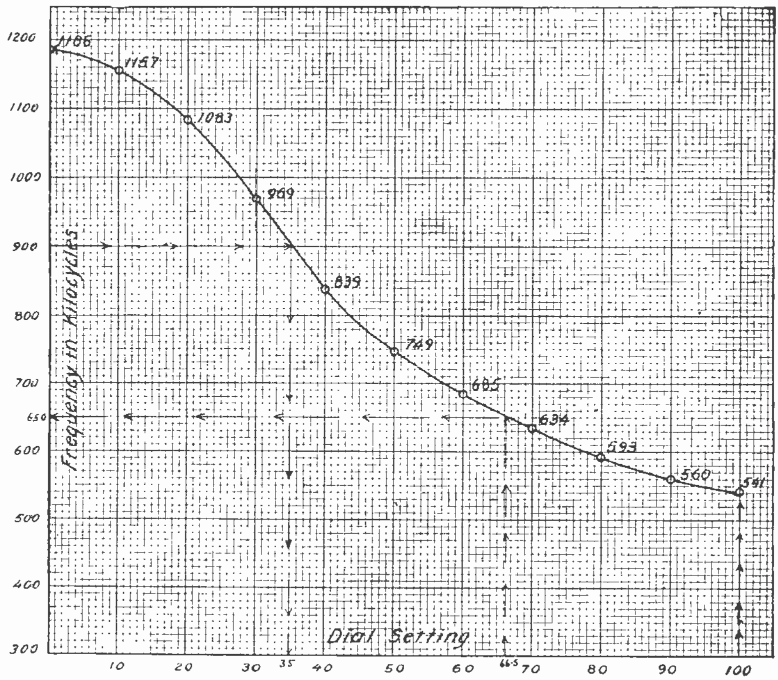


Fig. 5—Calibration curve for frequency meter using a coil of 180 microhenries with condenser having calibration curve shown in Fig. 4.

coil or with the new coil, the inductance of which we will now calculate.

Using Formula 3 we have:

Inductance equals 25,330,000,000 divided by the capacitance (480) multiplied by the square of the frequency (1,100 x 1,100), or:

$$L = \frac{25{,}330{,}000{,}000}{480 \times 1{,}100 \times 1{,}100} = 43.61 \text{ microhenries} \qquad (4)$$

Our new coil should therefore have an inductance of 43.61 microhenries. With this information, the size of wire, number of turns and diameter of coil can be determined using the data given in the text, "Inductance and Condenser Designs."

If we desire to find the **highest** frequency in kilocycles to which our frequency meter will resonate with this new coil, we refer again to Formula 1 and use in this formula the new value for inductance 43.61 microhenries and the **minimum** capacitance we can obtain from our condenser. This minimum capacitance will be obtained when the condenser dial is set at 0, which, as can be seen from Fig. 4, will be 100 micro-microfarads. Formula 1 states:

Frequency equals 159,154 divided by the square root of the quantity (LC) obtained by multiplying 43.61 microhenries by 100 micro-microfarads or $43.61 \times 100 = 4361.00$ $\sqrt{4361.00} = 66.0378$.

$$F = \frac{159{,}154}{\sqrt{43.61 \times 100}} = \frac{159{,}154}{66.0378} = 2{,}410 \text{ kilocycles.} \qquad (5)$$

Our new coil when used with our condenser will, therefore, cover the range extending from 1,100 kc. up to 2,410 kc. In a similar manner, coils can be designed which will cover the frequencies below 550 kc.

If you have received the radio apparatus which we send to our students, you can easily construct a frequency meter using one of the variable condensers and one of the coils you have wound. The condenser ordinarily supplied has a capacitance of approximately 350 micro-microfarads. The coil which you have built probably has about 71 turns of No. 24 double cotton covered wire wound on a form 2½ inches in diameter. The coil will be approximately 2 inches long.

By the aid of the design data already referred to, you can determine that the inductance of the coil will be approximately 245 microhenries. A coil of 245 microhenries used with a condenser having a capacitance of 350 micro-microfarads will, according to Formula 1, resonate at a frequency of 543.4 kc. when the condenser is set to give the maximum capacitance.

The condenser and coil you have may possess characteristics slightly different than those given in the above paragraphs but you will find that the coil has an inductance such that the circuit will cover at least most of the broadcast band with the condensers supplied to you. The condenser very probably has its plates cut quite differently from those illustrated by Fig. 2. They may be so cut as to result in a calibration curve showing frequency as a function of the condenser dial setting which is nearly straight. Such a condenser is often referred to as a "straight line frequency" condenser. See if you cannot think of the advantages possessed by such a condenser when used in a broadcast receiving set.

Very probably you do not have a capacitance calibration curve for the condenser you have nor will you know the exact inductance of the coil used with this condenser. You may then

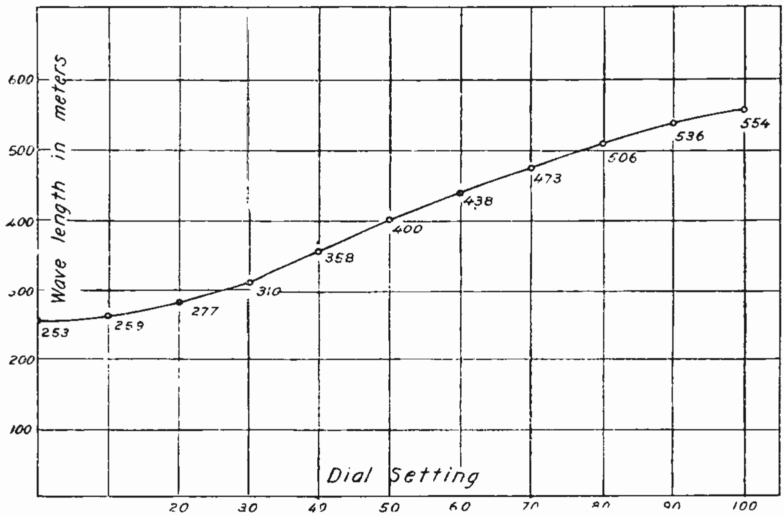


Fig. 6—Calibration curve for wavemeter using coil of 180 microhenries with condenser having calibration curve shown in Fig. 4.

