unknown resistance between points T1 and T2 and take the voltmeter reading.

The resistance value is obtained by using the following formula:

$$Rm\left(\frac{E}{E1} - 1\right) = R$$

Where Rm is the total resistance of the voltmeter (ohms per volt times maximum voltage on the scale), E is the voltage read with the test points connected together (voltage of the battery) and E1 is the voltage reading with the unknown resistor, R, connected between points T1 and T2.

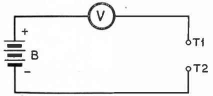

Fig. 7

Resistance values can be measured fairly accurately by comparison with standard resistors. A decade box, which can be adjusted, forms the best type of standard to use in such instances.

A circuit consisting of a battery, B, a milliammeter or ammeter A, and test points T1, T2, T3 and T4 with a switch S are arranged as shown in Fig. 8. A standard resistance Rs is connected between test points T1 and T2 while the resistance to be measured is connected between points T3 and T4 as shown. It is important in circuits of this type that the ammeter be capable of covering the range of current that will be drawn when very low values of resistance are connected in the circuit. In making preliminary tests it is advisable to connect a protective series resistance in the circuit to protect the measuring instrument. This protective resistance can be a variable high resistance whose full resistance is connected into the circuit at the start and which can be gradually reduced and finally shorted out when it is found that the resistance under test is sufficiently high to limit the current to within the range of the instrument.

Another very simple method of protecting the measuring instrument is to use a potentiometer across the battery in the manner described in the March Research Worker. By this means, the voltage applied in the circuit can be increased gradually and the current kept within the limits of the measuring capabilities of the meter.

The switch is then shifted from the switch point connecting to T2 to the switchpoint connecting to T4. When the switch connects to T2, the standard resistance Rs is connected into the ammeter circuit while when it is shifted to T4, the unknown resistance Rx is connected in the circuit. Readings of the ammeter or milliammeter are taken under both conditions whence the unknown resistance is obtained by using the following formula:

$$Rx = \left((Rs + Rm) \times \frac{Is}{Ix}\right) - Rm$$

Where Rx is the unknown resistor, Rs is the standard or known resistor, Rm is the meter resistance, Is is the current reading with the standard resistor connected in the circuit and Ix is the current reading with the unknown resistance connected in the circuit.

The most accurate readings are obtained when both resistances are approximately equal, that is when the current readings are approximately the same.

Another simple method of obtaining the resistance value of a resistor when a voltmeter and a standard resistance of known value is available makes use of the circuit shown in Fig. 9.

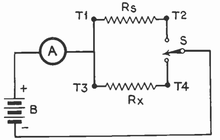

Fig. 8

In this method, the standard resistor Rs is connected in series with the unknown resistor Rx and the series combination of resistors is connected across a battery. A high resistance voltmeter is used to measure the voltage drop first across the known resistor, Rs, and then across the unknown resistor Rx.

The value of the unknown resistor is found by using the following formula:

$$Rx = \frac{Ex \times Rs}{Es}$$

in which Rx is the unknown resistance, Rs is the known standard resistance, Ex is the voltage across the unknown resistance and Es is the voltage across the known standard resistance.

This method should be used only with resistances whose values are low in proportion to the resistance of the voltmeter since otherwise, the current drawn by the meter resistance will introduce an appreciable error.

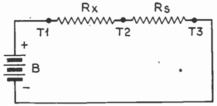

Fig. 9

This error may be eliminated by using a variable standard resistor which can be varied so as to be made equal to the unknown resistance. The variable resistance is equal to the unknown resistance when the voltage across both resistors is the same. In such cases, the current drawn by the voltmeter does not affect the accuracy of the measurement since the voltmeter will affect both readings to the same extent so that the error cancels out.

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Vol. 3 April 1930 No. 4

Simple and Efficient Ohmmeters for Resistance Measurements, Part 2*

By the Engineering Department, Aerovox Wireless Corp.

WHILE the method for measuring resistances described in the March issue of the Research Worker is one of the simplest and most effective methods of measuring a wide range of resistance values, there are a number of other methods of measuring resistances which may be used to obtain either more accuracy or to make the measurements more easily.

