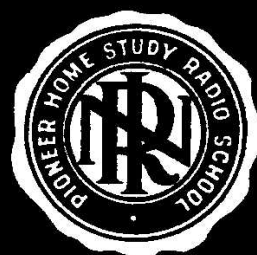# MEASUREMENTS AT AUDIO AND RADIO FREQUENCIES

30FR-1

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STUDY SCHEDULE NO. 30

For each study step, read the assigned pages first at your usual speed. Reread slowly one or more times, finish with one quick reading to fix the important facts firmly in your mind, then answer the Lesson Questions for that step. Study each other step in this same way.

☐ 1. **Introduction** . . . . **Pages 1-2**
Read this once carefully to get an idea of the measurements covered in this lesson, as well as the required accuracies in various radio fields.

☐ 2. **Inductance of Air-Core Coils** . . . . **Pages 2-7**
The simple methods discussed here can be carried out with a minimum of equipment. These methods require more work and are less accurate than some of the other methods but are useful where extreme accuracy is not required. Answer Lesson Question 1.

☐ 3. **Inductance of Iron-Core Coils** . . . . **Pages 7-8**
The method is similar to that used for air-core coils, with the addition of a direct current flow through the coil to provide the proper core flux density. This permits the measurement to be made under conditions simulating actual operation. Answer Lesson Questions 2 and 3.

☐ 4. **Condenser Capacity** . . . . **Pages 8-11**
The basic methods developed for coils are used to determine the capacity of solid-dielectric and electrolytic condensers, as explained here. Answer Lesson Question 4.

☐ 5. **Resonance Methods of Measuring L and C** . . . . **Pages 11-15**
By setting up a resonant circuit, the inductance and capacity values can be accurately found. Also, the coil r. f. resistance and distributed capacity can be measured and the coil Q calculated. This method is very valuable where r. f. circuit components are being checked. Answer Lesson Questions 5, 6 and 7.

☐ 6. **Bridge Measurements** . . . . **Pages 16-23**
The most commonly used method of measuring inductance and capacity makes use of bridge circuits. These circuits have the advantage of covering wide ranges, using only a few standard parts, and have a high degree of accuracy. Answer Lesson Questions 8 and 9.

☐ 7. **Frequency Measurements** . . . . **Pages 24-36**
There are many ways of checking frequencies, such as by comparison with a frequency standard, using a wave meter, tuning fork or reed, etc. You will find this section very interesting—giving an insight into the way service equipment is calibrated. Answer Lesson Question 10.

☐ 8. **Mail Your Answers for this Lesson to N. R. I. for Grading.**

☐ 9. **Start Studying the Next Lesson.**

MEASUREMENTS AT AUDIO AND RADIO FREQUENCIES

IN past lessons you have studied inductance, capacity, impedance, reactance, power factor and the Q factor possessed by coils and condensers at audio and radio frequencies. Now we are going to learn practical ways of actually measuring these properties.

Such measurements are made by using a circuit which allows the part in question to be compared directly or indirectly with a standard part. The National Bureau of Standards, in Washington, D. C., has a set of resistors, a set of coils and a set of condensers whose resistance, inductance and capacity values are accurately known. This government agency and other large laboratories calibrate radio parts for manufacturers and others engaged in research work. These calibrated parts, in turn, are used as standards in rating ordinary radio parts.

Usually some ratio circuit is used in making comparisons, so that fewer standard parts—which are very expensive—are needed. If the ratio test circuit is put together on the workbench, some simple calculation is required, using either Ohm's Law or simple multiplication or division. However, factory-made, precalibrated capacity bridges, Q factor meters, inductance bridges and other measuring apparatus are available with direct-reading dials which can be read as easily as ordinary meter scales.

▶ The method used to make the measurements depends on the accuracy desired and on the apparatus available. If coils had only induc-tance, condensers only capacity and resistors only resistance, measurement would be vastly simplified. Instead, coils have distributed capacities and both a.c. and d.c. resistances; condensers have resistances and inductances; while resistors may have inductances which, though small, are quite effective at higher frequencies. Measurements must either take all these factors into account or be somewhat in error.

▶ The accuracy with which you will wish to make measurements depends on the radio field you enter. If you become a design or research engineer, you must take into account all the properties of each radio part in your circuits. You will need to calculate carefully the values of parts to be used, then insert parts (whose values have been accurately determined) in a trial circuit to prove the design works. You will then vary parts values to find the tolerances permissible. The laboratory measuring procedures you will use require careful control and very expensive equipment.

If you enter production work in a radio factory as a laboratory technician, factory serviceman or inspector, you will need to make only semi-laboratory measurements. These do not require such complex procedures nor such expensive equipment, for you will usually make comparison measurements to see if parts are alike or within tolerance limits, rather than find absolute values directly. In other words, you will compare one coil with another similar one to find their inductance difference instead of to find

the actual inductance value accurately.

If you make servicing or radio communications your career, you will rarely make even these simplified measurements. Usually the radio trouble will be some simple breakdown which you can find from voltage, current or resistance measurements, and you can determine replacement parts values from the wiring diagram or previous experience with similar models. Even so, knowledge of ways of measuring coils and condensers, using ordinary shop equipment, will help you in special cases of unusual trouble and also in understanding more clearly the relations between these units.

▶ In this lesson we will discuss both simple methods and basic laboratory techniques. To do so, we here present a number of methods. Some use formulas, and in some cases we show how the formulas are obtained. We do not intend that you try to memorize the methods, the formulas, or the process of getting the formulas—they are presented here for your future reference and you can come back to this lesson should you need this information. We cover the field here, so you will have some idea of the measurements required in all branches of radio and will not have to start in absolutely green should you go into any field of radio requiring this information. You will probably never use all the methods described, no matter where you go, so just learn the basic principles of the methods and answer the lesson questions.

▶ Let us now see how measurements are made. We'll start with air-core inductances, then take up iron-core coils, condensers, resonance methods and bridge methods.

Inductance of Air-Core Coils

Inductance values of air-core coils are rarely given on service diagrams. However, just any coil cannot be used as a replacement, particularly for an r.f. transformer, where the inductance value may determine the tuning range, and the Q factor may affect both the sensitivity and selectivity. The practical serviceman would therefore replace a defective air-core coil with an exact duplicate ordered from the receiver manufacturer or a radio supply house. If a duplicate were unobtainable, he would send the original coil to a coil manufacturer specializing in winding coils for service purposes. The serviceman is thus likely to need to find the inductance of an air-core coil only when building something for experimental purposes (a wave trap, for instance).

To the factory man or engineer, on the other hand, inductance and Q factor are very important and must be found time and time again. Let's see how they can be measured. We'll use basic methods which are suitable for other r.f. measurements as well.

▶ The inductance of an air-core coil can be found from its physical dimensions—such as length and diameter of the coil, the number of turns and size of wire. You can then use these values with an inductance design chart or formula to determine the inductance within a few percent. These charts or formulas are found in engineering handbooks and radio publications.

However, at the time you need them, charts are not always available; they cannot be used when tolerance limits are being determined, nor do they give

the Q factor. So now let us study actual inductance measurements.

▶ We can find the inductance of an air-core coil by determining the coil reactance and calculating the inductance, by direct comparison methods, or by using bridge or resonant circuit methods. Since the last two can also be used to measure capacity and resistance, they will be covered in another section of this lesson. Let us now take up the reactance and direct comparison methods, which use equipment found in any laboratory and in many service shops.

REACTANCE METHODS

A very simple method which can be used with reasonable accuracy on air-core coils is to apply a known a.c. voltage to the coil and determine the current flow, as in Fig. 1. From Ohm's Law for a.c. circuits, you know that the impedance of the circuit equals the voltage divided by the current flow $(Z = E \div I)$. Also, you know that the impedance Z is a combination of the a.c. resistance and the reactance of the coil. $(Z = \sqrt{R^2 + X_L^2})$. If you neglect the a.c. resistance, the impedance is the same as the reactance of the coil. Once you find the inductive reactance, you can find the inductance from the formula $X_L = 2\pi f L$, which is easier to use if arranged in the form $L = X_L \div 2\pi f$*.

To find the inductance of the coil by this method, you must know the frequency and neglect the a.c. resistance. The frequency will be that of the voltage source, which will probably be a signal generator when an air-core coil is being checked. For accuracy, the frequency used to determine the reactance by this method must be

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* L=inductance in henrys
X_L=inductive reactance in ohms
f=frequency in cycles
2π=6.28, a constant

somewhere near the normal working frequency of the coil. Since air-core coils are used in r.f. circuits, radio frequencies must be used. Usually the frequency band in which the coil is designed to work is known, so you can choose some frequency in or near this band. (Remember that if the frequency is too low, the coil will have very little reactance and an extremely high current will flow.)

▶ This method is quite simple, since you just measure the voltage and current and perform a calculation. How-
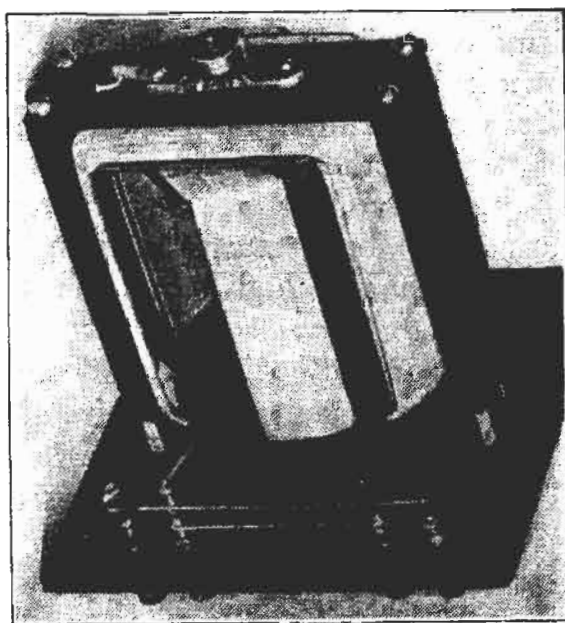
Interior view of a standard variable inductance.

ever, it is only accurate enough for a very rough approximation. Remember, you neglect the a.c. resistance of the coil, which may be appreciable. Also, since you use the frequency in your calculation, any error in the calibration of the signal generator will cause a similar error in your result. Further, you must use accurate a.c. meters, because any inaccuracies in current and voltage measurements will likewise affect the final result. Only a thermocouple type current meter and an r.f. vacuum tube voltmeter are accurate enough for r.f. measurements.

▶ You must also be careful how you use your meters. In the circuit shown

in Fig. *1A*, the current meter I_M actually measures the current through the coil, but the voltmeter V_M measures both the voltage drop across the coil and the drop across the current meter. If the current meter has an appreciably high resistance compared to the coil reactance, the measured voltage may be considerably different from the actual voltage across the coil, as it will be the sum of the coil voltage and the voltage drop across the current meter.

You can make the voltage measurement more accurate by placing the voltmeter directly across the coil, as shown in Fig. *1B*. Now, however, the current meter measures both the current through the coil and the current through the voltmeter, so the current reading will be accurate only if the voltmeter has a high ohms-per-volt sensitivity.

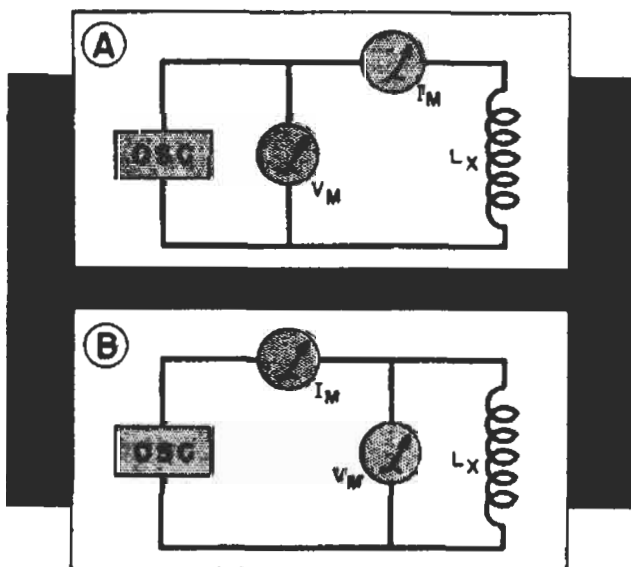Which connection is better depends on the meters used. At radio frequen-

FIG. 1. Two methods of connecting meters to measure voltage and current.

cies, the current meter must be a thermocouple or hot-wire type, as other a.c. meters are usable only at power and audio frequencies. Fig. *1A* can be used if the current meter has low re-

sistance, while Fig. *1B* can be used if the voltmeter has a high ohms-per-volt sensitivity. When a v.t.v.m. is used, Fig. *1B* is the better circuit.

▶ Another practical difficulty with this method is that the signal generator may not have sufficient output. If so, use a single stage amplifier to increase the output sufficiently.

Obviously, with so many chances of error, this method is not extremely accurate. However, it may be good
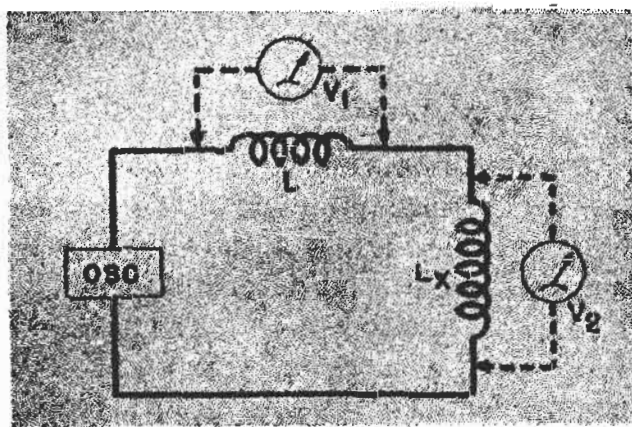

FIG. 2. The comparison method used for an air-core coil.

enough if accuracy within 10% to 20% is permissible.

COMPARISON METHODS

If a known inductance is available, you can place the unknown inductance in series with the cálibrated one, apply an r.f. voltage to the combination (as shown in Fig. *2*), and get the voltage readings. The voltage drops are proportional to the impedances. If we ignore the coil a.c. resistance, then the voltages are proportional to the reactances, which in turn are proportional to the inductances, so we can say that $\dfrac{V_1}{V_2} = \dfrac{L}{L_X}$ or $L_X = \dfrac{V_2 L}{V_1}$. Thus, to find the inductance of L_X, multiply the inductance of L by the voltage V_2 and divide by the voltage V_1. For best re-

sults, the standard should be near the value of the unknown, so the voltmeter readings will be similar.

▶ If a variable standard inductance is available, use it as L, then adjust the variable standard inductance until the voltage drops across the two coils are equal. When they are equal, the impedances of the two coils are equal and, neglecting resistance again, you can read the unknown inductance directly from the calibrated scale on the variable standard inductance. This method has many advantages over the reactance method. For example, you do not have to know the frequency of the source—and, with the variable standard, if identical voltmeters are used across each coil or the same one is moved from coil to coil, even the accuracy of the voltmeter does not matter. However, some error may be caused by neglecting the resistances of the two coils, which may be quite different.

Resistor Comparison. If a standard inductance is not available and great accuracy is not required, the method shown in Fig. 3 can be used. Here you use a variable resistor as the variable standard and adjust it until the two voltmeters read the same value.

To make the meters read alike, you may have to adjust the frequency of the a.c. source until the coil reactance falls within the resistance range. If the voltmeter reading across the coil is higher than the reading across the resistance, even with maximum resistance, you must either lower the frequency or use a higher resistance.

Again, equal voltages mean the impedances of the two devices are equal. If you neglect inductive and capacitive effects in the resistance and also neglect resistance within the coil, you can say that the resistance of R is

equal to the reactance of L_X. Then you can use the reactance formula to determine the inductance. Since the reactance of L_X is equal to R, the formula becomes $L_X = R \div 6.28f$, where L_X is in henrys, R is in ohms and f is in cycles per second.