very properly ask how a calibration curve covering the use of this coil and condenser as a frequency meter or as a wave-meter can be obtained. A little later in this lesson we will consider in detail a method by which you can easily calibrate a frequency meter for broadcast frequencies without knowing the inductance of the coil or possessing a capacitance calibration curve for the condenser. Before discussing this, however, let us consider some of the auxiliary apparatus that may be associated with our very simple condenser coil circuit.

The circuit we have been discussing is the basic circuit incorporated in practically all frequency and wave-meters. Ordinarily certain auxiliary apparatus is associated with an oscillatory circuit, the type of apparatus depending upon the particular use to which the meter is to be put. However, as we shall see later, the condenser-coil circuit in its simplest form as shown in Fig. 1 is often used; the auxiliary apparatus for detecting resonance being incorporated in other circuits.

USE OF A FREQUENCY METER WITH A THERMAL GALVANOMETER

A very common use for a frequency meter is for the measurement of the frequency transmitted by a radio transmitting station. Frequency meters intended for this purpose usually have a thermal galvanometer or a hot wire meter connected in series with the circuit as is shown in Fig. 7. **The meter is placed near the transmitter and the dial of the condenser varied until the maximum reading of the thermal galvanometer is obtained.** The dial reading at which this occurs is then noted and the frequency corresponding to this dial reading is obtained from the calibration curve according to the method already described. If it is desired to adjust the transmitter to a particular frequency then the dial reading for this frequency is obtained by noting the desired frequency on the Y axis, extending a line to the right to the curve and then down vertically parallel to the Y axis until it strikes the X axis where the corresponding dial setting is observed. The dial on the meter is then set for this value and the frequency control of the transmitter varied until the maximum reading on the galvanometer is obtained. The frequency radiated by the transmitter will then correspond to the frequency for which the frequency meter is adjusted.

There are one or two important facts to be noted in connection with the use of frequency or wave-meters of the type we have been discussing. In the first place it is essential that the frequency meter be not placed too close to the transmitter. Otherwise the current in the galvanometer may be so high as to cause damage to the galvanometer when the circuit is tuned to resonance.

Due to resistance in the circuit it is often difficult to determine the exact point of resonance. Because of this fact frequency meters of this kind are not ordinarily accurate enough for adjusting radio broadcasting stations. Too great an error in setting is likely to result. Consequently frequency meters of this type are not recommended for use under modern broadcasting conditions although they have very wide uses for other purposes. Meters which will meet modern conditions in the broadcast field will be described in later text-books.

USE OF A BUZZER AND BATTERY WITH A FREQUENCY METER

A very common use of a frequency or wave-meter is for the production of radio frequency energy of known frequency. One of the simplest ways of doing this is to incorporate with a circuit such as is shown in Fig. 1 a small buzzer and a dry cell or two as is shown in Fig. 8. The method by which a circuit of this type produces radio frequency energy has been described in a previous text-book. During the period when the buzzer contacts are closed a current from the dry battery flows through the coil. This current also flows through the winding of the buzzer causing the buzzer contact to open. Due to the inductive effect of the coil the current tends to flow even after the contact has opened and since it cannot flow through the buzzer circuit it flows into the condenser. Since the resistance of the circuit is

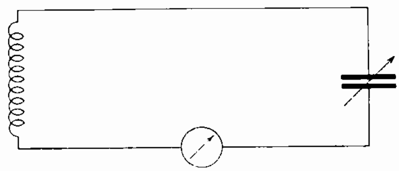


Fig. 7—Frequency meter circuit with thermal galvanometer for the measurement of frequency at a radio transmitting station.

very low the condenser will first charge up on one side then discharge through the coil and charge on the other side. We will therefore have an oscillatory discharge of the condenser through the coil and the frequency produced by the oscillation will be approximately as computed by Formula 1.

As has already been mentioned in previous texts the frequency produced by such a device is referred to as "damped." In addition to the one frequency for which the circuit is tuned there will be produced others of approximately the same value. As a result a device of this kind is said to tune rather broadly. For this reason its use is somewhat limited to measurements where a high degree of accuracy is not required. However, frequency meters of this type require so little apparatus and can so conveniently be used for a number of simple measurements that you will probably find it of interest to construct one.

You will note that we have used the term "frequency meter" almost to the exclusion of the term of "wave-meter" and that all of our instructions have applied to the construction and use of "frequency meters" rather than "wave-meters." This is in accord with the universal policy of recommending the use of frequencies in designating radio stations rather than the use of wave lengths. Unless you have already done so, you will find it to your advantage to adapt yourself as rapidly as possible to thinking in terms of "frequencies" rather than "wave lengths." Were it not for the fact that there are still in use many meters calibrated in terms of wave lengths we would use the term still less frequently in our lessons than we do.