One of the most accurate methods of measuring resistances involves the use of a Wheatstone Bridge circuit. There are many fine points involved in the use of bridge circuits for resistance measurements that cannot be taken up in an article of this type for lack of space. However, the most important facts will be mentioned and the reader who is interested in resistance measurements from the laboratory standpoint is referred to such books as the Standard Handbook for Electrical Engineers, Pender's Handbook for Electrical Engineers, Electrical Measurements by F. A. Laws and other such standard books on electricity and electrical measurements for more detailed information.

A simple Wheatstone Bridge circuit for measuring resistances is shown in Fig. 4. The circuit consists essentially of four resistances connected in the form of a diamond, with a resistor in each side of the diamond, as shown at A, B, Rs and Rx. A battery connected as shown to the E and F terminals of the resistance diamond will cause a current to flow in the resistors when the circuit is completed by closing switch S1. The current in the circuit will divide, one part flowing through one branch of the resistance network consisting of resistors A and B forming the path ECF and the other part flowing through the other branch consisting of resistors Rs and Rx forming the path EDF.

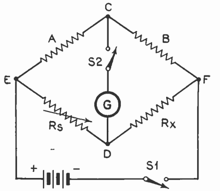

Fig. 4

If the resistances in such a circuit are adjusted or are of such values that no current will flow through the sensitive galvanometer G, connected between points C and D, when switch S2 is closed, there will be no difference of potential between those two points and the relation of the resistances of the circuit will be as follows: A/B = Rs/Rx or A times Rx = Rs times B. It is also true that A/Rs = B/Rx and also that Rs/A = Rx/B.

Under such conditions if three of the resistance values, such as A, B and Rs are known, and the galvanometer reading with those values of resistance is zero indicating that points C and D are at the same potential (the condition under which the bridge is said to be balanced) the value of the resistance Rx can be calculated.

In actual practice it is not necessary to know the exact value of the resistances A and B as long as their ratio is known. With the ratio of A to B or B to A and the resistance of Rs known it is a simple matter to determine the value of resistance of Rx. In practical Wheatstone bridges, the ratio arms, A and B are arranged so that the ratio between A and B can be varied progressively in multiples and submultiples of 10 while the variable standard resistor Rs is variable in

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*NOTE: The first article of this series on resistance measurements, describing a novel and simple method of measuring resistance, appeared in the March, 1930 issue of the Research Worker. Readers whose subscription begins with this issue (April) and who therefore missed the first article, may obtain the March issue on request. There is no charge or obligation. Merely write to the Research Worker, Aerovox Wireless Corporation, 70 Washington Street, Brooklyn, N. Y.

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small steps. A decade box usually serves as the variable resistor Rs.

The unknown resistor Rx (when the bridge is balanced) is then equal to the ratio of (B to A) times the value of Rs. If the ratio of B to A is one to one, then the value of Rx **is equal to Rs.** If the value of B to A is 10 to 1, then the value of Rx is 10 times Rs. If the value of B to A is 1 to 100 then the value of Rx is equal to Rs divided by 100.

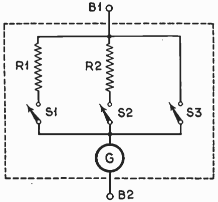

Fig. 5

The accuracy of the determination of resistance Rx depends on the accuracy of the ratio arms A and B, the accuracy of the standard resistance Rs, the sensitivity of the galvanometer G and the relative resistances of all four arms of the bridge.

Most accurate determinations are made when all the arms of the bridge are equal, or at least approximately equal.

In making adjustments of the bridge, certain precautions must be taken to avoid burning out the sensitive galvanometer. In testing, the battery switch S1, Fig. 4, should be closed before closing switch S2. The usual type of galvanometer used for such purposes is a zero center microammeter having a range of about 500 microamperes each side of zero.

Such units have an internal resistance of approximately 30 to 40 ohms, so that full scale deflection is obtained with a difference of potential of only .015 volts across the terminals. Unless the preliminary adjustment of the ratio arms is such as to make the bridge practically balanced, when the resistances of the bridge arms are low in value, the voltage applied across the galvanometer may be high enough to cause a dangerously high current to flow through the galvanometer and burn out its winding.

This danger to the galvanometer may be eliminated by using fairly high resistance ratio arms at A and B which will serve as protective resistors in series with the galvanometer, when either Rs or Rx are low in value. The minimum value of resistance which can be used at A or B to provide this protection can be calculated roughly by dividing the voltage of the battery used in making the test by the maximum range of the galvanometer in amperes. Thus if a 6-volt battery is used, and the maximum scale reading of the galvanometer is 500 microamperes or .0005 amperes, the resistance that should be used at A and at B (the ratio arms) to protect the galvanometer, should be 6 divided by .0005 or 12,000 ohms for A and 12,000 ohms for B.