▶ This method has the advantage of not requiring a standard inductance. You do not even need a calibrated resistor, because you can measure the resistance with an ohmmeter after equal voltages are obtained. However, it does require the use of either two identical voltmeters or one meter with a very high ohms-per-volt rating such as a v.t.v.m.

The accuracy is affected by neglecting both the resistance of the coil and the inductance and capacitive effects in the resistance unit, and also depends
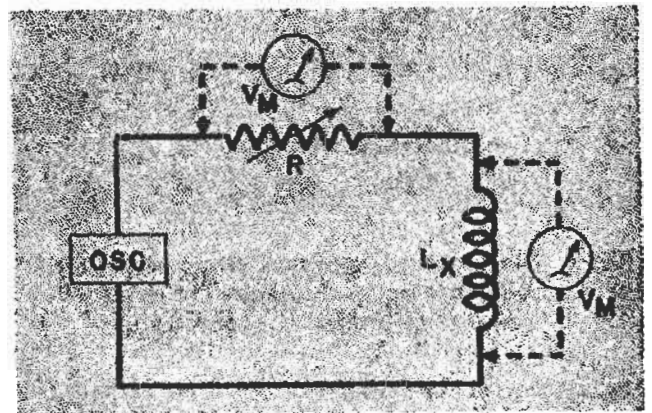

FIG. 3. How to use a variable resistance as the standard in the comparison method.

upon the accuracy with which the resistance and frequency are determined. However, this method eliminates current measurements and does not require accurate meters, so it is rather commonly used when errors of 10% to 20% can be permitted.

Three-Voltage Method. By making three voltage measurements and using a graph, you can improve con-

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siderably the accuracy of the method of Fig. *3*. The measuring circuit is shown in Fig. *4A*. Here, R need not be variable, but its resistance must be known (or measured) accurately. Preferably, R should have a resistance such that E_R is somewhere near the value of the voltage E_Z, but this is not necessary.

After making the three voltage measurements shown in Fig. *4A*, you must draw a graph. To do this, first mark a horizontal line on a sheet of
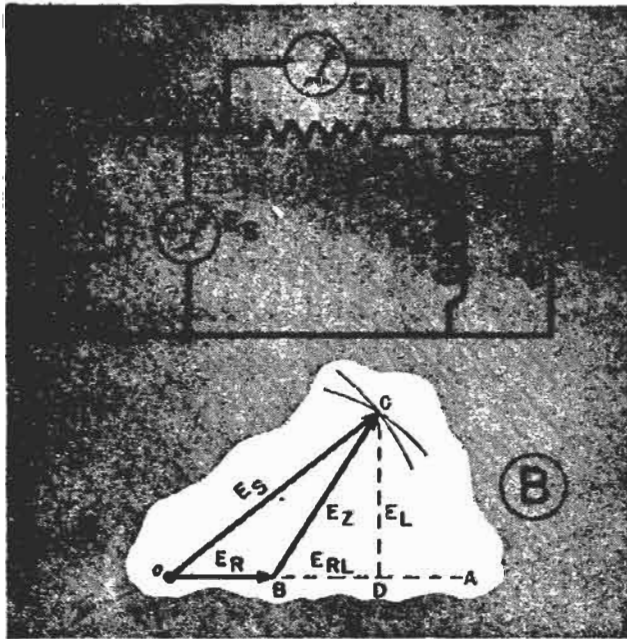

FIG. 4. The three-voltage method. Not only is this method more accurate, it can be used when only a voltmeter is available.

paper, such as the line O–A in Fig. *4B*. Along this line, measure off a distance proportional to the voltage found across resistor R. Any satisfactory scale can be used, such as 10 volts to the inch. After you have measured the proper length along this line from point O with a ruler, mark point B. The distance O–B is then proportional to the voltage E_R.

Now, take a compass (a drawing instrument similar to a pair of dividers, with a pencil attachment) and adjust the compass so that the distance between its point and its pencil is proportional to the voltage E_S, using

the same scale of volts-per-inch used for laying out the line O–B. With the compass point set at point O, draw an arc or semicircle with the compass.

Next, adjust the compass so that the distance between its point and pencil is proportional to voltage E_Z, using the same volts-per-inch scale as before.

With the compass point now set at point B, draw an arc with the compass that crosses the arc you made from point O. The point where they cross is point C in Fig. *4B*. Now, draw lines from point C to point B and from point C to point O. The line O–C is then proportional to the voltage E_S, while the line B–C is proportional to the voltage E_Z.

Next, drop a vertical line (line C–D) from point C at right angles to line O–A. You can use the right (90°) angle of a triangle to do this.

You have now formed a triangle having as its sides the lines B–C, B–D and C–D. As line B–C represents the voltage across the coil *impedance*, the line C–D is proportional to the voltage drop across the inductive reactance alone, while the distance B–D is proportional to the voltage drop across the coil a.c. resistance. The combination of these two voltages, of course, makes up the total voltage drop across the coil, which you have found to be E_Z.

Now since the voltage E_L is caused by the reactance alone, dividing this voltage by the current flow will give you the true coil reactance. The voltage E_L can be determined by measuring the line C–D with a ruler, then converting the number of inches into volts, using the same volts-per-inch scale you used in drawing the other lines.

The current is, of course, equal to the resistor voltage E_R divided by R. Compute this current, divide E_L by it,

and you have the coil reactance. You can now find the true inductance from the formula $L = X_L \div 6.28f$.

▶ This method eliminates one error by taking the coil a.c. resistance into account. Using identical voltmeters (or the same one), your accuracy depends only on the accuracy with which the resistance is found, the accuracy with which the frequency is known, and the care used in drawing the graph. Make the graph as large as possible (fewer volts-per-inch scale) for greatest accuracy.

▶ The three-voltage method also lets you determine the Q factor of the coil at the frequency of measurement. You know the Q factor is equal to the reactance of a coil divided by its a.c. resistance ($Q = X_L \div R$). As the coil resistance and coil reactance are effectively in series, with the same current through each, the reactance and resistance are proportional to their voltage drops. Therefore, you can find the Q factor directly by dividing voltage E_L by voltage E_{RL}.

Other Methods. You can also measure inductance by using various bridge circuits and resonant circuits. Since these methods can also be used to measure capacity, they will be discussed by themselves later in this lesson.

Inductance of Iron-Core Coils

You cannot determine the inductance of an iron-core coil except by electrical measurements, as its physical size does not indicate its inductance. A serviceman would probably replace a defective coil with a duplicate, but it might be necessary for him to measure the inductance to be sure the coil replacement is proper.

The methods of measuring the inductance of an iron-core device are somewhat similar to those already discussed for air-core coils. However, you must be careful to measure the inductance under the operating conditions which will exist in the radio receiver, transmitter or other apparatus, because the actual amount of inductance depends on the core flux density. If the coil is used in a circuit where d.c. flows through it, you must approximate the same d.c. flow during tests. You must also have about the same a.c. flow as in normal operation, and the frequency used for measurement must be within the normal range of the device.

▶ If the iron-core coil is used in a circuit where no d.c. normally flows, its inductance can be measured by the methods used for an air-core coil as long as a normal a.c. voltage and frequency are employed. With a transformer, you must remember that you are determining the inductance of only the one coil which is connected in the measuring circuit. The inductance of the other windings must be determined separately. Also, to find the actual operating inductance of any winding, you must connect the normal loads to all the windings of the transformer—even to those not being measured.

POLARIZING CURRENT

In most radio uses, an iron-core coil will have both d.c. and a.c. flowing through it. As you know, you must send normal amounts of both a.c. and d.c. through such a coil to measure its inductance under working conditions. A circuit for doing so is shown in Fig. 5.

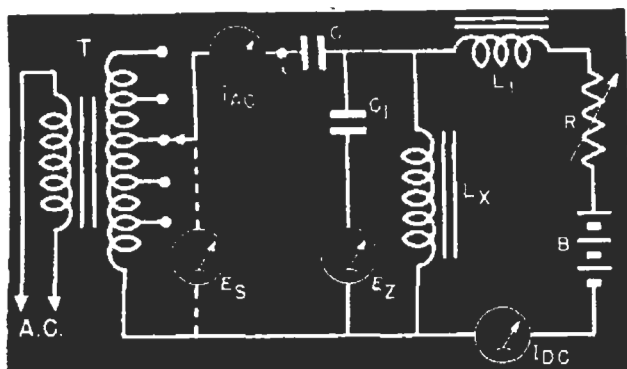In this circuit, coil L_x is the induct-

FIG. 5. Iron-core coils require a polarizing current, so this circuit is used.

ance under test. The battery B causes d.c. to flow through the coil; this current is read on I_{DC} and adjusted to the required value by resistor R.

A.C. is applied through transformer T and condenser C. Condenser C prevents d.c. from flowing through the secondary of transformer T, while choke coil L_1 prevents a.c. flow through the battery and R. Thus, d.c. flows only from battery B through R, L_1 and L_X, while a.c. flows only from the transformer through condenser C and coil L_X.

Condenser C should have a large capacity, so its reactance will be negligible. Also, L_1 must be a high-inductance coil so the a.c. flow through L_1-R-B (in parallel with L_X) will be negligible.

After the d.c. has been adjusted to

approximate the amount which normally flows through the coil when in use, a tap on the secondary of transformer T is chosen which produces about the normal a.c. voltage drop across coil L_X, as indicated by E_Z. (This meter must measure a.c. only, so blocking condenser C_1 is placed in series with it.) Then the current meter I_{AC} is read. Dividing the voltage E_Z by the alternating current gives the impedance of the coil L_X. If the a.c. resistance of the coil is assumed negligible, the impedance will be approximately the same as the reactance of the coil, and the inductance can be found from the formula $L = X_L \div 6.28f$.

▶ However, most iron-core coils are low-Q devices, having large windings with appreciable a.c. resistance which cannot be ignored. To eliminate the large error introduced when assuming the impedance equals the resistance, the best way to measure the inductance of such coils is the three-voltage method already described. To use it, first insert a known resistance at point X, then adjust the d.c. to the proper value and measure: 1, the voltage E_S; 2, the voltage across the resistor at X; and 3, the voltage E_Z. You can then use exactly the same procedure followed for Fig. 4.

Condenser Capacity

We normally deal with three kinds of radio condensers; air-dielectric condensers (usually variable condensers), solid-dielectric condensers, and electrolytics.

The serviceman is interested primarily in the last two types. (Measurement of an air-dielectric condenser is almost never required in servicing, so we will cover this type later.) Next

to tubes, solid-dielectric and electrolytic condensers cause more troubles than any other parts. While ohmmeter measurements or part substitution will show up most of these defects, condenser measurements are required frequently enough so that test equipment manufacturers have brought out capacity testers for servicemen. These

will be described shortly, when we take up bridge circuits.

SOLID-DIELECTRIC CONDENSERS

Let us first see how to measure capacities of ordinary solid-dielectric by-pass condensers—paper, mica, ceramic, and similar types. The methods we will now discuss are satisfactory for capacities above .01 mfd.

Reactance Methods. Condenser capacity can be measured in almost
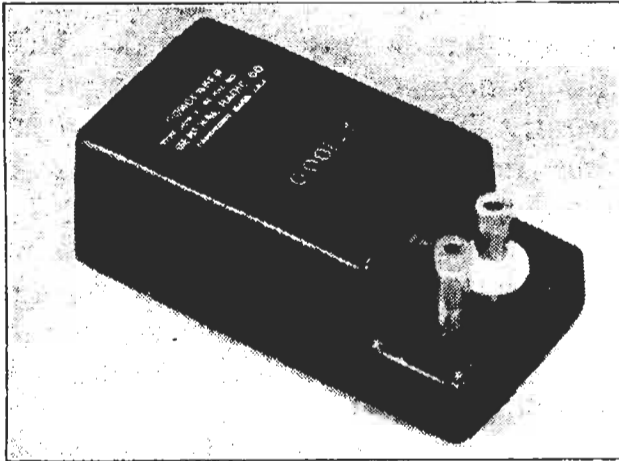
Courtesy General Radio

A standard fixed condenser, which has been accurately determined and sealed within a protective container.

exactly the same manner as coil inductance, by measuring the applied a.c. voltage and the current flow. It's a wise precaution to determine first whether the condenser is short-circuited, since the alternating current meter can be damaged by excess amounts of current. Also, be sure the applied a.c. voltage peak is well below the peak voltage rating of the condenser.

After measuring the a.c. voltage and current, you can find the impedance by dividing the voltage by the current. Since the a.c. resistance of the normal solid-dielectric condenser is negligible at low frequencies, you can say that the reactance equals the impedance and then use the formula for capaci-

tive reactance, $X_c = \dfrac{159,000}{fC}$ (where f is in cycles per second and C is in microfarads), to find the capacity. This is usually converted to the handier form $C = \dfrac{159,000}{fX_c}$, where X_c is the capacitive reactance in ohms.

As you know, the larger the condenser, the lower the reactance, hence the greater the current flow for a fixed voltage. This means it is possible to make a simple capacity meter with a basic circuit like that in Fig. 6. Using a fixed frequency and a fixed applied voltage, the current meter scale can be calibrated directly in terms of capacity. Shunts can be used to give different current ranges and extend the capacity range. However, the larger the condenser the lower the reactance, and hence, the higher the current. This means the condenser size range is limited by the current range and too large a condenser can cause the meter to be ruined by excess current. A shorted condenser used in this circuit will also ruin the meter. All condensers must first be checked with an ohmmeter to prevent such damage.

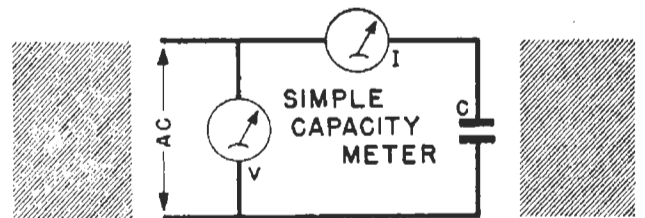▶ You can also measure condenser capacity with the comparison circuit

FIG. 6. Circuit for solid-dielectric condensers. They must be in good condition or the current meter can be ruined.

shown in Fig. 7, which requires a vacuum tube voltmeter and a condenser C_s of known capacity. You compare the voltages across the two condensers. As you know, the capacitive reactance increases as the capacity is decreased.

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Since the voltage drop depends on the reactance, this means the larger voltage drop will appear across the smaller condenser. In other words, the voltage across each condenser is inversely proportional to its capacity.

Therefore, you can say that the ratio of the voltage across the known condenser to that across the unknown condenser equals the ratio of the capacity of the unknown to that of the
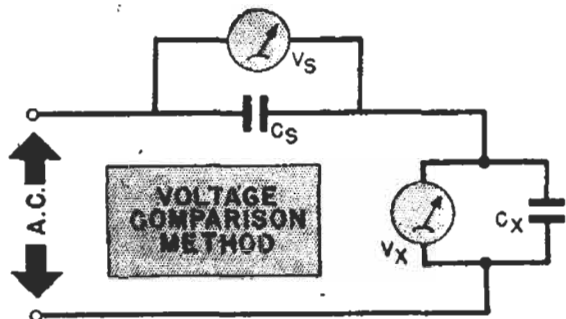

FIG. 7. The comparison method for condensers.

known condenser. Putting this in a formula, $\dfrac{V_s}{V_x} = \dfrac{C_x}{C_s}$ or $C_x = \dfrac{C_s V_s}{V_x}$. Thus, to find the capacity of the unknown condenser, multiply the capacity of the known condenser by the voltage across it, then divide this product by the voltage across the unknown condenser. The answer is the capacity of the unknown condenser in the same units as the known condenser (usually in microfarads).

If C_s is adjusted so the two voltages are equal, then the capacities are equal. Thus, if you use a calibrated variable condenser at C_s, you can make the voltages equal (so C_s equals C_x) and read the value of C_x directly from the calibration of C_s.