A SIMPLE VACUUM TUBE RADIO FREQUENCY GENERATOR

We have shown by connecting a buzzer and a battery to our basic frequency meter circuit how we can produce damped waves of known frequency. However, the use of damped waves for radio measurements is open to the objections we have already pointed out. A much more suitable source of radio frequency energy can be obtained by incorporating our basic frequency meter circuit with a vacuum tube in such a way that the tube produces undamped radio frequency energy. Energy of this type will be free from the objections we have pointed out above and therefore far more suited to radio frequency measurements. Vacuum tube circuits which can be used to produce energy such as has been described are known as **vacuum tube radio frequency generators or vacuum tube oscillators.**

Figure 9 shows the circuit for a radio frequency generator which will be found very useful. The way in which a vacuum tube produces high frequency continuous waves has been thoroughly discussed in previous lessons. We will therefore concern ourselves now only with the details of operation of the circuit and not with the fundamental theory involved. For our purposes we may assume that we have substituted a vacuum tube and a couple of batteries in place of the buzzer and batteries in Fig. 8. The result as we have seen is that we now generate continuous waves instead of damped waves.

We have learned that if we used buzzer excitation the frequency produced would be approximately that determined by the value of inductance and capacitance used. However, since the buzzer circuit has some capacitance, the calibration curve for a circuit consisting of a condenser and coil alone will be somewhat different from the curve for a circuit using the same condenser and coil with a buzzer and a battery. It is also true that the incorporation of a vacuum tube with the associated batteries will result in a calibration curve somewhat different from that obtained when using the coil and condenser alone. In fact, the addition of the vacuum tube and batteries will have a greater effect upon frequency than will the buzzer and battery. If it is necessary that the frequency produced by a vacuum tube generator be known fairly accurately then the same vacuum tube should be used at all times and the filament and plate voltages should be kept at the same value. If very accurate results are desired, voltmeters should be connected across the filament terminals and across the plate battery as is shown in Fig. 9 by the

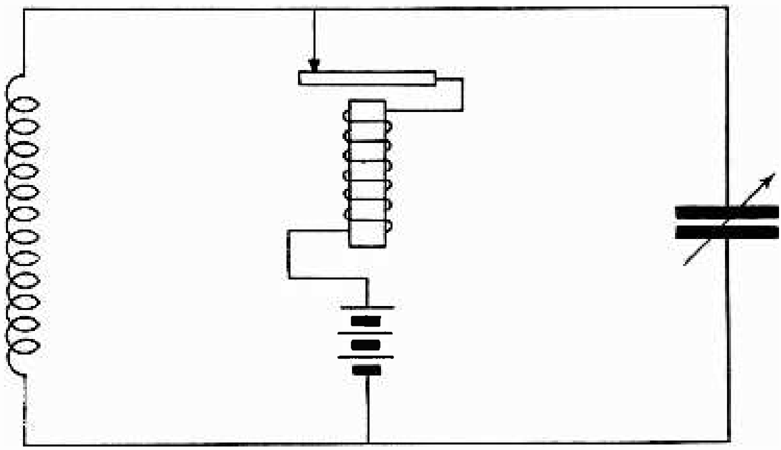


Fig. 8—Buzzer excited frequency meter circuit.

dotted lines. The voltmeter shown across the plate battery is, however, not so necessary as the one across the filament.

The above precautions are necessary if accurate measurements are desired. However, they are not necessary for the experiments we are going to discuss. It is possible to design vacuum tube oscillator circuits so that the frequency produced will not vary to any appreciable extent with the filament or plate voltage or even if different tubes are used in the circuit. Such circuits, however, require more apparatus than the one shown in Fig. 9, and, inasmuch as we are now primarily concerned with the simplest of radio measurements, we will reserve the more complicated circuits for later study. The vacuum tube circuit we have given is entirely practical and will permit you to make a number of very interesting experiments and to secure much valuable information.

The parts necessary for the vacuum tube generator shown in Fig. 9 are as follows:

T—One vacuum tube 199 type.

—One vacuum tube socket.

C—One variable condenser maximum capacitance 350 micro-microfarads.

L—One coil of approximately 245 microhenries (72 turns of No. 24 wire on a cylindrical form 2½ inch in diameter) tapped near the center of the coil. Note: If tap is not at center connect the smallest section of the coil between the grid and filament.

R—One filament control rheostat approximately 30 ohms.

A—Three dry cells for lighting filament of tube.

B—Two 22½ volt "B" batteries for plate voltage.

One baseboard of wood about 10 inches square.

One panel large enough to mount condenser.

If desirable the following may also be used:

VM_1—Filament voltmeter 0-5 volts.

VM_2—Plate voltmeter with switch 0.50 volts.

Figure 10 shows a very simple radio frequency generator such as we have just described. This was constructed at the National Radio Institute using parts such as are sent to National Radio Institute students. In order that there might be plenty of space available upon which to mount both "A" and "B" batteries, the standard 18-inch panel with the wooden baseboard 10 inches wide was used. Except where a high degree of portability is desired, much trouble is avoided by allowing plenty of space for apparatus.

There are many ways in which we might modify the simple circuit shown in Fig. 9 and greatly increase its usefulness. Since continuous waves will not ordinarily produce any sound in the head-set or loud speaker of a radio receiving set unless some special form of reception such as heterodyne reception is used, it is very convenient to be able to modulate the output of an oscillator as shown in Fig. 9, so that signals from it can be readily detected in an ordinary broadcast receiving set. A very convenient method of doing this is to connect a buzzer as is shown by the dotted lines in Fig. 9. The buzzer is so connected that it is energized by one of the "A" batteries. The making and breaking of the buzzer contacts periodically shorts the plate circuit coil. The interruptions can, of course, be clearly heard in any receiving set. If you have available a key and buzzer set such as used by students studying the continental code, you can readily modulate the output of the oscillator shown in Fig. 9 by connecting the extreme left-hand binding post of your buzzer and key set to the + terminal post of the "A" battery which has