It is also possible to protect the galvanometer without resorting to limitations on the resistances of the bridge arms by using a protective resistance in series with the galvanometer in making trials in establishing a balance of the bridge.

In the Jewell Pattern 51 galvanometer, for instance, three switch test buttons are provided, as an integral part of the galvanometer, in addition to the binding posts used to connect the galvanometer into the circuit, as shown in the circuit diagram of the instrument in Fig. 5.

In this diagram, G is the galvanometer movement proper. B1 and B2 are the instrument binding posts or terminals. Switches S1, S2 and S3 are spring button switches which remain open normally except when depressed by the operator. When switch button S1 is depressed a high resistance R1 is connected in series with the galvanometer, limiting the current to within the range of the instrument even when connected across a 10-volt source. When switch button S2 is depressed a lower resistance R2 is connected in series with the galvanometer. When switch button S3 is depressed, the galvanometer is connected directly across the instrument terminals.

In operation, after a preliminary setting of the bridge arms, switch button S1 is depressed first. If the reading is high the bridge arm Rs is adjusted to give a very low reading. Switch button S1 can then be released and switch button S2 depressed. If the reading on this setting is high, a further adjustment on the bridge arm Rs is made until the reading is reduced practically to zero showing a comparatively small difference of potential applied across the instrument terminals. Switch button S2 can then be released and switch button S3 can then be depressed, connecting the instrument directly across the bridge for greater sensitivity. Final adjustments of the bridge can then be made safely without endangering the galvanometer.

The voltage of the test battery should be selected so as to prevent excessive current flow through the resistors which would be likely to either burn out the resistors or change their resistance through excessive heating.

In making resistance measurements to determine the resistance of a unit under actual conditions of operation, it is desirable to select the voltage of the battery of such a value as to cause a current to flow through the resistor of the value which it will normally carry in operation. Care must be taken, however, that the resistors in the decade box Rs used as the standard are so made that they will carry the current without undue heating or change in resistance, and that the resistors used at A and B are also designed to carry the current they will be called upon to carry.

One of the simplest and most useful types of direct reading ohmmeters, which while not accurate enough for laboratory work, is sufficiently accurate for routine testing, can be made by connecting a battery, B, a milliammeter, A, and a protective resistance, R, in series as shown in Fig. 6. Terminals T1 and T2 are the test points or terminals.

The range obtainable with such instruments depends on the range of the milliammeter and the voltage of the battery. If we take a zero to 1 milliammeter such as the Jewell Pattern 88 direct current meter having an internal resistance of 30 ohms and 50 scale divisions, each scale division represents a current of 20 microamperes or .00002 amperes.

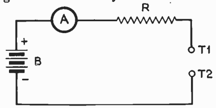

Fig. 6

To obtain full scale deflection of 1 milliampere with a battery of 4½ volts, the resistance in the circuit would have to be 4½ divided by .001 ampere or 4,500 ohms. Since there is already 30 ohms, due to the resistance of the milliammeter in the circuit, the additional resistance necessary at R in Fig. 6 to give full scale deflection when the test points T1 and T2 are touched together is 4,470 ohms.

If an additional resistance is connected between points T1 and T2, the reading on the milliammeter will be less than 1 milliampere. If for instance a resistance of 2,000 ohms is connected between the test points, the total resistance in the circuit, neglecting the resistance of the battery, will be 6,500 ohms. With this resistance in the circuit and a 4½-volt battery as the source of voltage, the current in the circuit will be 4½ divided by 6,500 or .000692 ampere which equals 692 microamperes. The nearest scale division on the milliammeter scale is 700 microamperes (.7 milliampere). This scale division corresponds then to a resistance of 2,000 ohms connected across the test points.

It is possible then to calibrate the scale of a milliammeter in terms of resistance connected across the test points. All that is necessary is to determine the corresponding resistance of every scale division on the milliammeter and either make a chart or calibrate the scale of the milliammeter.

In making the calculations, divide the voltage of the battery by each scale division of the milliammeter and from the answer subtract the resistance of the test circuit consisting of resistance R and the resistance of the milliammeter, Fig. 6.