A vacuum tube voltmeter should be used for making measurements—unless the capacities are quite large and the test frequency is lower than 10 kc., when an ordinary copper-oxide rectifier type meter can be used. If the resistance of the meter is many times

higher than the reactance of the condensers, one meter will suffice. But if the meter has such low resistance that it may affect the results, two identical meters should be used.

ELECTROLYTIC CONDENSERS

The capacity of an electrolytic condenser should be measured with a d.c. voltage applied, because practically all electrolytics need a d.c. voltage to keep the film formed on the anode of the condenser. If an a.c. voltage of more than 3 or 4 volts is applied by itself, the condenser may be ruined. Also, the condenser power factor must usually be taken into consideration, since in electrolytics the series resistance is relatively high.

Fig. 8 shows a circuit for checking an electrolytic. The three-voltage method is used. As the voltmeters must read a.c. only, they are isolated by blocking condensers.

▶ First, adjust the d.c. voltage to equal some value higher than the peak of the a.c. to be applied. This value plus the applied a.c. peak value must be below the working voltage rating of the condenser. After waiting a
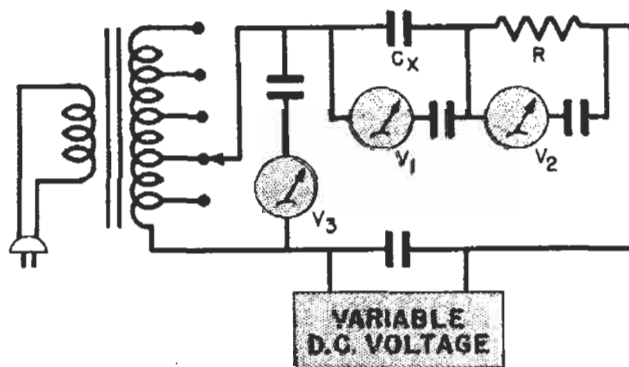

FIG. 8. The polarizing and testing circuit for electrolytics.

reasonable length of time for the d.c. to form the condenser, apply an a.c. voltage from the transformer. (This a.c. voltage must not exceed the d.c. voltage.) Now, measure voltages V_1, V_2 and V_3. Next, construct the triangle shown in Fig. 9 by the same

method used in Fig. *4*, using V_2 as the horizontal reference vector. Finally, drop a vertical line from the point *P* to form the line V_X, and extend the line V_2 to form V_R.

The line V_X represents the true voltage across the condenser reactance. Measure the length of this line, convert it into volts, and divide the voltage thus found by the actual current
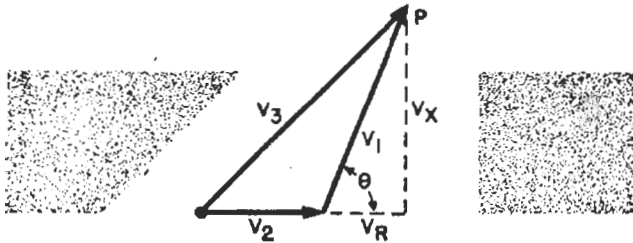

FIG. 9. The three-voltage triangle for electrolytics.

flow in the circuit (which is equal to voltage V_2 divided by R in ohms). The result is the condenser reactance, which you can readily convert to capacity by using the reactance formula.

Power Factor. The power factor is found by dividing the resistance of a part by its impedance. This result is multiplied by 100 to express the power factor as a percentage.

A resistor has a power factor of 1, or 100%, because the resistance is equal to the impedance. On the other hand, a perfect coil or a perfect condenser should have zero resistance and thus zero power factor. Therefore, a coil or condenser with high power factor has considerable series resistance, and so will not act as much like a perfect inductance or perfect capacitance as will a similar device with a lower power factor.

After having made the triangles shown in Fig. *9*, you can determine the power factor of the condenser by measuring the line V_R (which represents the voltage drop across the condenser resistance), then dividing this amount by the voltage V_1. Multiply by 100 to give the power factor as a percentage. The smaller the power factor, of course, the better the condenser. Measured on 60-cycle a.c., a good electrolytic should have a power factor of about 6%. If the percentage is above 25% or 30%, you should replace the condenser.

▶ Another point of interest is the Q of the condenser. The larger the Q factor, the better the condenser. This factor may be obtained by dividing the value of V_X by the value of V_R. If angle θ is close to 90°, the Q factor is approximately equal to one, divided by the power factor.

▶ The circuit in Fig. *8* can be used also to measure the capacity of solid-dielectric condensers. To do so, short-circuit the d.c. power pack terminals and make measurements with a.c. only.

Resonance Methods of Measuring L and C

While most of the circuits discussed so far are satisfactory for measuring power supply and audio components, they are not always usable or reliable at radio frequencies. Resonant circuits are usually better for r.f. measurements, both because they will measure small inductances and capacities accurately, and because these measurements can be made regardless of the a.c. resistance or distributed capacity of the device.

In general, to make a resonant circuit measurement, you insert the inductance or capacity to be measured in a circuit which you tune to resonance. Then, since you know the values of the other circuit components,

the value of the inductance or capacity under test may be easily determined. Either a series or a parallel resonant test circuit may be used. In a series resonant circuit, a maximum current flow through the circuit or a maximum voltage across one of the parts will show when you reach resonance. In a parallel resonant circuit, a maximum voltage across the circuit, maximum circulating current, or minimum line current will all indicate resonance.

▶ To set up one of these measuring circuits, you need: a signal source capable of delivering about 5 watts of power, with a calibrated frequency output; some means of making measurements at radio frequencies (such as a thermocouple ammeter or an r.f. type vacuum tube voltmeter); and either a calibrated precision condenser or a known inductance. For resistance measurements, a variable resistor calibrated for r.f. will be necessary.

Fig. 10 shows two typical circuits. In Fig. 10A, you know you have reached resonance when the circulating current (measured by the thermo-

couple type meter) is at a maximum. The indicator in Fig. 10B is a v.t.v.m. which will show a maximum voltage across the condenser at resonance.

In both circuits, the coupling to the oscillator is adjusted to the minimum value which will give a reasonable meter reading. Very frequently an electrostatic shield S (shown by dotted lines) is used between the link coil and the coil in the resonant circuit to eliminate capacity coupling effects.

CAPACITY MEASUREMENTS

Suppose coil L is a known inductance. You can then measure capacity by inserting the unknown condenser in place of condenser C_s and adjusting the frequency of the oscillator until resonance is indicated by a maximum meter reading. The resistor R should be adjusted to zero resistance if the circuit in Fig. 10A is used.

Knowing the frequency and the inductance, you can determine the condenser capacity from the fact that, at resonance, the capacitive reactance equals the inductive reactance. This gives you a formula $C = \dfrac{25,330}{f^2 L}$ (where C is the unknown capacity in microfarads, f is the frequency in kilocycles, and L is the inductance in microhenries) from which you can calculate the unknown capacity.

In this method the a.c. resistance has no effect (because you use a reactance balance, not an impedance balance), and the accuracy depends entirely upon the accuracy with which the inductance and frequency are known. Even the meter accuracy does not matter, since you use it only to indicate a maximum. However, in Fig. 10B, the input capacity of the v.t.v.m. is included in the calculated value. This capacity is small in a well-de-
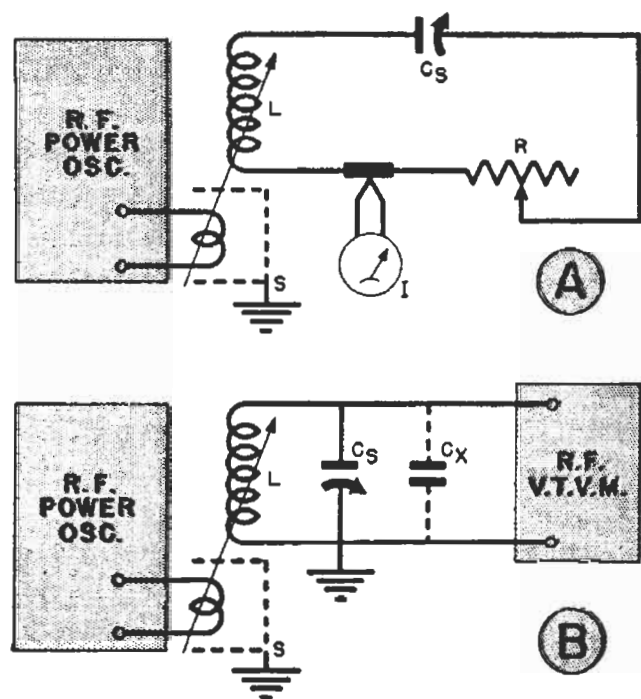

FIG. 10. Resonance methods for measuring inductance and capacity.

signed unit, but the measurement is in error by this amount. When doubtful about this capacity, Fig. *10A* should be used if possible.

▶ If you have a calibrated condenser instead of a known inductance, you can use any coil which will give resonance and find the unknown capacity by a substitution method, provided the unknown capacity is within the range of the known capacity. First, put the unknown condenser in place of C_s and
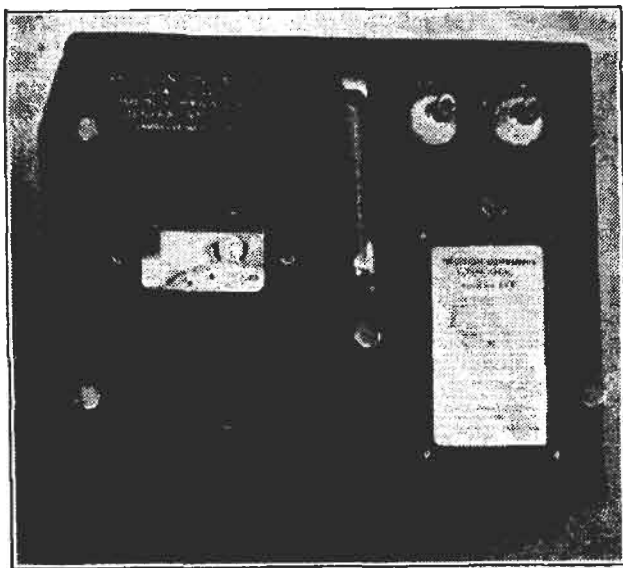
Courtesy General Radio
The front panel of a standard variable condenser.

adjust the frequency of the oscillator until resonance is indicated. Then replace the unknown condenser with the standard calibrated condenser and adjust the latter until resonance is again indicated, using the same coil and the same frequency. The capacity of the unknown condenser can now be read directly from the scale of the calibrated condenser. We do not need to know the frequency nor the inductance value and make no calculation. Even the v.t.v.m. input capacity will not matter, as it will be present in both cases so the standard condenser has exactly the capacity of the unknown. Only the accuracy of the standard condenser determines the accuracy of the result, so this method can be very precise.

▶ Another method of using a calibrated condenser is particularly valuable where the unknown condenser is very small. Leave the calibrated condenser in the circuit and adjust the frequency of the oscillator so that resonance will be obtained with nearly maximum capacity of C_s. Call this C_s value C_1. Next, shunt condenser C_s with the unknown capacity C_x, as in Fig. *10B*. This increases the capacity of the circuit, so reduce the value of C_s until resonance is again obtained with the same frequency. Call this value C_2, and find the value of the unknown condenser C_x by subtracting C_2 from C_1. In other words, the capacity of the unknown condenser is equal to the difference in the two values of the standard condenser. If a vernier (a geared tuning arrangement or a calibrated trimmer) is used on the standard condenser C_s, you can measure values as low as 2 micro-microfarads accurately by this method.

INDUCTANCE MEASUREMENTS

Either of the circuits in Fig. *10* can be used to measure inductance if you use a standard condenser and set resistor R at zero. The unknown coil is used as the inductance L. Bring the circuit to resonance, either by using a fixed capacity C_s and varying the oscillator frequency, or by leaving the oscillator frequency fixed and varying C_s, then calculate the inductance from the formula: $L = \dfrac{25,330}{f^2 C}$ (where L is in microhenries, frequency is in kilocycles and C is in microfarads).

Since the oscillator link coupling may affect the inductance somewhat, weak coupling should be used. You can easily tell when the coupling is too tight, because you will get a double resonant hump (two maximum peaks) rather than a single sharp peak indica-

tion on your meter. Again, the a.c. resistance has no effect; the accuracy of the measurement depends only on the accuracy with which the capacity and the frequency are known.

COIL A.C. RESISTANCE

Almost always, the a.c. resistance in a tuned circuit will be in the coil. You can neglect the resistance in the average tuning condenser.

You can use the circuit shown in Fig. *10A* to measure the coil resistance. First, set resistor R to zero, bring the circuit to resonance and note the current reading on the meter. Then adjust resistor R to a value which reduces the current meter reading to one-half its first reading. This value of R is equal to the a.c. resistance of the coil.

You can easily see why. At resonance, the coil inductive reactance and the capacitive reactance cancel each other, and the circuit current is determined only by the source voltage and the a.c. resistance. When resistor R is increased to a value which cuts the current in half, the resistance in the circuit must have doubled, because you have not changed the source voltage. Therefore, this value of resistor R is equal to the a.c. resistance of the coil. Of course, this method requires that resistor R be variable and be calibrated at the frequency used in making the measurement.

If a variable resistor is not available, then a slight change in the method will allow you to use a fixed resistor to measure the coil resistance. To do so, first measure the current flow with the resistance out of the circuit. Call this I_1. Then, insert a fixed resistor R in the circuit, remeasure the current and call the new reading I_2. The a.c. resistance of the

$$\text{coil} = \frac{I_2 R}{I_1 - I_2}.$$

The fixed resistor should have a value reasonably close to the expected coil resistance, which may range from a fraction of an ohm to 10 or 15 ohms. If it is too large, I_2 will become a very small reading, difficult to accurately determine on the meter scale.

COIL Q FACTOR

As you know, the Q factor of the coil is equal to its reactance divided by its a.c. resistance. If you know the inductance, you can compute the reactance $(X_L = 6.28fL)$, find the resistance by one of the methods just described and so find the Q of the coil at that particular frequency.

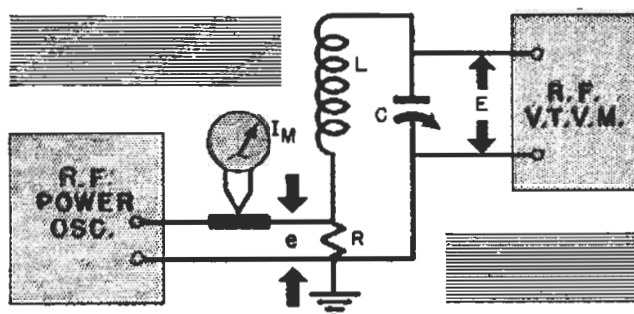You can also find the Q of the coil with the circuit shown in Fig. *11*. You

FIG. 11. A circuit for determining Q.

do not need to know the inductance or resistance of the coil, nor do you need a calibrated condenser. This circuit works on the basic principle of resonant voltage step-up, making use of the fact that, at resonance, the voltage across the condenser or the coil equals Q times the source voltage. Thus, you can divide the voltage across the condenser by the source voltage and obtain the Q of the circuit—which is the coil Q when the resistance is all in the coil.

You can easily measure the voltage across the condenser with an r.f. vacuum tube voltmeter, but measuring the source voltage in the resonant circuit is more difficult. The best way is to insert a known small resistance in the resonant circuit and use the voltage

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drop across it as the source voltage (Fig. *11*). Resistor R has very low resistance (a fraction of an ohm) which is only a fraction of the expected coil resistance value. By measuring the current flow from the oscillator through R with the meter I_M, you can find e, which equals $I_M \times R$.