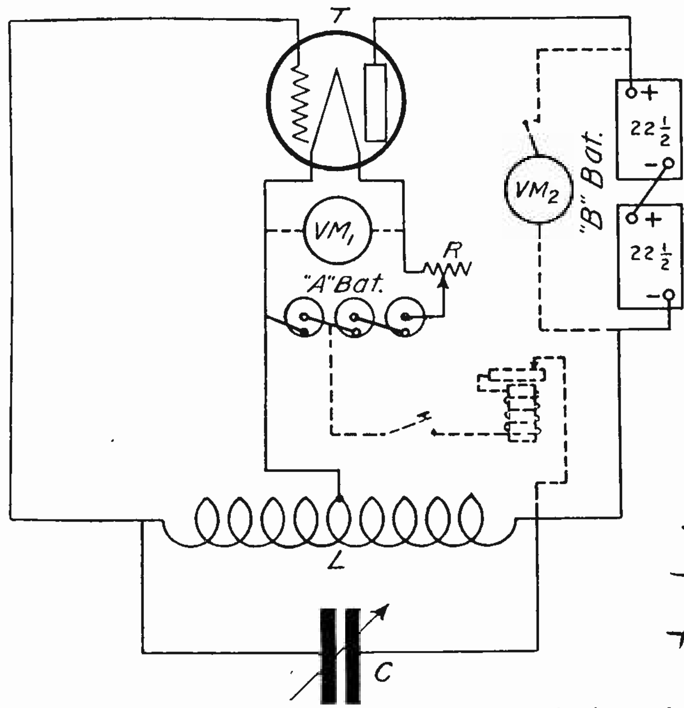


Fig. 9—A very simple vacuum tube continuous wave generator using buzzer shown in dotted lines for modulation.

its — post connected to the — filament and the right-hand binding post of the buzzer set to the — B. Upon pressing the key, the filament battery will actuate the buzzer and the interruptions will occur as described. A buzzer set connected as described here can be seen in Fig. 10.

Another very convenient method of modulating a high frequency generator, such as is shown in Fig. 9, is to insert in the grid lead a condenser of about 250 micro-microfarads with a grid leak of approximately 5 megohms connected across it. The periodic charging and discharging of the condenser through the leak will modulate the output of the generator at an audio frequency, the exact value of which will depend upon the capacitance of the condenser and the resistance of the leak.

It is important to note that the **interrupted continuous waves** furnished by a circuit such as is shown in Fig. 9 are far superior for measuring purposes to those which can be produced by the buzzer excited frequency meters shown in Fig. 8. In Fig. 8, oscillations are produced by charging a condenser and allowing the condenser to discharge through an inductance. In Fig. 9, a generating device is incorporated in the circuit which,

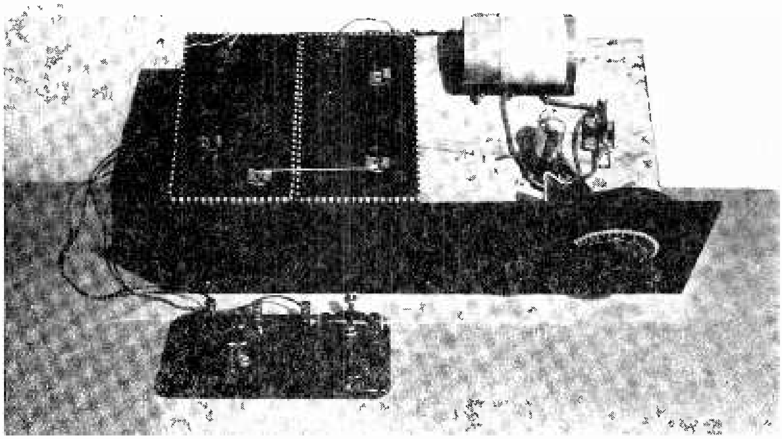
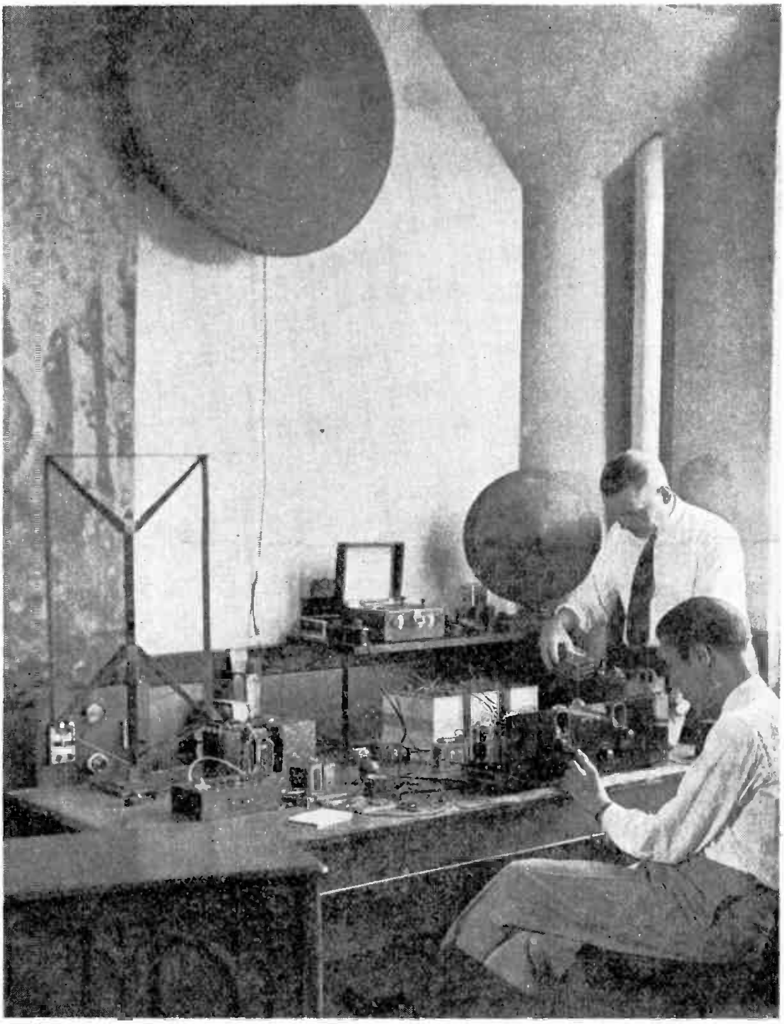


Fig. 10—Simple continuous wave generator built at the National Radio Institute, Washington, D. C.

except for the action of the buzzer, would produce continuous waves. The waves produced by the circuit shown in Fig. 9 are much sharper and the results that can be obtained by using a generator of this type are much more satisfactory.

