The same voltage ranges between the A terminal of the voltmeter and the B, B1, B2, B3 and B4 terminals respectively of the arrangement shown in Fig. 10 can be obtained by using 50,000 ohm resistors at R1 R2, R3 and R4, in the arrangement shown in Fig. 11.

Because smaller resistance values can be obtained in higher watt ratings, are easier to obtain, and will keep their resistances values more constant, the arrangement of multipliers shown in Fig. 11 is more desirable. This arrangement also has the advantage of giving greater accuracy because inaccuracies in resistors used in the series arrangement often balance out. Thus if R1 in Fig. 11 is 10% less than the required value and R2 is 10% over the required value, the inaccuracies of both resistors will balance out giving a value of exactly 100,000 ohms for the resistor consisting of R1 and R2.

When the exact required values of resistors cannot be obtained to provide even multiples, it is possible to use approximate values of resistances in the multipliers and determine the ratio between the new total resistance of the voltmeter and the old value of resistance. The ratio between the old scale reading without the series resistance and the new scale reading with the resistance in the circuit also gives the multiple by which the old scale reading must be multiplied to get the new voltage reading.

If for instance the voltmeter reading on a 0 to 50 voltmeter is 45 volts when using a given battery between terminals A and B of the voltmeter shown in Fig. 8 and the voltage reading drops to 20 volts when a resistance R1 is connected in series with the voltmeter as shown in Fig. 9, the multiple by which each scale reading of the voltmeter must be multiplied to get the actual voltage is 45/20 or 2.25, when that particular resistor is used in series with the voltmeter.

The reason why this is so can be proved very easily. If the milliammeter used in the voltmeter has a range of 0 to 1 milliampere to give the required 1,000 ohms per volt characteristic when used with a resistance of 50,000 ohms and a scale reading from zero to 50 volts, the current in the circuit when reading is 45 volts, is 45/50ths of a milliampere. The voltage required to cause a current of 45/50ths of a milliampere to flow through a resistance of 50,000 ohms is 45/50-000 (ampere) times 50,000 (ohms) which equals 45 volts.

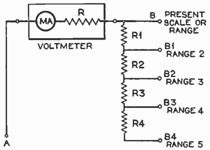

Fig. 11

When the reading drops to 20 on the scale (with the same voltage connected across the test terminals but with a resistance R1 connected in series with the voltmeter) the current represented is 20/50ths of a milliampere.

The resistance required to obtain a current of 20/50ths of a milliampere with a voltage applied of 45 volts is 45 (volts applied across terminals A and B in Fig. 9) divided by the current flowing in the circuit 20/50,000 ampere (20/50th milliampere) which equals 112,500 ohms. Since 50,000 ohms of this is in the voltmeter itself, the balance or 62,500 ohms must be in resistor R1.

We have already found that to find the external resistor required to increase the range of a given voltmeter by any desired multiple, the resistance of the voltmeter must be multiplied by one less than the multiple. Since the multiple which we found that this range, 0 to 50, had to be multiplied by in this last case is 2.25, one less than the multiple is 1.25. Multiplying the resistance of the voltmeter, 50,000, by 1.25 gives 62,500 ohms as the value of the external resistor, R1 of Fig. 9.

This method, by the way, can be used to measure the resistance of a unit when only a high resistance voltmeter is available.

An Important Decision on Mica Condenser Patents

THE AEROVOX WIRELESS CORPORATION

is pleased to announce that by a decision rendered January 13, 1930,

The United States Circuit Court of Appeals
For the Second Circuit

has affirmed the decree of

The Federal District Court

in favor of

The Aerovox Wireless Corporation

in the suit brought against it by

The Dubilier Condenser Corporation

for alleged infringement of Dubilier Patent No. 1,497,095
on mica condensers

THE AEROVOX WIRELESS CORPORATION

is pleased to renew its pledge to the industry that Aerovox prices shall never be padded with royalties on invalid or worthless patents.

1930-2

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The AEROVOX Research Worker

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Vol. 3 February 1930 No. 2

METER MULTIPLIERS: A Convenient Method of Increasing the Range of Milliammeters and Voltmeters

Part 2*

By the Engineering Department, Aerovox Wireless Corp.

ANOTHER simple method of calibrating a milliammeter or ammeter for a different range is to arrange a series circuit consisting of the milliammeter, a battery and a series resistance of such value as to give a full scale or practically full-scale reading on the meter. The series resistance may be a variable resistor which can be set high to start so as to limit the current through the meter. The resistance can then be reduced gradually until a value is obtained that gives a full scale deflection on the meter.

If we use the 0 to 10 milliampere milliammeter for instance, which has a resistance of 8.5 ohms, and a battery having a voltage of 22 volts, the required series resistance in the circuit to give a full scale reading of 10 milliamperes will be 22 divided by 10 milliamperes (.010 ampere) or 2,200 ohms. Any resistance slightly higher than this may be used and will give a reading of less than 10 milliamperes.