Tune the circuit to a maximum reading on the v.t.v.m., divide this voltage by e, and you have the Q of the circuit. While this does not give the a.c. resistance or coil reactance, it does give you a way to compare coils for merit. If

Interior construction of a standard variable condenser.

you know either the reactance or the r.f. resistance, you can find the other from $Q = \dfrac{X_L}{R}$. Of course, the circuit

resistance found from this formula includes the resistance of R, but this is usually small enough to neglect. If you wish to be very accurate, you can subtract it from the total resistance found.

▶ Of course, the reactance and a.c. resistance both vary with frequency, so the Q found holds good only near the frequency used. If the Q at some other frequency (or over a band of frequencies) is required, then you will have to tune the oscillator to these other frequencies, retune for resonance, and divide the new value of E by the new e to get the Q at these points.

DISTRIBUTED CAPACITY

Occasionally you may want to know the distributed capacity between the turns of a coil. You can measure this with either of the circuits in Fig. *10*. First, tune the circuit to resonance at some frequency which uses near maximum capacity of condenser C_S. Call this capacity C_1. Now, without changing the r.f. oscillator frequency setting, adjust C_S to tune the circuit to the second harmonic of the oscillator. Record this value of C_S (which will be about one-quarter the first value) as C_2. The distributed capacity of the coil, C_0, equals $\dfrac{C_1 - 4C_2}{3}$.

Bridge Measurements

The bridge circuit is the most widely used means of measuring inductance and capacity values. It has the advantage of being a ratio device, so that the values of parts far different from the standard can be checked. Just a few standard parts permit a very wide range of measurement. Let's see how these circuits work.

THE WHEATSTONE BRIDGE

You have met the basic bridge circuit in other lessons. Essentially, it is a connection of four resistors, with a voltage supplied to two terminals and a meter between the other two terminals, as in Fig. *12*. To see how the circuit works, let us presume that R_X is an unknown resistor, and that R_8 is adjusted until a value is found which makes the meter read zero.

The fact that the meter reads zero means that points *B* and *C* are at the same potential. Tracing the circuit, you will see that this means the voltage drop across R_1 equals that across R_8, and the drop across R_X equals that across R_2. In other words, assuming that a current I_1 flows through resistors R_1 and R_2, and that another current I_2 flows through R_8 and R_X, the circuit is so adjusted that:

$$R_X \times I_2 = R_2 \times I_1$$

and

$$R_8 \times I_2 = R_1 \times I_1$$

If you divide the upper equation by the lower equation, the currents will cancel and you will have:

$$\frac{R_X}{R_8} = \frac{R_2}{R_1}$$

This says that the ratio of R_X to R_3 is the same as the ratio of R_2 to R_1. Carrying this a step further, you have:

$$R_X = \frac{R_2}{R_1} \times R_8$$

This is a very important equation. It shows that if you make R_1 equal to R_2, then R_X will be equal to the value of R_8 which will bring the bridge into balance (give zero meter reading). But if R_1 and R_2 are not equal, this equation further shows that R_X will be equal to the *ratio* of R_2 to R_1, multiplied by the value of R_8 which balances the bridge. This means that even if resistor R_8 has only a limited range of variation, you can still measure an unknown resistor R_X of almost any value merely by choosing the proper ratio between resistors R_1 and R_2. This, of course, gives you a highly flexible measuring circuit.

In practical bridge circuits, resistors R_1 and R_2 are made so that they can
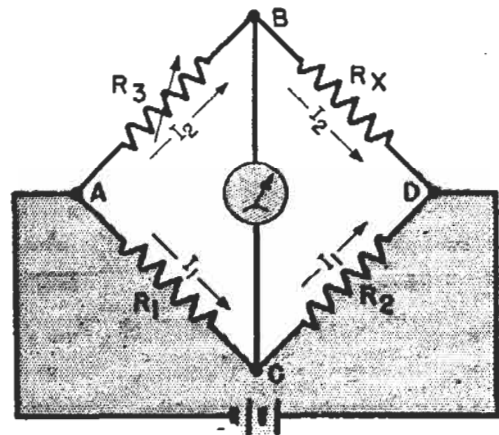

FIG. 12. The basic Wheatstone resistance bridge.

be varied in decimal ratios to each other—such as 1 to 1, 1 to 10, 1 to 100, 1 to 1000, or 1000 to 1, 100 to 1, or 10 to 1. Usually, R_1 is an accurate fixed resistor, and R_2 a series of fixed resistors arranged with a switch so the ratio can be varied in steps. Then the only continuously variable resistor will be R_3, and even for this, fixed resistors in a decade box arrangement may be used.
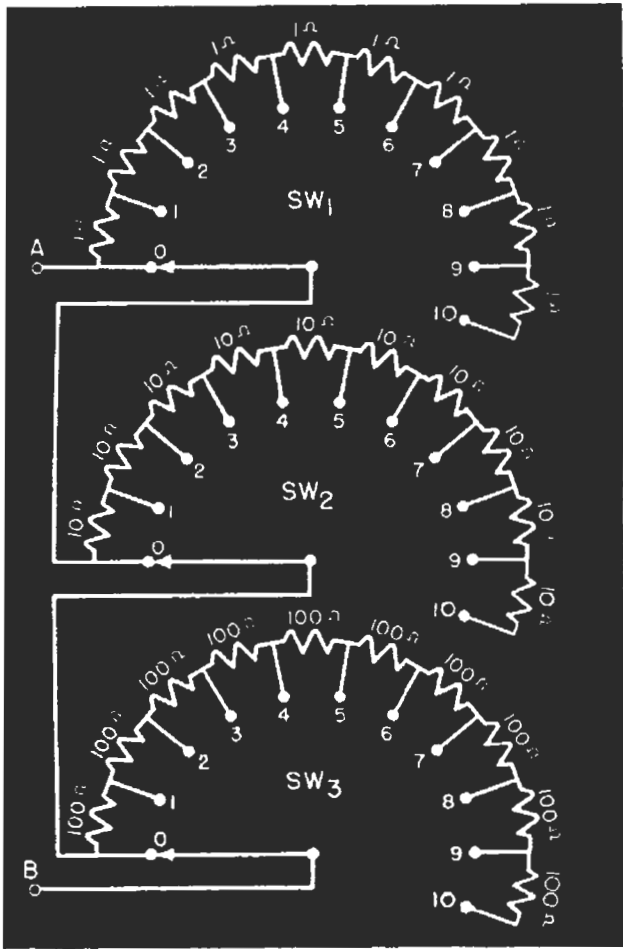
FIG. 13. A decade box.

The values of the resistances need not be 1, 10 and 100 ohms each; they can be small fractions of an ohm or much larger values, depending on the design of the decade box.

▶ In using a bridge, the ratio of $R_2 \div R_1$ is adjusted to a likely value (R_X may or may not be approximately known) and R_3 is adjusted to make the meter read zero. If the bridge cannot be made to balance, other ratios are tried until the zero reading is found. Then the value of R_X is the $R_2 \div R_1$ ratio multiplied by R_3.

▶ Of course, the meter will read until the bridge is balanced. Since the amount of meter current depends on the amount of unbalance, it may be large if the bridge is far from balance. Further, the direction of current flow through the meter depends on whether the unknown is larger or smaller than the ratio times R_3.

In order to let the meter pointer swing in either direction, the meter springs are adjusted so zero is in the center of the scale. By noting which way the meter deflects, you can tell what adjustment is needed to balance the bridge. Thus, a deflection to the left may mean an increase in R_3 is needed for a balance, while a deflection to the right may mean R_3 should be decreased. It may be the other
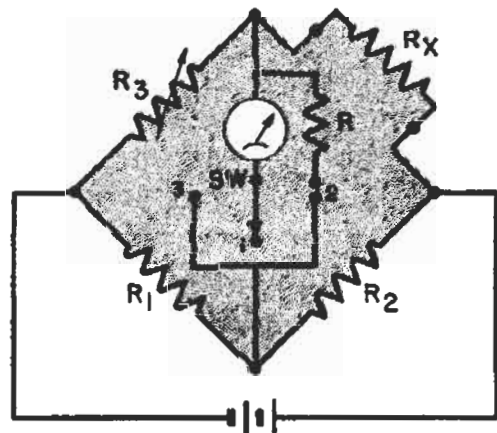
▶ As shown schematically in Fig. *13*, a decade resistance box is a series of accurate resistances connected to contacts. Various resistances can be obtained by switching to various contacts. The name comes from the fact that each switch section has ten contacts, so there are ten steps (decade means a group of ten) in each section.

With the particular arrangement shown, any resistance between 0 ohms and 1110 ohms can be obtained in 1-ohm steps. (The switches are shown set in the 0 ohm position.) If, for example, switch SW_1 is moved over to contact *4*, there will be 4 ohms resistance between terminal *A* and terminal *B*. If SW_2 is then set to contact *6*, 60 ohms will be added to the 4 ohms and you will have 64 ohms. If SW_3 is moved to contact *8*, 800 ohms will be added in the circuit; you would then have a total of 864 ohms, etc.

FIG. 14. For meter protection, switch position 2 is used until the bridge is nearly balanced.

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way around, depending on how the battery is connected to the bridge terminals.

To prevent ruining the meter with excess currents, a switch like *SW* in Fig. *14* is usually used. This is a three-position switch that can be thrown to the right or the left from its normal resting position. Position *1* is the normal position and opens the meter circuit. (A spring returns the switch to this position when it is not held in one
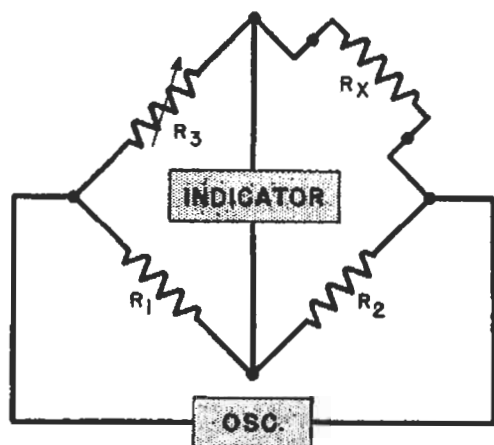

FIG. 15. This basic a.c. bridge is just like the d.c. bridge except for a change in the voltage source and the indicator.

of the other positions by the operator.) In making readings, the switch is first thrown to position *2*, closing the meter circuit and connecting a shunt across the meter at the same time. This makes the meter insensitive and protects it from excess current. The bridge is adjusted until the meter shows little or no deflection, then the switch is moved to position *3*, which places the sensitive meter directly in the circuit, and a final balance is found.

Until the bridge is almost balanced, the switch is closed only long enough to see whether the meter pointer moves rapidly away from zero. Then, as the balance point is neared, the current drops so that a reading can be taken safely. Even so, the switch is allowed to return to position *1* while any adjustment is made.

A. C. BRIDGES

It is not necessary to use a d.c. power supply with a bridge. You can use an a.c., a.f. or r.f. voltage if you wish— but you must use an indicating device suitable for the kind of voltage used. For an audio voltage, an a.c. meter or a pair of headphones may be used, connected in the position shown in Fig. *15*. Balance will be shown by a zero meter reading or minimum sound in the phones. R.F. voltages require a v.t.v.m. as the indicator.

Generally speaking, an a.c. bridge is more useful than a d.c. bridge, for we can measure coils and condensers as well as resistors with it. The a.c. bridge comes to balance when the *impedances* of the arms are in the proper ratios.

You might think that you have to use coils in all four arms of the bridge to obtain an inductance balance, and capacities in all arms for a capacity balance. The fact is, the ratio arms R_1 and R_2 can be resistances as long as they do not have appreciable inductance or capacity. Then a standard inductance can be used in place of R_3 for inductance measurements, or a
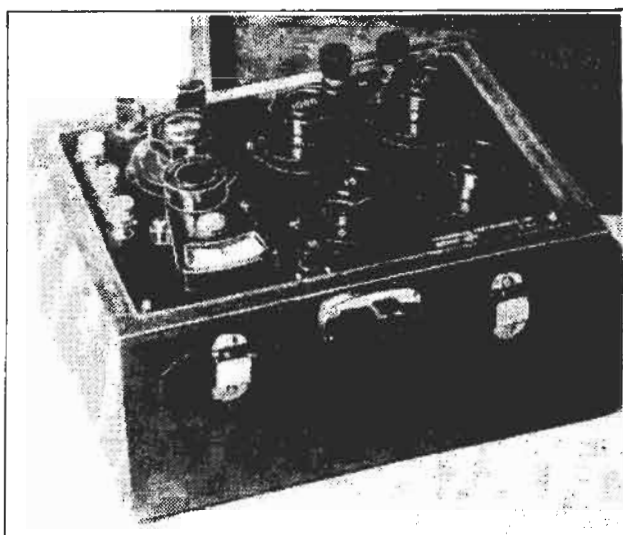
Courtesy Industrial Instruments Co.

A typical bridge, having a built-in decade box. The decade can be used separately, if desired, as it is connected to a pair of terminals on the panel.

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standard capacity in place of R_3 for capacity measurements.

Capacity Bridge. The bridge for capacity measurements shown in Fig. *16A* looks just like the resistance bridge of Fig. *15* except for the substitution of the two condensers. This bridge will balance when the impedances of the condensers have the relationship $Z_{CX} = \dfrac{R_2}{R_1} \times Z_{CS}$.

We can find the capacity of C_X if we assume that the impedance of a condenser is approximately the same as its reactance (for air- or solid-dielectric types the resistance is negligible) and remember that the reactance is inversely proportional to the capacity,

$$(X_C = \frac{1}{6.28fC}).$$

Substituting this relationship in the above formula and simplifying, you get $C_X = \dfrac{R_1}{R_2} \times C_S$. Notice that this capacity formula has *just the opposite ratio of resistances* from the formula used with the resistance bridge.

Inductance Bridge. On the other hand, you should use the *same* resistance ratio for the inductance bridge (Fig. *16B*) as for a resistance bridge, because inductive reactance is proportional to inductance. The formula for this bridge is: $L_X = \dfrac{R_2}{R_1} \times L_S$.

Fixed Standards. In the circuits shown in Fig. *16*, the standard parts are variable. Each circuit is used just like a resistance bridge, with ratio arm adjustments made if the range of the variable is not great enough to balance the bridge. Often, however, variable standards are not available. If they are not, fixed coils or condensers can

be used as L_S or C_S and the ratio arms can be adjusted to balance the bridge. When this method is used, R_2 should be a continuously variable resistor rather than a step or decade box type.

While theoretically you need only one fixed standard part for this bridge, in practice you will find a fine balance cannot be easily obtained, and the bridge becomes inaccurate if the ratio between R_1 and R_2 becomes very large. Therefore, it is usually best to have several fixed standard parts available and use the one which gives a balance most nearly in the ratio of 1 to 1. If the value of the unknown part cannot be guessed, use a fixed part of any
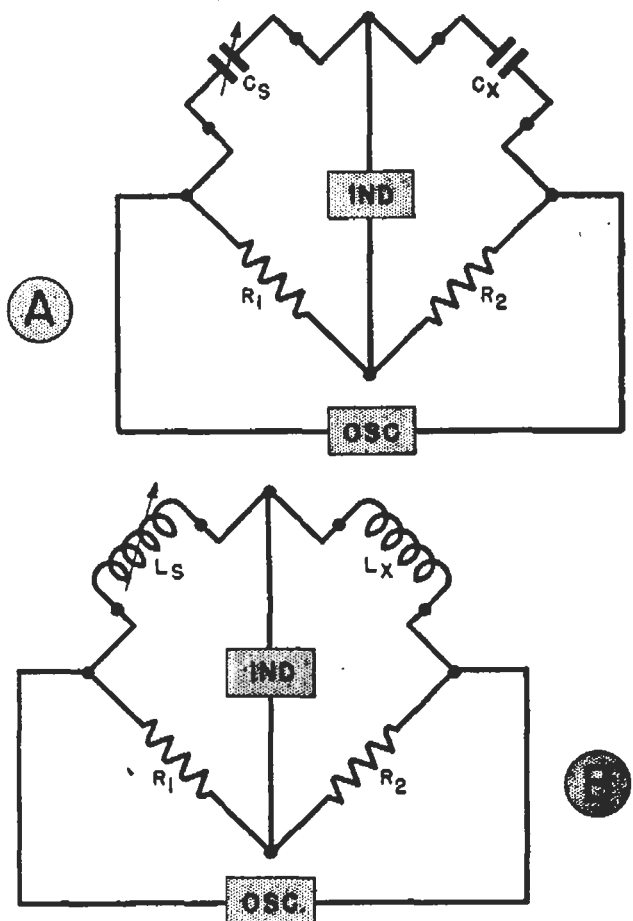

FIG. 16. The bridge at A is a capacity bridge, while B shows an inductance bridge.

value and determine the approximate ratio. Then use a smaller or larger part to bring the ratio down to a point where a fine balance may be easily obtained.