If you remove the tube from the circuit shown in Fig. 9 and then close the buzzer key, the inductance—capacitance circuit will be excited in a way identical with that shown in Fig. 8. You can readily notice the difference in the sharpness of the energy produced in the two cases by listening with a receiving set to the note produced by the generator with the tube out and then with it in the circuit.



A corner of an experimental radio laboratory showing engineers at work in calibrating receiving apparatus.

If your home is wired for electric lights and is supplied by 60-cycle alternating current, then you can readily construct an oscillator for use in radio frequency measurements which will derive all of its power from the lighting circuit. The same circuit can also be used if direct current is used to light your home with the exception that the waves produced by the circuit will be practically continuous except for such disturbances as occur on the line. With the alternating current supply, however, the alternations of the electric voltage will serve to modulate the output of the oscillator. The oscillator can, therefore, be used with any receiving set.

Figure 11 shows the circuit for an oscillator such as we have been discussing. If the oscillator is intended for use with a 110-volt source and a 201-A or a 301-A type tube is used, then the electric light bulb connected in series with the filament circuit should be a 25 or 30-watt light.

The current through the filament of the vacuum tube will then be approximately .25 amperes which is the correct value for the 201-A or 301-A tube. These types are recommended as the plate voltage will be 110 volts. This total line voltage is applied directly to the plate of the tube as can be seen from Fig. 11.

A coil of the same design as we have described can be used with a condenser having the appropriate capacitance but it will be necessary to cut the wire in the middle of the coil thereby completely isolating the plate and grid sections, as is shown in Fig. 12. The condenser shown as connected across the 110-volt source is ordinarily not necessary. The condenser must be capable of standing 110 volts and should not have a capacity greater than .01 microfarads otherwise a considerable alternating current will flow through it. The stopping condenser should have a capacitance of .00025 microfarads or greater and the grid leak should be of the order of 1 megohms.

CALIBRATION OF FREQUENCY AND WAVE-METERS DESIGNED TO COVER THE BROADCAST BAND

The entire frequency spectrum lying between 550 and 1,500 kc. is occupied by radio broadcasting stations, all of which are operating upon specific frequency assignments. These assignments have been made by the Federal Radio Commission and Call Books showing what stations are operating on specific frequencies are readily obtainable. It is possible therefore to obtain a fairly satisfactory calibration curve for a vacuum tube oscillator or a frequency meter using buzzer excitation by the use of an ordinary radio receiving set and a Call Book, showing the frequency assignments upon which broadcasting stations are operated. The accuracy of calibration, which can be obtained by this method, will depend primarily upon the accuracy with which the broadcasting stations, whose signals are to be used, can be relied upon to maintain their carrier frequencies at the assigned values. Some broadcasting stations can be depended upon to keep their

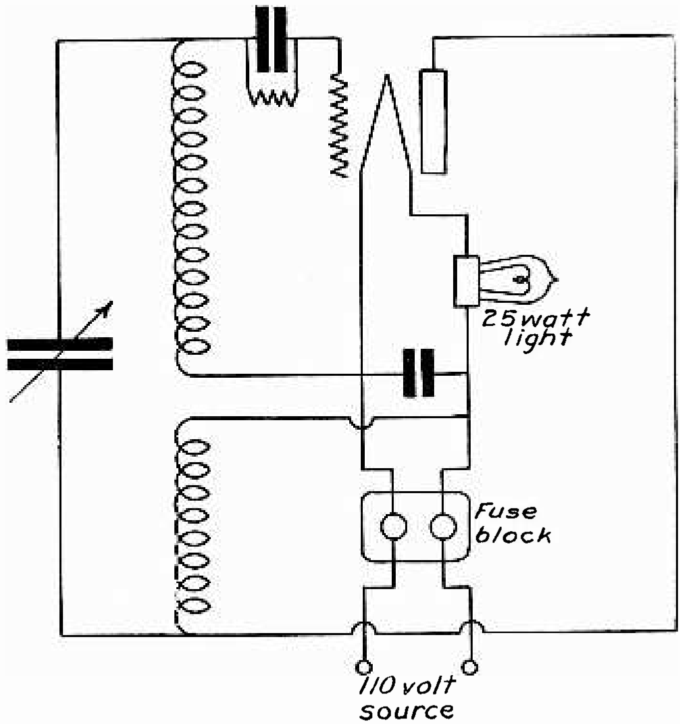


Fig. 11—Circuit for a vacuum tube high frequency generator for operation from a 110-volt source.

transmitters operating on the correct frequency with a high degree of accuracy while others cannot. If an accurate calibration is desired it is essential that as many reliable stations as possible be utilized.