The disadvantage of this type of ohmmeter from the standpoint of accuracy is the crowding of the scale toward the high resistance end of the scale (low current readings of the milliammeter). It must be kept in mind that zero resistance (between test points T1 and T2) is obtained with full scale deflection of 1 milliampere, and that increasing the resistance by inserting resistances between the test points gives lower and lower readings on the milliammeter scale.

At the lower milliammeter readings, say at the lowest scale division of .02 milliampere, the total resistance necessary in the circuit to obtain this current reading is in this case equal to 4½ divided by .00002 ampere or 225,000 ohms. Since 4,500 ohms will be in the resistance R and the resistance of the meter, the resistance required between the test points will be 220,500 ohms. At the .04 milliampere scale division, the total resistance required in the circuit will be 112,500 ohms, of which 108,000 ohms must be between the test points T1 and T2. Thus the difference in the resistance measured between two scale markings in this case will be 220,500 minus 108,000, or 112,500 ohms.

At the high end of the milliammeter readings, the resistance required at full scale deflection will be 4,500 ohms for one milliampere (zero resistance between the test points). At the next lower scale division, .00098 ampere, the resistance required will be approximately 4,592 ohms. Since 4,500 ohms of this is in the resistance R and the internal resistance of the meter, the resistance between the test points must be 92 ohms. At this end of the scale therefore, the difference in resistance between two scale markings is only 92 ohms.

In this instrument therefore, the resistance readings taper down from 220,500 ohms at the .02 milliampere division to 92 ohms at the .98 milliampere division with differences of resistance values of 112,500 ohms at one end between scale divisions tapering down to 92 ohms between scale divisions at the other end.

Because of its direct reading characteristics, however, and because there can be no danger of burning out the meter winding (due to the use of the protective resistance R) when used with a voltage for which the protective resistance is calculated, this type of testing circuit is very popular for general testing or to obtain a rough, preliminary estimate of the resistance of a unit to be checked up more accurately by the bridge method.

This type of tester is very valuable in making the routine inspection tests in radio circuits since it gives quickly an approximate idea of the resistances of the instruments tested which serves as a fairly reliable indication of the condition of the instrument being tested.

Commercial instruments of this type are available for experimenters who do not care to construct their own units. The Weston Electrical Instrument Co. makes a milliammeter type unit with self-contained external resistance which when used with a battery of a given voltage, serves admirably as a direct reading ohmmeter. This meter is designed to operate with a battery of 3 volts. The range of the milliammeter used and the series resistance employed are designed to provide an instrument which will give a direct reading ohmmeter having a range of 0 to 10,000 ohms and a low resistance voltmeter having a range of 0 to 3 volts. The type number is Model 506 Resistance Meter.

A similar instrument, the Pattern 135 ohmmeter is made by the Jewell Electrical Instrument Co.

The Jewell Electrical Instrument Co. makes Ohmmeters of this type, their Pattern No. 2 Ohmmeters covering ranges up to 50,000 to 1,000,000 ohms. General Radio Co. also makes instruments of this type, their Type 287-A unit covering the range from 0 to 10,000 ohms and their Type 287-B covering the range from 0 to 2,000 ohms.

All of these commercial units have refinements to permit zero adjustments and compensation for variation in battery voltages. These refinements of course are desirable but are often unnecessary in ordinary routine inspections where exact resistance values are not required. For more accurate determinations of resistance values, the bridge method or the method described in the March issue of the Research Worker are recommended.

In addition to the three methods already described in the present issue and in the March issue of the Research Worker, there are innumerable other methods of measuring resistances and a few of these will be described in the following paragraphs more to illustrate the adaptability of electrical instruments and the interesting applications of electrical laws than for any really practical value of the methods. Of course in some cases they will prove very useful in emergencies where other measuring instruments are not available, but they serve more as examples of electrical juggling and the use of makeshift instruments.

The method shown in Fig. 7 illustrates how a resistance can be measured by means of voltmeter and battery. For maximum accuracy the battery should be of a value such as to give practically full scale deflection of the meter when the test points are connected together, thus connecting the voltmeter directly across the battery. The resistance to be measured is then connected between the test points. For low values of resistance, a low resistance voltmeter will give most accurate results. For high values of resistance, a high resistance voltmeter should be used.

The resistance is measured by first taking the reading of the battery by connecting test points T1 and T2 together. Then connect the