The fact that a fixed inductance or

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capacity can be used in the bridge makes the instrument very practical. Fixed standards are comparatively cheap and readily available. For ordinary service work, readily obtainable parts of 2% to 5% tolerance may be entirely adequate for checking the radio parts—which often have tolerances as high as 20%.

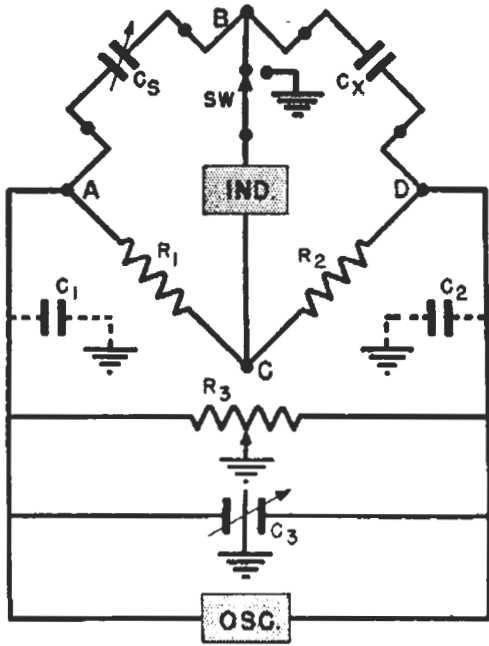**Wagner Ground.** When you measure high-impedance parts (small-

FIG. 17. Balancing to ground to eliminate body capacity effects.

capacity condensers or high-inductance coils), particularly at high frequencies, you may find that body capacity unbalances the bridge. For example, putting on the phones used as an indicator—or even bringing your hand close to the bridge—may change your readings. Grounding the bridge directly would solve this difficulty, but would also present us with another one just as bad, for the stray capacities C_1 and C_2 shown in Fig. 17 would then shunt the ratio arms and would themselves determine the ratio setting.

The best solution is to balance the entire bridge with respect to ground. One way to do so is to use a system known as a Wagner ground, shown in

Fig. 17. A low-resistance potentiometer R_3 is connected across the bridge and the variable arm is grounded. As you see, this puts a low-resistance shunt across C_1 and C_2. To operate a bridge using this ground, first balance the bridge in the usual manner as well as possible. Then, throw switch SW to the ground position and adjust R_3 to give a minimum indication. (Notice that grounding one terminal of the indicator through switch SW makes another bridge of R_1, R_2 and the two sections of R_3, as this connects the indicator between C and ground, and through the ground to the arm of R_3.)

The bridge is balanced with respect to ground when a minimum indication is obtained. You should then throw the switch back to its normal position and readjust the bridge to give a minimum indication. If necessary, repeat this process until further adjustments cause no upset of the bridge.

▶ Since the trouble is caused by capacity to ground, the resistance of R_3
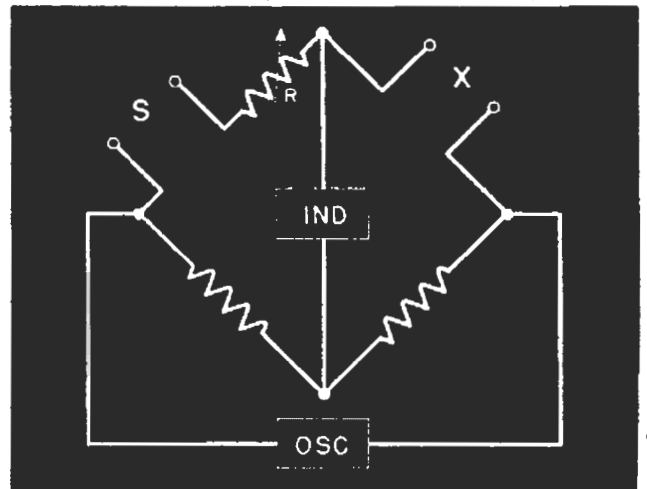

FIG. 18. Using R permits the bridge to be balanced for the resistance of the unknown part while its reactance is balanced by that of the standard part. This gives a direct measure of the a.c. resistance of the unknown part and permits the calculation of the Q.

may be too high to permit a fine balance at the higher radio frequencies. For high-frequency work, some bridges use the split stator condenser C_s shown
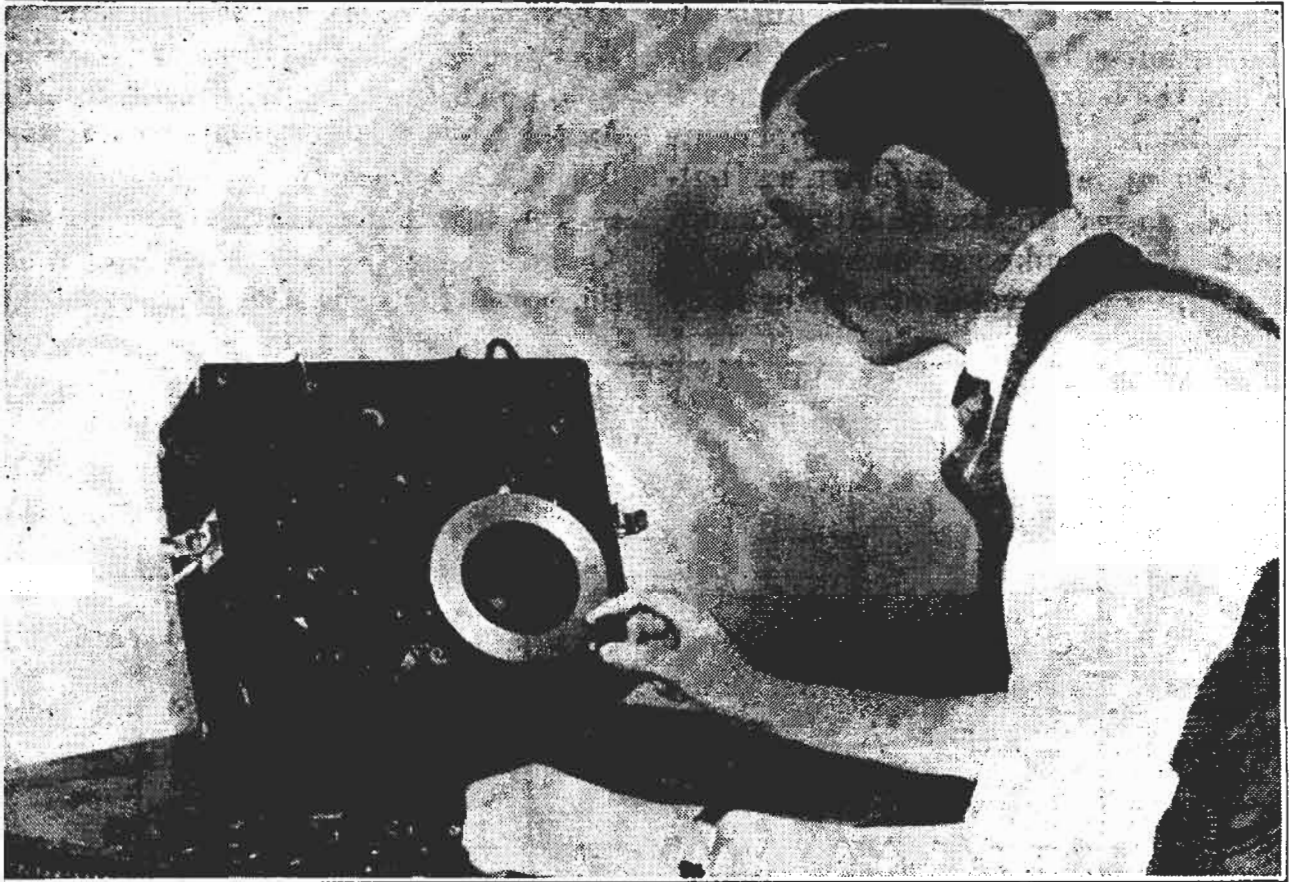
Using a capacity bridge of the type having a tuning eye indicator. This bridge will measure the power factor as well as the capacity.

in Fig. *17*. This is a condenser with two stator sections and a single common rotor section; as the condenser is rotated, the capacity of one section increases while that of the other decreases. Its capacity can thus be varied to make the capacitive reactance between A and ground and that between D and ground have the same ratio as the $R_1 \div R_2$ ratio, thus balancing the bridge with respect to ground. The balancing procedure is exactly like that used with the Wagner ground—except, of course, you vary C_3 instead of R_3.

IMPROVED BRIDGE CIRCUITS

The basic bridge we have discussed so far is excellent if you can neglect resistance in the coil or in the condenser being checked and the resistance in your standard. But a zero current indication can be obtained only if the *impedances* of the arms are exactly equal; if the unknown has appreciable resistance as well as reactance, you can get a *minimum indication* but not a true *zero indication*. Also, this causes some error in adjusting the bridge. However, a rather simple means can be used to get a true null (zero) balance and, at the same time, determine the Q factor of the coil or condenser.

Usually the standard coil or condenser is chosen to have very low resistance, so if a resistance unbalance exists, it will usually be the fault of the unknown coil or condenser. As shown in Fig. *18*, you need only add resistance in series with the standard coil or condenser to bring the bridge back into balance. To use this circuit, insert the coil or condenser standard and the unknown as indicated, and adjust the standard or the ratio arms to give a minimum indication. Then, adjust R for a further reduction. Repeat the

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standard and R adjustments until the indication cannot be reduced further. When the *least possible* signal is heard or indicated, the reactive components of the standard and unknown are balanced, and so are the resistive components of the unknown and resistor R. Multiplying the value of resistor R by

$$X_c = \frac{1}{6.28fC}, \text{ so } Q_c = \frac{X_c}{R} = \frac{1}{6.28fCR}.$$

As the power factor is approximately $\dfrac{1}{Q}$ — for low power factor condensers, the power factor is $6.28\,fCR$.
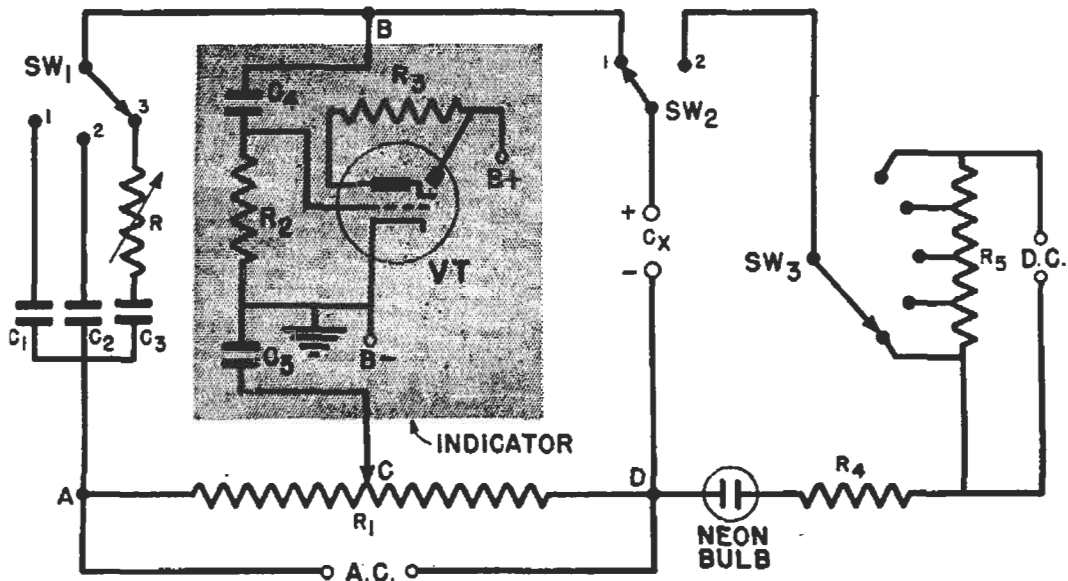
FIG. 19. A simplified diagram of a typical capacity bridge of the type made for radio servicemen. The bridge "corners" are A, B, C and D. Condensers C_1, C_2 and C_3 are the standard parts, selected by SW_1. Resistor R_1 makes up the A-C and C-D legs of the bridge. When it is varied, it adds resistance in one leg and takes it out of the other at the same time. Condensers C_4 and C_5 are just blocking condensers to isolate the indicator, which is a magic eye tube VT operating from the voltage across R_2. An adjustable d.c. supply is at the right, for leakage tests. To use, the unknown condenser is connected to C_x and SW_2 is thrown to the right to apply the rated d.c. from SW_3. The neon bulb will flash or glow, the rate of flash depending on the leakage. Assuming a satisfactory leakage value (and no short-circuit causing a continuous glow), SW_2 is thrown to the left, SW_1 is set to use the proper standard, and R_1 is adjusted for a maximum closure of the eye indicator, indicating a minimum voltage across R_2. Should the adjustment of R_1 approach but not pass through a balance when moved all the way to the A end, the wrong standard is selected by SW_1 or the C_x condenser is open. The same indication at the D end shows the wrong standard or a shorted C_x. When checking large condensers, the SW_1 setting including R in the circuit is used, and R is adjusted for further closure of the eye. This resistor is calibrated to show the power factor directly.

the bridge ratio will give the amount of resistance in the unknown part.

Thus, you can determine the capacity or inductance and the a.c. resistance of the unknown part at the same time. If you want to find the Q factor of an inductance, find the inductive reactance from the formula $X_L = 6.28fL$, then divide this reactance by the resistance. Similarly, you can find the Q of a condenser by dividing the reactance by the a.c. resistance. However, the reactance of the condenser is

► The circuit shown in Fig. *18* is the basis for several capacity bridges designed for radio servicemen. A typical instrument is shown in Fig. *19*. By calibrating R in terms of power factor and inserting a d.c. power supply to polarize electrolytic condensers, a bridge of this kind can be used to measure capacities, leakage and power factor for condensers ranging from the smallest air and mica types up through large electrolytic condensers. The capacity and power factor are in-

dicated directly on a calibrated scale.

Comparing L with C. In the basic bridges covered so far, coils have been compared with coils and condensers with condensers. There are many variations of these bridges, found mostly in laboratories. Some have resonant circuits in their arms while others are designed for certain special purposes.

Another type, which balances a condenser against a coil, is very useful. A basic form of this bridge, using a standard condenser (which is more likely to be available than a standard coil) is shown in Fig. *20*. Since the

R_X. The a.c. resistance of the coil is found from the formula

$$R_X = \frac{C_1}{C_2} \times R_3,$$

while the inductance is found by the formula in the preceding paragraph.

This bridge is easily converted into a standard capacity bridge, so it can be used to check both inductance and capacity, using only a standard condenser.

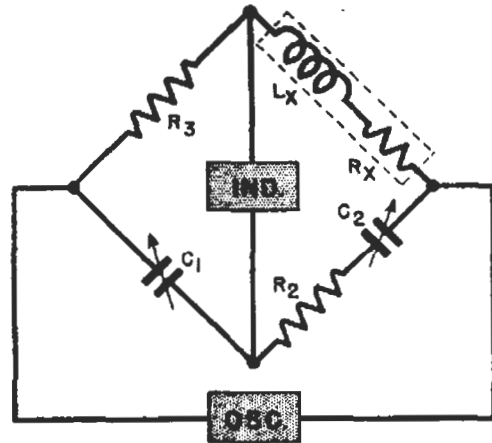**Bridge Limitations.** Most a.c. bridges work over a limited audio to low r.f. range. If the frequency is

FIG. 20. This bridge balances a capacity against an inductance.