Any type of radio receiving set designed for operation throughout the broadcast band can be utilized for the experiment we are about to describe. In the experimental work conducted at the National Radio Institute prior to the preparation of this text-book, a very simple regenerative receiver wired according to the circuit shown in Fig. 13 was used and a calibration curve obtained for the vacuum tube continuous wave generator shown in Fig. 10 was obtained. This vacuum tube generator was equipped with a buzzer and was wired in accordance with the circuit shown in Fig. 9. In addition to obtaining a calibration curve for the vacuum tube generator data a similar calibration curve for the receiving set was obtained. However, since the set was of the regenerative type this data would be of value only in case the same antenna and the same degree of coupling between the antenna and the receiving set were maintained. It should be

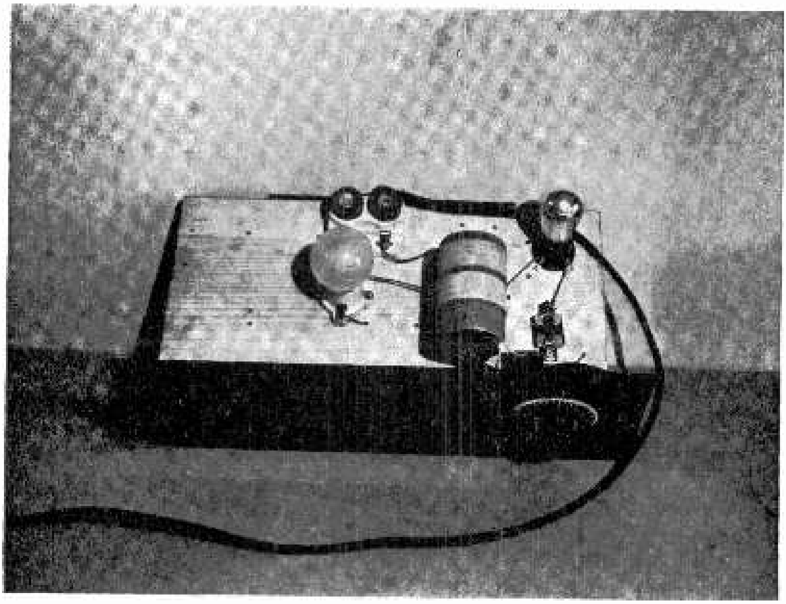


Fig. 12—High frequency generator for operation from 110-volt source built at the National Radio Institute.

borne in mind that the tuning of a regenerative receiving set will to some extent depend upon the setting of the dial controlling regeneration, the dimensions of the antenna in use and the degree of coupling between the antenna circuit and the receiving set itself, etc. If, however, you happen to use a receiving set of the tuned radio frequency type, as is probably the case, these factors will not be involved and the calibration curve which you can obtain by the methods to be described will be of great value to you.

The receiving set was connected to a small antenna from the roof of the National Radio Institute's building. The vacuum tube generator was placed upon the same table as the receiving set and about three feet from it. The receiving set was placed in operation and tuned for Station WRC, which at the time of the experiment was operating upon a frequency of 640 kc. The tuning dial and the regeneration dial were adjusted until the signal reached its maximum intensity in the head-set. The dial readings were then recorded in Columns III and IV of Table II.

The filament of the tube in the vacuum tube generator circuit was then lighted and the rheostat adjusted until the voltage across the filament terminals was 3 volts. The condenser

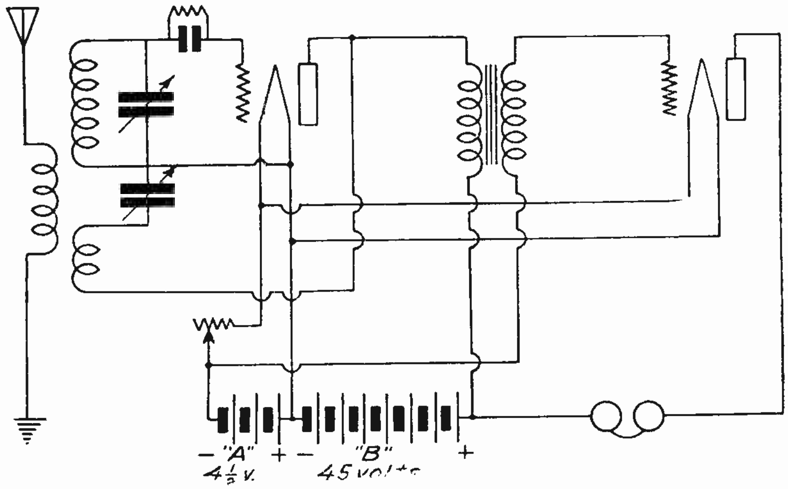


Fig. 13—Schematic circuit diagram for radio receiving set used to obtain data for calibration curve for high frequency generators shown in Figs. 10 and 12.

dial of the generator circuit was then adjusted until the frequency produced by the generator was so close to that produced by station WRC that a heterodyne beat note could be heard in the head-set connected into the circuit of the receiving set. The vacuum tube generator was then moved back and forth across the table until a suitable intensity of this heterodyne note was obtained. The dial on the generator circuit was then very carefully adjusted until the beat note became so low as to be almost inaudible. When this is the case, you can readily see that the frequency produced by the generator must be almost the same as that produced by Radio Station WRC. The reading on the generator circuit condenser dial was then recorded in Column V of Table II. This reading was 82. Thereafter to produce a frequency of 640 kc. it was only necessary to turn on the vacuum tube generator and to set the condenser dial at 82.

The radio receiving set was then tuned for another station which happened to be station WRHF also located in Washington, D. C., and at the time of the experiment transmitting upon a frequency of 930 kc. With the tuning and regeneration dial set

TABLE NO. II.

Calibration Data for Vacuum Tube Continuous Wave Generator Shown in Fig. 10.

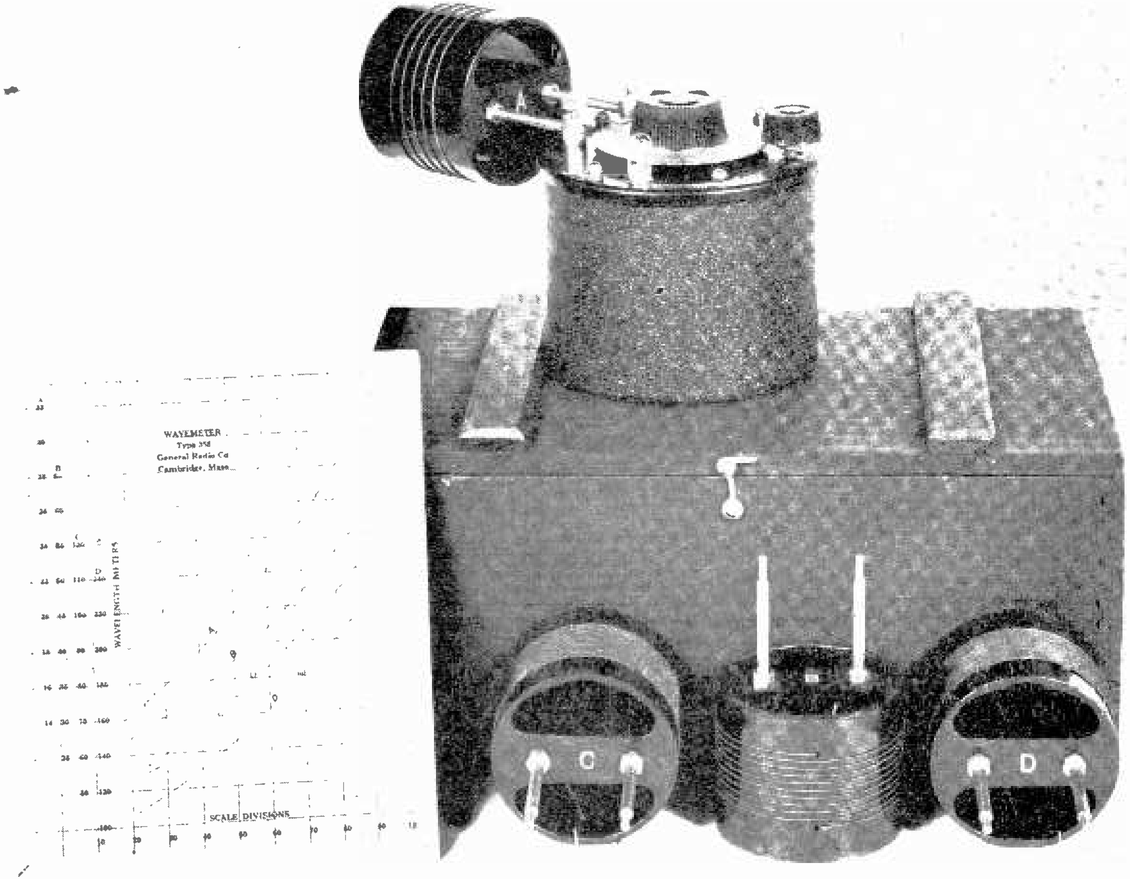
I Station	II Assigned Frequency	III Receiving Set Tuning Dial Setting	IV Receiving Set Regeneration Control dial Setting	V Vacuum Tube Generator Dial Setting
WRC.........	640	84	90.5	82
WKBW.......	1380	15	91	77.5(690kc)*
WGY.........	790	61	60	68
KDKA.......	950	51	85	54
WBAL.......	1050	48	84	44.5
WPG.........	1100	29	86	39
WMAL.......	1240	0	100	25
WRC.........	640	22	77	18 (1280)†

*Note: Generator tuned to frequency one-half that of transmitting station.

†Note: Receiving set and oscillator both wired to second harmonic from WRC.

for maximum volume from this station, the oscillator was then adjusted as before until the beat note between the oscillator and station WRHF was as low as possible. The reading of the generator circuit condenser dial was then noted and found to be 57. In a similar manner additional data were obtained as shown by the additional figures in Table II. The data given in Table II were then plotted so as to give a calibration curve for the radio frequency generator. Figure 15 shows the curve obtained. Dial settings are plotted as abscissa and frequencies as ordinates.

Harmonics from broadcasting stations, if they are of sufficient intensity, and harmonics from the continuous wave generator may also be used to obtain points on the calibration curve. Two sets of data shown in Table II illustrate how this is done. At the time the calibration curve was obtained the receiving set was only a very few blocks from station WRC. This station in addition to radiating energy at the fundamental frequency 640



General Radio type 358 wave-meter, showing various size coils used to check wave lengths between 14 and 224 meters.

kc. also radiates a small amount of energy at the second harmonic, 1,280 kc. By very careful tuning of the receiving set it was possible to hear the program from station WRC when the set was adjusted for 1,280 kc. The continuous wave generator was then adjusted so as to produce this frequency using the heterodyne beat note between the double frequency energy from WRC and the fundamental produced by the oscillator to deter-

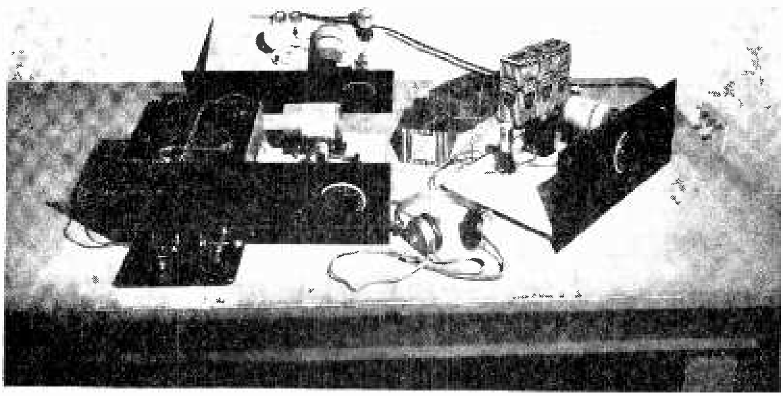


Fig. 14—Radio receiving set and continuous wave generator on table preparatory to calibration.

mine when the oscillator was set at 1,280 kc. The data obtained are plotted on Fig. 15.