FIG. 21. The Owen bridge.

capacitive reactance is opposite in phase to the coil reactance, the balancing condenser must be in the position shown. The value of

$$L_X = R_2 R_3 C_1.$$

Fig. *21* shows the Owen bridge, a more common form of this circuit, which also takes the a.c. resistance of the coil into account. The capacity C_2 is used to balance the coil resistance

increased, complete shielding of each element becomes necessary, and many precautions must be observed, to prevent stray fields and coupling between parts from upsetting results. Although high-frequency r.f. bridges are available, they are costly and are found only in large laboratories. For ordinary purposes, the resonance method is usually used when very high frequencies are involved.

Frequency Measurements

The number of times an event repeats itself within a specified length of time is its frequency—usually measured in cycles per second. Therefore, the first requirement for accurate measurement of frequency is a highly accurate way to tell time. The fundamental unit of time is determined by the rotation of the earth. By observing the positions of certain stars, astronomers determine this period very exactly. From these observations extremely accurate standard clocks are calibrated. Now if you were to operate an oscillator in such a way that an electric clock is driven from its output, you could compare the time kept by the electric clock with that kept by a standard clock and have a very precise way to measure both the frequency of the oscillator and its ability to maintain that frequency. You could then use the oscillator output as a standard of frequency.

Primary standards of frequency of this kind are found in the National Bureau of Standards and other large laboratories. They are crystal oscillators, because this type has the great-
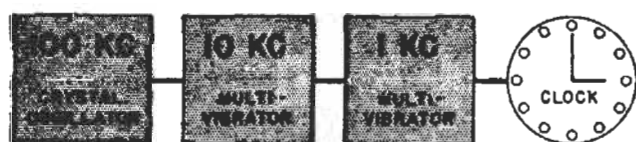

FIG. 22. How an electric clock is run from a crystal oscillator.

est frequency stability, and are kept at constant temperatures to make them as stable as possible.

Usually these oscillators produce frequencies of 50 or 100 kilocycles. Either frequency is too high to drive an ordinary clock, so it is stepped down by a chain of multivibrators. (The multivibrator is a circuit which

can produce an accurate fraction of a frequency fed into it.) Fig. 22 shows how the crystal oscillator is used to drive a chain of multivibrators which finally produces a signal capable of driving a clock. The clock used follows frequency exactly, so comparing its time with that of a standard clock shows us the frequency of the crystal oscillator and also indicates any variations in this frequency. By making adjustments to keep the clocks together, the output of the oscillator can be used as a frequency standard.

The Multivibrator. This interesting circuit does not "vibrate"—it is
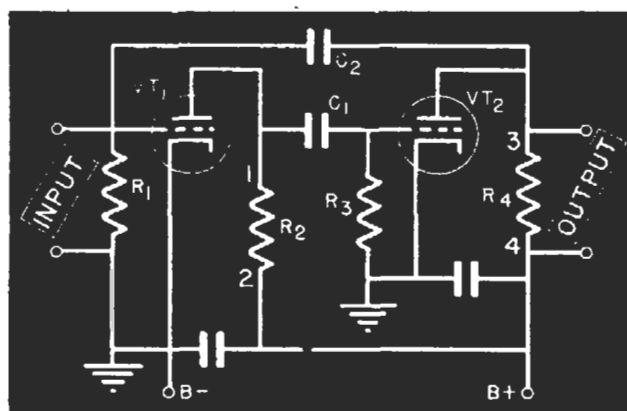

FIG. 23. A multivibrator is a resistance-coupled amplifier which can oscillate.

an oscillator consisting of a two-stage resistance-coupled amplifier like that shown in Fig. 23. Notice that condenser C_2 provides a feedback path from the plate circuit of the tube VT_2 to the grid circuit of tube VT_1. Each tube reverses phase by 180° so two tubes produce a 360° reversal. This means the voltage across R_4 is back in phase with the input of VT_1, so this feedback path allows the circuit to oscillate.

▶ By inserting a bias, we can make one tube draw slightly more plate current than the other when the circuit is first turned on. For this explanation,

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we will assume that VT_1 draws more current than VT_2. The initial rush of current through R_2 produces a voltage pulse across it, with a polarity such that the end of R_2 marked *1* is negative. This pulse passes through C_1 and is developed across R_3, driving the grid of VT_2 negative and so cutting off its plate current. This causes a rapid decrease in the voltage drop across R_4; you can consider this decrease to be a voltage pulse with a polarity such that the end of R_4 marked *3* is less negative (more positive than normal). This pulse, in turn, passes through the coupling condenser C_2 and is developed across R_1, making the grid of VT_1 positive and so increasing its plate current.

The plate current of VT_1 increases until the tube becomes saturated. When this occurs, the current becomes constant, and so does the voltage drop across R_2. In other words, there is no longer a voltage pulse across R_2 and, naturally, no pulse voltage developed across R_3. With the disappearance of the pulse voltage across R_3, the grid of VT_2 is able to go back to its initial bias. (This does not happen instantaneously, however, because C_1 has been charged and must discharge through R_3 before the grid of VT_2 can reach its original bias; this discharge, of course, takes a little time.)

As the grid of VT_2 approaches its initial bias, plate current again starts to flow through the tube. This increasing current creates another voltage pulse across R_4. Because the current is increasing, this time the pulse has a polarity such that the end of the resistor marked *3* is negative. This pulse, passing through C_2, drives the grid of VT_1 negative, and stops the flow of plate current through the tube. This causes a voltage pulse across R_2, with a polarity such that

point *1* is more positive; passing through C_1, this pulse makes the grid of VT_2 positive, and the current through VT_2 increases.

Now it is the turn of the current through VT_2 to increase until saturation is reached. When the tube does saturate, VT_1 is able to pick up again, while VT_2 shuts off. This process is repeated over and over, with current flowing through first one tube, then the other. The net effect of this action, as far as output is concerned, is that voltage pulses appear across R_4.

▶ The rate at which these pulses occur—that is, the frequency of oscillation of the circuit—depends on the time constants of the C_1-R_3 and C_2-R_1 combinations. As you just learned, C_1 must discharge through R_3 before VT_2 can pick up; similarly, C_2 must discharge through R_1 before VT_1 can pick up. By adjusting the capacities and resistances of these combinations, you can obtain almost any fundamental frequency you want—from a very low one to a frequency well up in the r.f. range.

The output of this oscillator is rich in harmonics—in fact, the output wave may be triangular or even square in shape because there are so many.

▶ Although the multivibrator is fairly stable, its frequency can shift somewhat with changes in tube characteristics, operating voltages, etc. However, it will "lock in" with control pulses fed in the input, and will then produce its fundamental just as accurately as the control pulses are maintained. Equally as important— it will lock with a control pulse which is some multiple of its fundamental. For example, a 1-kc. multivibrator can be controlled by a 10-kc. control unit, as it will ignore all pulses in the input except the one it is locked with.

You see, at some time during the cycle of operation the voltage on the
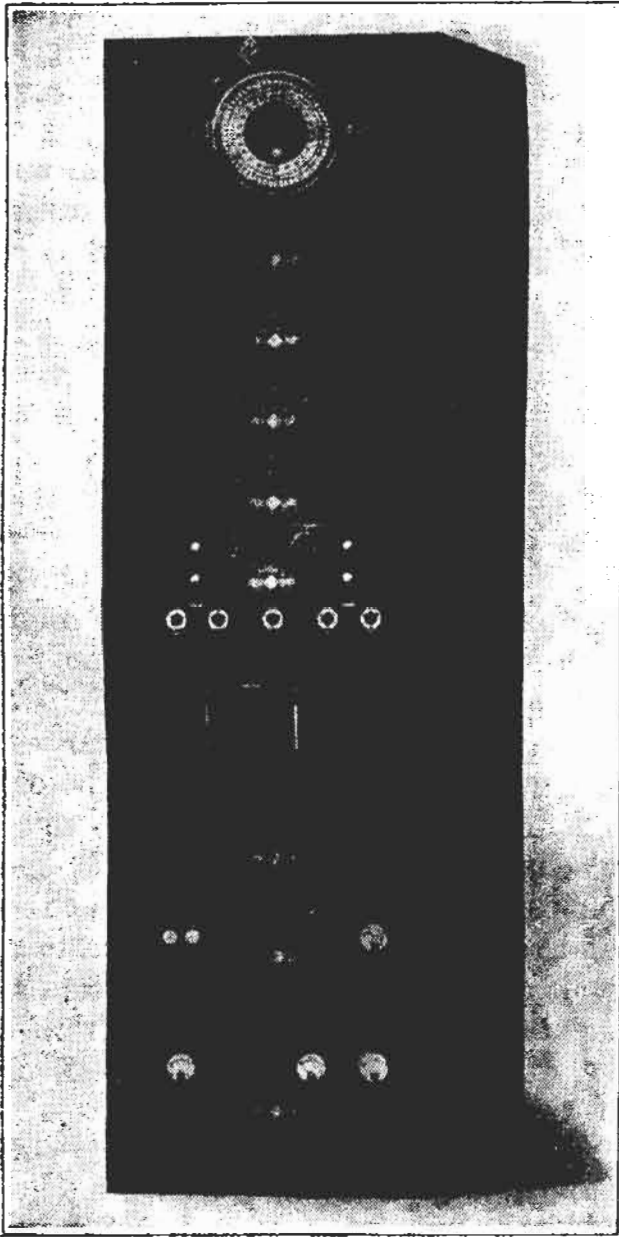
This rack contains a frequency standard, employing a 50-kc. crystal and two multivibrators. By checking the clock against standard time signals, the accuracy of the frequency standard can be determined. By using the multivibrator outputs, frequencies from one cycle per second up to several megacycles can be obtained.

grid of VT_1 has such a value that the tube can almost conduct current. Now suppose you feed in a 10-kc. signal across R_1. This signal adds to the voltage already present across R_1. If you adjust the amplitude of this signal carefully, you can make it increase the voltage on the grid of VT_1 just enough to make the tube start conducting a tiny fraction of a second ahead of the time it would have started

if the signal had not been fed in. The circuit then proceeds through its normal operating cycle, unaffected by the input voltage, until it reaches the precise point where the input voltage is again able to make VT_1 conduct. Since the fundamental frequency of the circuit is 1 kc., this point will not arrive until 9 cycles of the input signal have passed by, as these intermediate pulses, when added to the voltage across R_1, are not of sufficient amplitude to start tube conduction. However, the feedback voltage is continuously building up, and the tenth cycle of the input signal will make VT_1 conduct again. Thus, the multivibrator locks in step with every tenth cycle of the input frequency, but ignores the cycles in between.

▶ In other words, the oscillation of the vibrator is precisely controlled by the input voltage, which overcomes the tendency of the circuit to wander and shift frequency. Thus, the fundamental and all its harmonic frequencies will be just as accurately controlled as is the input voltage. Further, the circuit can be controlled by frequencies as high as the tenth harmonic of the fundamental. Therefore, you can lock the circuit at the input side with one of its harmonics, but use the fundamental as the output frequency, and so get an output which is any fraction (up to, say, a tenth) of the input frequency.

It is this characteristic that makes the multivibrator useful in the circuit in Fig. 22. The crystal produces a 100-kc. voltage which controls the 10-kc. (fundamental frequency) multivibrator. The 10-kc. multivibrator in turn controls a 1-kc. multivibrator. By bringing out taps from the multivibrators in Fig. 22, you can obtain voltages with frequencies maintained just as accurately as the crystal oscillator frequency itself.

▶ Because it has so many harmonics, you can obtain from the 10-kc. multivibrator frequencies of 10 kc., 20 kc., 30 kc., etc., all the way up to 1000 kilocycles. Similarly, the 1-kilocycle multivibrator produces 1-kilocycle steps

Courtesy General Radio

An engineer reading the clock on a primary standard of frequency.

all the way up to 100 kilocycles. If you wish, you can feed these outputs into other multivibrators and so get a large number of extremely accurate frequencies.

Then, the output from such a primary frequency standard can be used to calibrate secondary standards—such practical radio devices as signal generators, wave meters and other frequency determining devices. Let us now see just how such secondary standards are used in practical radio work.

THE WAVE METER

A very common frequency-indicating device is a wave meter. This is nothing more than a coil-condenser resonant circuit. Many have some means of indicating when they are tuned to resonance—such as a vacuum tube voltmeter, a thermocouple current meter in series with the resonant circuit, or a pilot lamp (which will

burn brightest when resonance is reached).

When the wave meter has no indicator, you must depend on the meters associated with the source as indicators. Practically all r.f. power oscillators and power amplifiers have plate current meters. When a wave meter is brought near a resonant circuit and is itself tuned to resonance, it will absorb energy from the source. The plate current rises when this power is being furnished, so the point of maximum rise in plate current is the point of resonance; provided you are not too closely coupled, so as to cause a broad response or stop the oscillator.

▶ To use a wave meter, bring its coil close to an inductance in the circuit producing the frequency to be checked. If it is physically impossible to do this, feed the output of the circuit into a coil and bring the wave meter near this coil. Then, vary the tuning condenser dial until resonance is indicated and read the frequency off
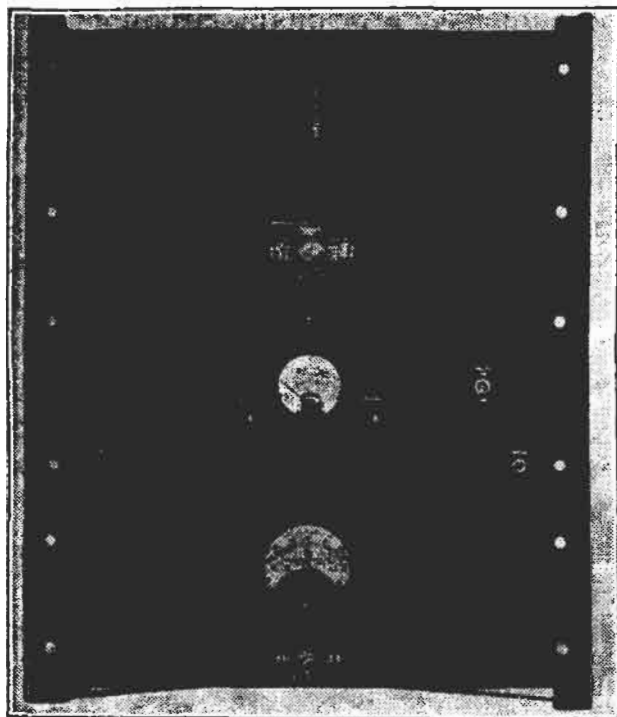

Courtesy General Radio

The condenser for this wave-meter is inside the box, while the round black object at the side is one of the plug-in coils. A pilot lamp on the panel is used as the resonance indicator. The condenser dial is directly calibrated in frequency, different scales applying to the different coils.

the dial. You may have to use a calibration chart if the condenser dial is not calibrated directly in frequencies.

Wave meters will maintain their accuracy of calibration for quite a long time if made from precision parts.

A frequency monitor used to check the frequency deviation (or frequency change) of a transmitter. An extremely accurate crystal oscillator produces a practically constant frequency. The crystal output is mixed with the transmitter carrier and the resulting beat frequency operates the deviation meter. A transmitter shift of one-half cycle can be observed on the meter, allowing the operator to keep the transmitter accurately adjusted to its assigned frequency. The use of this kind of equipment makes the carrier frequency of broadcast transmitters useful sources of known frequency for calibrating radios and service type signal generators.