In a somewhat similar way the harmonic produced by the continuous wave generator can also be used. The receiving set was adjusted to receive signals from station WKBW assigned a frequency of 1,380 kc. The continuous wave generator was not capable of producing a frequency as high as this with the coil in use. However, when the generator was adjusted for 690 kc. the 1,380 kc. harmonic (second harmonic) produced was of sufficient intensity to beat with the incoming signals from station WKBW. The generator dial was then adjusted until the beat frequency was reduced to zero and the data obtained used to plot the point shown in Fig. 15.

The student will find in this text-book much valuable and understandable data concerning the calculation of inductance, wave length, frequency, capacity, etc., also a description of the simple devices with which these measurements may be made.

Perhaps there is no more important instrument used for radio measurements than the frequency or wave-meter. It may be employed in many calculations and, contrary to what might be expected, it may be constructed and operated by students of the science with little or no trouble.

A frequency meter is really a combination transmitter and receiver of the calibrated type. That is, it may be adjusted to admit a wave of a definite length or frequency and it may be set to receive a wave or frequency of a definite length. In this way, it is possible to calibrate transmitters and receivers by its use.

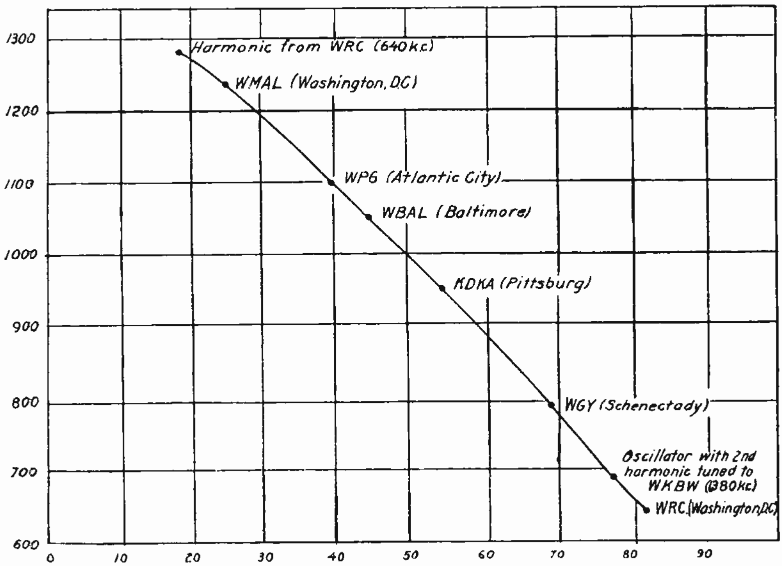


Fig. 15—Calibration curve obtained with a radio receiving set of continuous wave generator shown in Fig. 10.

UNITS OF THE METRIC SYSTEM

Electrical units are based upon the units of the metric system which is the name given to the system of units used throughout the world of science.

In connection with the units of the metric system, the prefixes given in Table III are used to indicate the smaller or larger units.

The **units of capacity** actually used in radio work are the **farad, microfarad** and the **micro-microfarad.**

1,000,000 **microfarads** equals one **farad.**

1,000,000 **micro-microfarads** equals one **microfarad.**

1,000,000,000,000 **micro-microfarads** equals one **farad.**

TABLE III

Prefix	Abbreviation	Meaning
micro	μ	One-millionth
milli	m	One-thousandth
centi	c	One-hundredth
deci	d	One-tenth
deka	dk	Ten
hekto	h	One hundred
kilo	k	One thousand
mega	M	One million

The **units of inductance** commonly used in radio work are **henry, millihenry** and the **microhenry.**

Another unit sometimes used is the centimeter of inductance.

1,000 **millihenries** equals one **henry.**

1,000 **microhenries** equals one **millihenry.**

1,000,000 **microhenries** equals one **henry.**

1,000 **centimeters** equals one **microhenry.**

1,000,000 **centimeters** equals one **millihenry.**

1,000,000,000 **centimeters** equals one **henry.**

TEST QUESTIONS

Number your Answers 22—3 and add your **Student Number.**

Never hold up one set of lesson answers until you have another set ready to send in. Send each lesson in by itself before you start on the next lesson.

In that way we will be able to work together much more closely, you'll get more out of your course, and better lesson service.

1. Why is it advisable to calibrate receiving apparatus in terms of frequency?
2. At what frequency will a circuit resonate using a 180-microhenry coil, the capacitance of the condenser being 300 micro-microfarads? (See Table No. I.)
3. Draw a circuit diagram of a frequency meter using a thermal galvanometer or a hot wire ammeter.
4. Explain how the apparatus used in Fig. 7 is used for measuring the frequency of a radio transmitter.
5. Draw a circuit diagram of a buzzer excited frequency meter.
6. What kind of waves will the buzzer excited frequency meter produce?
7. Draw a circuit diagram of a vacuum tube continuous or modulated continuous wave generator.
8. State what device is used in Fig. 9 to modulate the output of the oscillator.
9. What other methods can be used for modulating a high frequency generator such as shown in Fig. 9 ?
10. Draw a circuit diagram of a vacuum tube high frequency generator which can be operated from a 110-volt line.

RADIO BY MAIL

National Radio Institute

STUDENTS ALL OVER THE WORLD