However, a wave meter must be carefully made to be at all accurate—and even then will not show small variations in frequency less than 1% of the fundamental. For this reason, they are now used primarily for experimental purposes where an approximate frequency measurement is all that is required.

FREQUENCY COMPARISON

The radio serviceman often makes frequency comparisons. The signal generator normally available for service work is accurate enough for all practical alignment purposes, but not for precision measurements if they should be necessary. Furthermore, the service instrument may drift, so its frequency scales are usually not accurately calibrated after a period of time.

However, a signal generator may be easily recalibrated by comparing its output with the frequencies of broadcast stations. These stations make handy frequency standards, since they are required by law to maintain their frequencies within 20 cycles of the assigned frequency.

All you need to recalibrate a signal generator (or any other oscillator with a frequency in the broadcast range) is a receiver and a knowledge of the exact frequencies of several stations, which you can find in any log book. Tune the set to a particular broadcast station as accurately as possible, using an output indicator. Then, tune the signal generator near the same frequency and feed its output into the receiver at the same time as the incoming program. You will hear a high-pitched squeal which will change to a lower and lower frequency as you tune closer to the broadcast frequency. If the signal generator is tuned past the broadcast frequency, the pitch will rise from a low-frequency to a high-frequency squeal.

At the point where the squeal is of the lowest frequency or disappears entirely, the frequency of the signal generator is identical with that of the broadcast station. This is known as the zero beat method of determining frequency.

After finding the zero beat point, all you need do is mark the signal
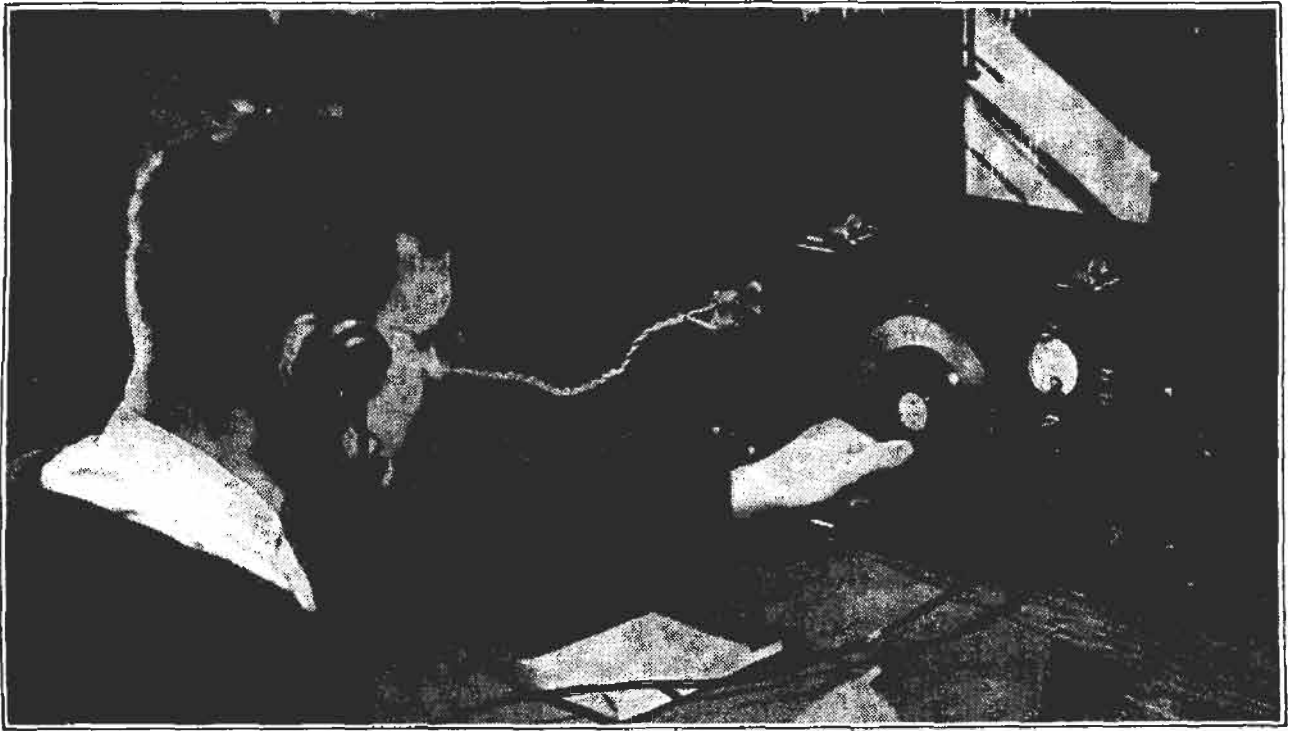
Using a heterodyne frequency meter to check a transmitter frequency. This device uses a stable variable oscillator and a crystal oscillator. The crystal and its harmonics are beat against the variable oscillator. The zero beat points, as indicated in the headphones, are the points where the frequency of the variable oscillator is exactly the same as the crystal or a crystal harmonic. Thus, the crystal oscillator serves to check the calibration of the variable oscillator and allow corrections to be made. Then, the output of the variable oscillator can be beat against the output of any other oscillator or transmitter within its range and will indicate the frequency of this transmitter or oscillator.

generator dial or adjust its trimmers so the frequency marking corresponds with the frequency of the broadcast station to which you are tuned. Then repeat the process with other broadcast stations, and you will be able to calibrate the signal generator (or oscillator) dial very accurately for broadcast frequencies.

Using Harmonics. By using harmonics of the signal generator output, you can calibrate it over the frequency bands which are lower in frequency than the broadcast band, and thus have available an accurately calibrated signal generator for making intermediate frequency alignments.

You recall that if an oscillator produces a fundamental frequency of 300 kilocycles, its harmonics will be at 600 kilocycles, 900 kilocycles, 1200 kilocycles and 1500 kilocycles. The 300-kc. frequency is below the broadcast band, but all of the above-mentioned harmonics are within the broadcast band. Therefore, if you tune the receiver to a broadcast station which has one of these particular frequencies, then tune the generator to exactly 300 kilocycles, you will get a zero beat from the harmonic of the oscillator beating with the incoming signal. (If the receiver dial is calibrated accurately, we need only tune in the signal generator harmonics at the proper points on the dial. However, the zero beat method is more accurate.)

In a similar manner, other points in the frequency range from 100 to 500 kilocycles can be checked by beating harmonics against known broadcast station frequencies.

▶ You should tune in harmonics at more than one place on the dial, unless you are certain of the fundamental frequency within a few kilocycles. For example, if you set the receiver

dial at 900, harmonics of 90, 100, 112.5, 128.5, 150, 180, 225, 300 and 450 kc. would all cause zero beats. You must tune away from 900 and see where the next signal comes in, to identify the fundamental frequency accurately. Thus, if you get signals at 900 and 990 kc., the fundamental must be 90, because this is the only one of this group which would have harmonics coming in at these two points. Similarly, harmonics of 100 would come in at 900, 1000, 1100 kc., etc.

Remember, you can find the fundamental frequency by locating any two consecutive points on the dial where harmonics can be heard, and then finding the frequency difference between these dial settings. This difference is equal to the fundamental frequency of the signal generator.

You will have to be careful to identify each and every harmonic to be sure that you have the right fundamental. Thus, if you use 900 kc. as one setting and find another signal at 1350, you'll have to be very certain there is no signal in between. Harmonics of 112.5, 150, 225 and 450 kc. will all come in at both 900 and 1350 kc.

If you hear no signal between 900 and 1350, the fundamental must be 450 kc., because 1350 minus 900 is 450. In other words, you have picked up the second and third harmonics of this frequency. On the other hand, if there are intermediate signals between 900 and 1350-kc. settings, you must determine where they are and must find the frequency difference between any two consecutive ones to find the fundamental frequency.

▶ This method lets you correct or calibrate a signal generator with sufficient accuracy for most measurement purposes. If the procedure is followed carefully, the accuracy will be that of the broadcast station fre-

quencies, which are usually accurate within one part in 100,000, or better, so the inaccuracy will be within a small part of 1%.

Broadcast stations themselves use accurate means of frequency determination to maintain their frequencies within the above-mentioned limits. Naturally, this maintenance of frequency is very important—for, if they drifted about, they might interfere with each other.

DETERMINING FREQUENCY OF AN UNCALIBRATED OSCILLATOR

The method just discussed can be used for other purposes than correcting an approximately calibrated oscillator. You can also use it, for ex-
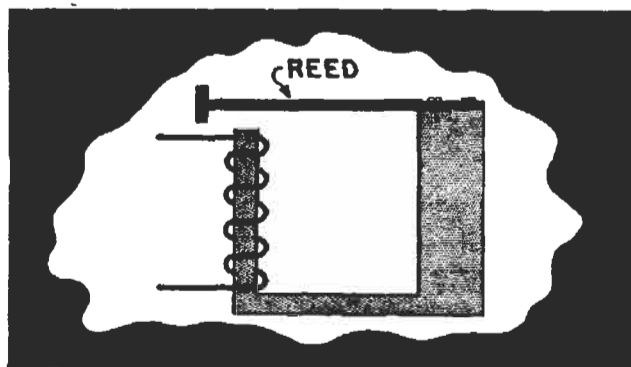

FIG. 24. A vibrating reed is shown here. A somewhat similar arrangement can be used to operate a tuning fork, which is a two-pronged "fork" made so its mass and springiness cause it to be mechanically resonant to some desired frequency.

ample, to calibrate an oscillator which is not calibrated at all.

To do so, just feed the output of the oscillator into a receiver and set the oscillator dial to a zero beat setting with a broadcast station, or depend on the receiver dial indications if it is accurately calibrated. Then tune the receiver slowly to higher frequencies and find the next zero beat setting. The difference between the two receiver frequencies which give successive zero beat indications is, of course, the fundamental frequency of the par-

ticular oscillator setting you chose.

By marking this oscillator dial setting with the frequency found, then repeating the process for other oscillator settings, you will be able to calibrate your oscillator accurately. Of course, as you learned in the previous section, you must be careful not to miss any harmonics as you tune the receiver.

AUDIO FREQUENCY MEASUREMENTS

The standard frequency source shown in Fig. 22 can be used to check audio frequencies by adding another multivibrator or two to the chain. This will give frequencies of 100 cycles or 1 cycle per second, depending upon whether one multivibrator or two are added, which can be used to calibrate an audio signal generator or an audio wave meter. Either of these devices can then be used to determine the frequency of an audio voltage.

▶ There is another source of standard low frequencies—a vibrating reed or tuning fork. These devices have a natural frequency of vibration which depends on mass and springiness. When forced into vibration by an electromagnetic device like that shown in Fig. 24 the fork or reed will vibrate with the greatest amplitude when the frequency of the voltage applied to the coil is the same as the natural frequency of the device.

This fact has been used as the basic principle of a simple frequency indicator, using the less-expensive reeds. Several reeds, each with a different natural frequency, are mounted so that they are driven by an electromagnet. When an a.c. voltage is fed into the electromagnet, the reed with the natural frequency closest to the frequency of the a.c. vibrates with the greatest amplitude.

Of course, such a device would re-

quire a great many reeds to cover the entire audio range, because a different reed would have to be used for every few cycles. It is therefore usually used only to measure frequencies within a small range, particularly those near power line values. As you know, the standard a.c. power line in the United States is a 60-cycle line. Power companies use vibrating-reed meters a great deal in checking the line frequency so as to keep it accurately controlled. (Incidentally, the accuracy of electric clocks used in
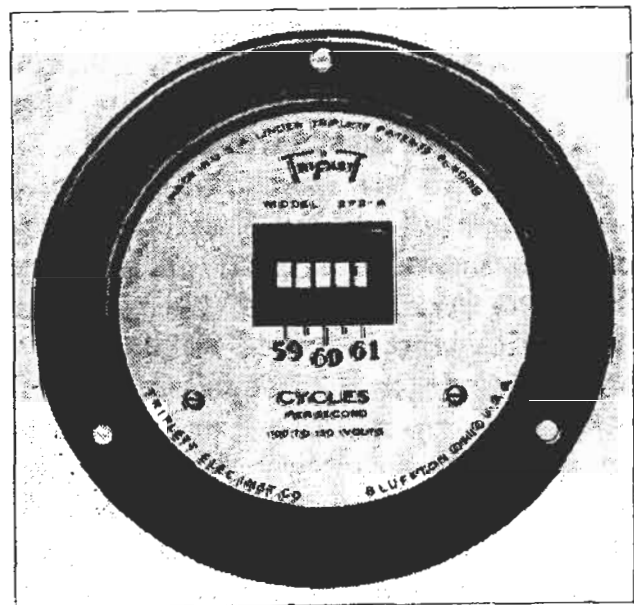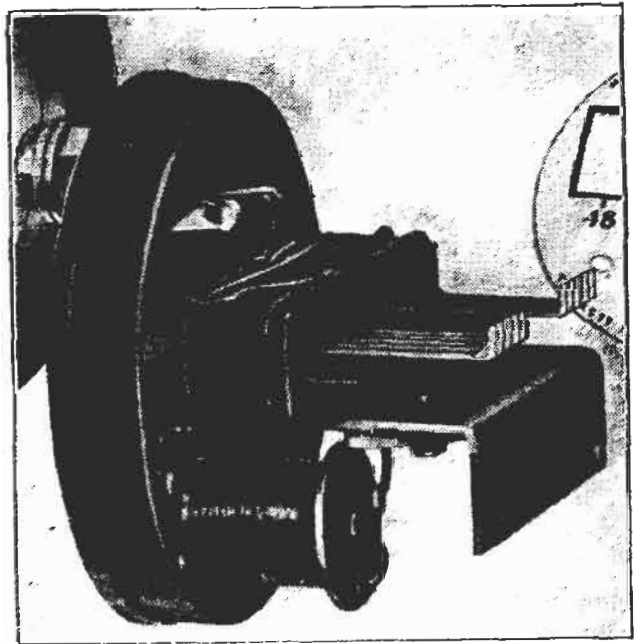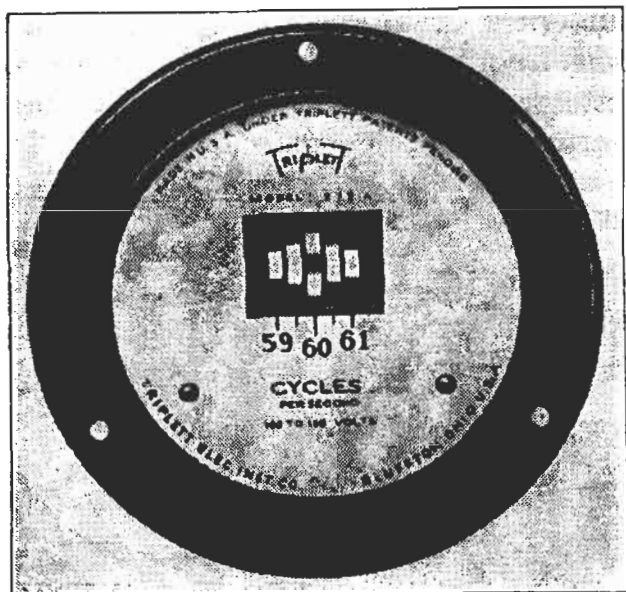

Courtesy Triplett Elec. Inst. Co.

FIG. 25. An interior view and a face view of the vibrating reed type frequency indicator.

homes depends entirely on the accuracy of the power line frequency. The fact that they keep such good time shows how well this frequency is controlled.)

A typical vibrating-reed meter is shown in Fig. 25. The ends of the reeds are painted white, so you can see when they vibrate. Fig. 26 shows

Courtesy Triplett Elec. Inst. Co.

FIG. 26. How the reeds indicate the frequency. As the 60-cycle reed appears largest, the frequency is 60 cycles.

its appearance when a frequency of 60 cycles is being measured. The 60-cycle reed appears the largest because it is vibrating at its natural frequency and so has a large amplitude of vibration. The reeds on each side are also vibrating, but not as much.

▶ While we are on the subject, another type of power line frequency meter is shown in Fig. 27. This meter has two coils (L_1 and L_2), with a magnetic vane mounted so it is free to turn in their fields. When an a.c. voltage is applied to the terminals, current will flow through both coils. The external circuit parts R_1, L_3, R_2 and L_4 are so proportioned that equal currents flow in L_1 and L_2 when the applied a.c. has a 60-cycle frequency. The normal tendency of the magnetic

vane in the meter is to line up along the axis of one or the other of the coils, but since both have equal fields, it stands still, halfway between the two axes.

Changes in applied voltage will not move the vane, because the voltage drops will merely increase or decrease in proportion in both halves of the circuit. However, as you know, coil reactance goes up with frequency. So, if the frequency increases, the drop across L_3 will increase, producing a greater current through coil L_1; at the same time, the reactance of L_4 will increase, allowing less current to flow through L_2. Since L_1 now has the stronger field, the magnetic vane will swing to the right to line up more nearly with the axis of coil L_1. On the other hand, if the frequency decreases, opposite effects occur and the vane will move to the left.

Properly designed, this instrument will measure very small frequency changes. A picture of a typical instrument is shown in Fig. 28.

▶ While vibrating-reed and magnetic
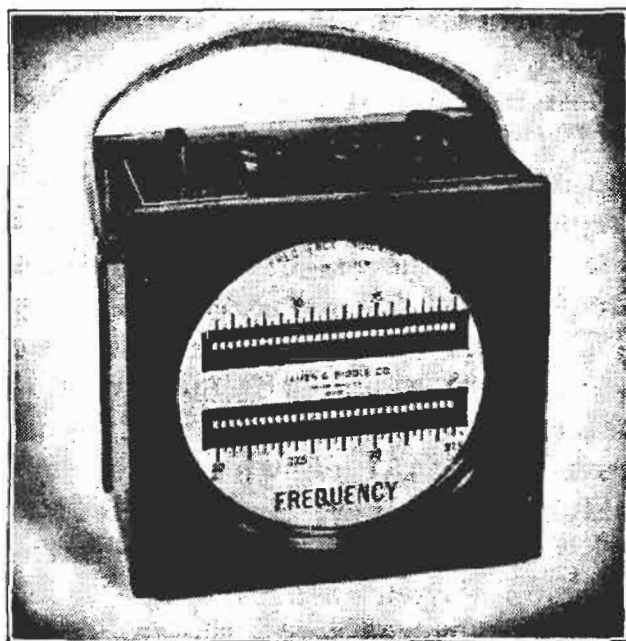
Courtesy James G. Biddle Co.

A portable laboratory type vibrating reed frequency indicator. Note the large number of reeds, providing a wide frequency range in one-quarter and one-half cycle steps.

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vane meters are found mostly in power stations, many laboratories also use them to check audio frequencies within their ranges.

THE WIEN BRIDGE AS A FREQUENCY INDICATOR

Any resonant bridge circuit can, of course, be used like a wave meter to determine frequencies. For audio frequencies, a bridge known as the
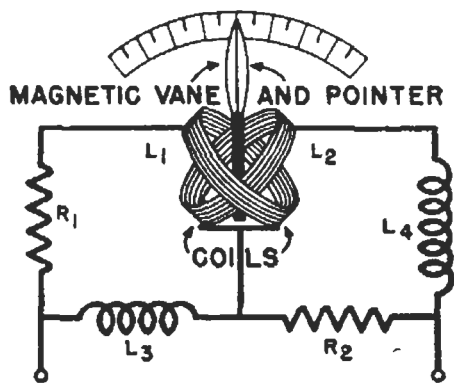

FIG. 27. The magnetic vane frequency meter.

Wien bridge (which is also very popular for measuring capacities) is particularly useful. Its circuit is shown in Fig. 29.

This bridge can measure frequencies because of the actions of the arms containing the condensers. Notice C_1 is in shunt with R_3, while C_2 is in series

FIG. 28. A face view of a typical magnetic vane frequency meter.

with R_4. As you can see, the impedance between terminals A and C can drop to a very low value at high frequencies because of the drop in reactance of C_1. However, no matter how high the frequency, the impedance between C and D can never drop below the value of R_4. On the other hand, if the frequency is decreased, the impedance between A and C will never go higher than the value of R_3, while that between C and D can go on up to practically an open circuit.
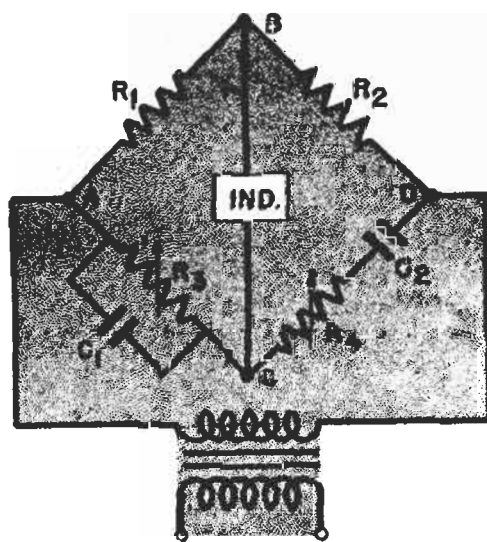

FIG. 29. The Wien bridge used as a frequency indicator.

Therefore, as you move from some one particular frequency in either direction, the reactances of the two arms will behave in different manners. In fact, they act much as a coil and condenser would—therefore, in effect, this is a resonant circuit. We won't go into the engineering behind this bridge, but if resistor R_1 is twice R_2, C_1 equals C_2 and R_3 equals R_4, the frequency of balance of the bridge will be

$$f = \frac{159,000}{R\,C}, \text{ where } f \text{ is in cycles,}$$
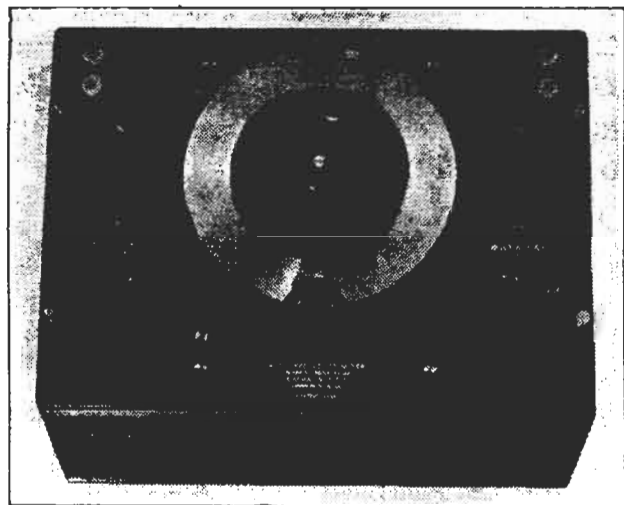
C is in microfarads and R is in ohms. In this case, R is the value of either R_3 or R_4, and C is the value of either of the condensers.

By varying the resistances of R_3 and R_4 (but keeping them equal), or by using different sizes of condensers (but keeping them equal also), we can change the frequency to which the bridge will be balanced. Thus, we can use the bridge to determine the fre-

FIG. 30. A typical laboratory type frequency meter using the Wien bridge.

quency of the source connected to it, provided we know the capacity of the condensers and the value of the resistors. A typical audio frequency bridge is shown in Fig. *30*. The main dial varies the resistors, which are ganged together.

USING THE C. R. O. TO DETERMINE FREQUENCIES

From your previous study of the cathode ray oscilloscope, you know that you can get an image on the face of the tube which will be an exact reproduction of the applied voltage. Furthermore, when the sweep frequency is locked in with the incoming signal frequency, you'll get a single cycle of the incoming wave. Now, let's see how you can use these characteristics of the c.r.o. to measure frequencies.

As you know, a stationary pattern can be obtained if the sweep frequency is a sub-multiple of the incoming frequency. The number of complete cycles in the pattern gives the relationship between the sweep frequency and the incoming frequency. For example, if the incoming wave is 1000 cycles and the sweep is set to 500 cycles, you will get a 2-cycle pattern as shown in Fig. *31A*. Similarly, a wave four times the sweep frequency makes four complete cycles, as shown in Fig. *31B*, and so on up to 15 or 20, depending on the size of the c.r.o. screen.

When the sweep frequency is adjusted the other way so it is above the incoming signal frequency, you no longer get an image of the incoming signal. Instead, there will be a series of more or less horizontal lines on the c.r.o. screen. When there are two stationary lines, the sweep frequency is twice the incoming signal; when there are three lines, the sweep is three times the frequency, etc. Fig. *31C* shows five lines, so the sweep fre-
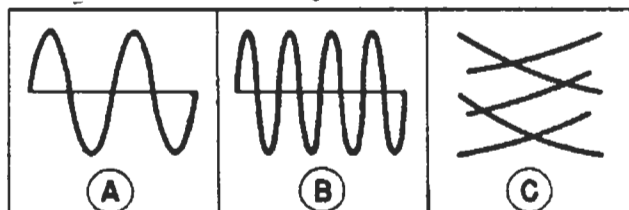

FIG. 31. The number of cycles or lines in the c.r.o. pattern can be used to indicate frequency.

quency is five times the incoming frequency.

Thus, if the sweep generator in the c.r.o. is calibrated, you can easily determine the approximate frequency of the incoming signal from the setting of the sweep controls and the pattern formed. You can calibrate the sweep by feeding known frequencies into the c.r.o. and noting the setting of the sweep frequency control necessary to produce stationary patterns.

LISSAJOUS FIGURES

Since the sweep of the c.r.o. may drift in frequency and thus be of varying accuracy, the calibrated sweep method is used only for rough measurements. When you want greater accuracy you should use Lissajous figures to measure frequencies with the c.r.o.

To use Lissajous figures, you must have an accurate source of known frequency. The unknown frequency is fed to the vertical plates of the c.r.o. tube, while the known standard is fed to the horizontal plates. An excellent source for the standard frequency is a.c. from a 60-cycle power line, which is accurately controlled by the power company.

If the frequency of the unknown and the known frequencies are exactly equal, you will get a single slanting line, an ellipse, or a single circle on the c.r.o. screen. The possible pattern

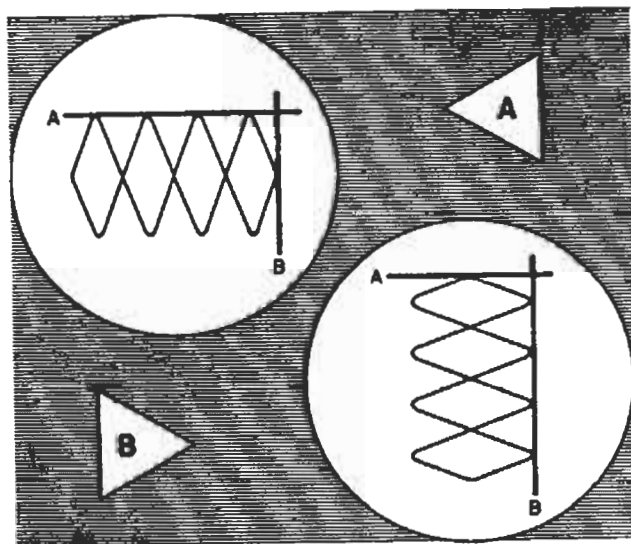FIG. 33. Several typical Lissajous figures showing frequency ratios.

FIG. 32. Using imaginary lines A and B to determine the frequency of a Lissajous figure.

differences are due to phase shifts. However, any pattern which is a single line, oval or circle shows that the two a.c. voltages have the same frequencies.
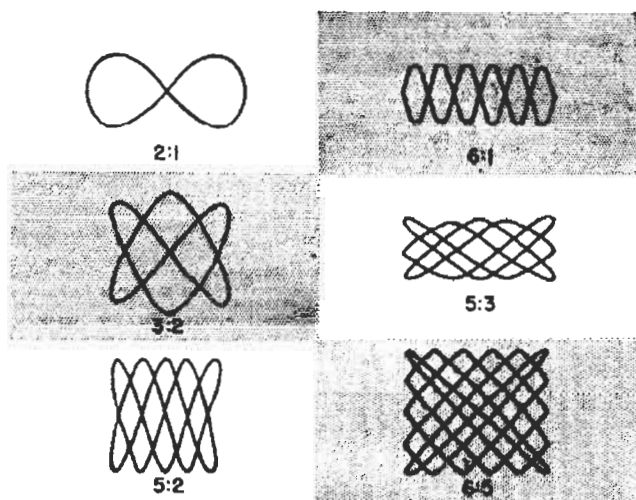
On the other hand, if you get a series of closed loops, the voltages have different frequencies. The position and number of the loops give the ratio of the applied frequencies; even fractional ratios can be determined in this way.

For example, suppose you get a pattern like that shown in Fig. *32A*. To determine the frequency ratio, draw or imagine the lines *A* and *B*. Notice the number of times each line is touched by the pattern. Line *A* is touched four times, while line *B* is touched once. This means the frequency ratio is 4 to 1—that is, the signal applied to the vertical plates is four times that on the horizontal plates. Thus, if a 60-cycle voltage is applied to the horizontal plates, the vertical plate voltage has a frequency of 240 cycles.

If the image is turned around, as shown in Fig. *32B*, so the figure touches the line *A* once and the line *B* four times, the ratio will be 1 to 4. This means the horizontal signal frequency will be four times the vertical signal frequency; if the horizontal voltage is still a 60-cycle signal, the vertical voltage must be a 15-cycle signal.

A number of typical patterns are shown in Fig. *33*. In all cases, count-

ing the number of times the loops touch the imaginary lines *A* and *B* will give the frequency ratios. These ratios, multiplied by the frequency of the horizontal voltage, equal the frequency of the vertical voltage. Thus, if the horizontal voltage is 60 cycles a pattern with a ratio of 5 to 3 shows that the frequency of the vertical voltage is $5/3 \times 60$, or 100 cycles. This method is quite accurate if the pattern is studied carefully.

Lesson Questions

Be sure to number your Answer Sheet 30FR-1.

Place your Student Number on *every* Answer Sheet.

Send in your set of answers for this lesson immediately after you finish them, as instructed in the Study Schedule. This will give you the greatest possible benefit from our speedy personal grading service.

1. What factor is found when you divide the coil reactance by its resistance $(X_L \div R)$?   *The Q factor*

2. When measuring the inductance of an iron-core coil, what value of polarizing (d.c.) current should flow through it?   *About the same value as when the coil is in use in the radio*

3. When measuring the inductance of an iron-core coil which has a high resistance, would you use: *1, The reactance method;* or *2, the three-voltage method,* if the true inductance is to be found?

4. Which of the following condensers requires a polarizing voltage when checking the capacity: *1, Air dielectric; 2, paper; 3, ceramic; 4, electrolytic; 5, mica?*

5. When using the resonance method of measuring inductance, what condition is indicated by a double-hump (two peaks) reading on the meter?   *The link coupling is too tight between the oscillator and the resonant circuit*

6. Using a resonant circuit like the one in Fig. *10,* what four factors of a coil can be measured or figured?   *Inductance, A.C. resistance, Q factor, + distributed capacity.*

7. When finding the Q using the circuit of Fig. *11,* what basic principle is being used in the measurement?   *Resonant voltage step-up.*

8. Using the decade box of Fig. *13,* to which contacts would you set switches SW_1, SW_2 *and* SW_3 so that you would have 471 ohms between terminals *A* and *B*? $SW_3 - 4$; $SW_2 - 7$, $SW_1 - 1$.

9. When a bridge circuit is balanced, does the indicator show: *1, Maximum current;* or *2, minimum current?*

10. Suppose you are using a wavemeter, consisting of a coil and a condenser, which has no built-in indicator. If this wavemeter is brought near an oscillator tank circuit, what indication will be obtained on the oscillator plate current meter when the wavemeter is tuned to resonance?   *The current meter will show a rise in current in*

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