A shunt resistance can then be connected across the meter terminals. The connection of this shunt resistance across the milliammeter will immediately reduce the reading on the milliammeter because now only part of the total current in the circuit flows through the meter. This shunt can be increased or decreased until the ratio of the original reading and the reading with the shunt across the meter is approximately equal to the multiple by which it is desired to multiply the meter scale.

If for instance the original meter scale is 0 to 10 and it is desired to increase the range to 0 to 50, the multiple is 5.

If the original reading of the meter with the battery mentioned and the series resistance is 10 milliamperes, the shunt resistance should be adjusted until the reading with the shunt resistance connected across the meter is reduced to 1/5th of the original reading or 2 milliamperes. With this value of shunt resistance connected across the meter, the readings of the meter when used in any circuit must be multiplied by 5.

If the value of the series resistance is such that the original reading of the meter in the circuit is 9 milliamperes, and the use of a shunt across the meter reduces the reading to 2.2 milliamperes, the multiple by which each value on the meter must be multiplied, when that value of shunt resistance is connected across the meter, is 9 divided by 2.2 or 4.09.

The slight change in the total series resistance in the circuit due to the lowered resistance of the meter when a shunt is connected across the meter resistance, introduces a slight inaccuracy in the readings, but this is so small as to be negligible.

In making a calibration chart for the above conditions, lay out the present readings of the scale along the horizontal line. Pick out any value and multiply it by the multiple which will give the corresponding value on the new scale. Then draw a line through the zero of both scales and the point just located to give the line which locates all corresponding points on both scales.

All high resistance voltmeters consist essentially of a sensitive current indicating instrument, such as a milliammeter, connected in series with a high resistance that limits the flow of the current through the meter, when the series combination of meter and resistance is connected across a source of voltage.

Note *—The first article of this series on the use of multipliers to increase the range of ammeters and voltmeters appeared in the January, 1930 issue of the Research Worker. Readers whose subscription begins with this issue (February) and who therefore missed the first article, may obtain the January issue on request. There is no charge or obligation. Merely write to the Research Worker, Aerovox Wireless Corporation, 70 Washington St., Brooklyn, N. Y.

If we take a 0 to 1 milliampere milliammeter such as the Weston Model 301 or the Jewel Pattern 88 meters of that range, a full scale deflection of 1 milliampere will be obtained when the meter is connected across a voltage of a value such that the voltage divided by the internal resistance of the meter is equal to 1 milliampere (.001 ampere). In other words, the voltage necessary to obtain full scale deflection is equal to the resistance of the meter multiplied by .001.

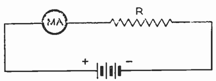

Fig. 7

In the case of the Weston Model 301, 0 to 1 milliammeter, the table of meter resistances given in last month's Research Worker shows that the internal resistance of this type of milliammeter is 27 ohms. The voltage necessary to give full scale deflection is therefore equal to 27 times .001 or .027 volts.

In the case of the Jewell Pattern 88, 0 to 1 milliampere milliammeter, which has an internal resistance of 30 ohms, the voltage required to give a full scale deflection would be .03 volts.

If we connect a resistance R in series with the milliammeter and connect the series combination of milliammeter and resistance across a battery or other source of voltage, as shown in Fig. 7, the current in the circuit will be equal to the voltage of the battery divided by the resistance, in accordance with Ohm's Law.

Since the full scale deflection on the milliammeter will be obtained when a current of 1 milliampere flows in the circuit, we can therefore say that the voltage reading at full scale deflection will be equal to .001 times the total resistance in the circuit. If the total resistance in the circuit (the value of the internal resistance of the milliammeter plus the value of the external resistance R) is equal to 1,000 ohms, the voltage required in the battery to give full scale deflection will be 1,000 times .001 or 1 volt. If the total resistance in the circuit is 20,000 ohms, the voltage required in the battery to give full scale deflection will be 20,000 times .001 or 20 volts. If the total resistance in the circuit is 250,000 ohms, the voltage required in the battery to give full scale deflection will be 250 volts, etc.

If however, we use a meter having a range of 0 to 10 milliamperes, (.01 ampere) full scale deflection when using a total resistance of 1,000 ohms in the circuit will be obtained with a voltage of 1,000 times .01 or 10 volts. If a total resistance of 20,000 ohms is used, full scale deflection of 10 milliamperes will be obtained with a voltage of 200 volts. With a total resistance of 250,000 ohms, full scale deflection will be obtained with a voltage of 2,500 volts.

It will be noted that in the case of the 0 to 1 milliampere milliammeter, the ratio of total resistance in the circuit to the maximum voltage at full scale deflection, (1,000 ohms—1 volt; 20,000 ohms—20 volts; 250,000 ohms—250 volts) is 1,000 ohms per volt. The maximum voltage reading at full scale deflection is governed by the total resistance in the circuit, and is proportional to the resistance.

In the case of the 0 to 10 milliampere scale milliammeter, the ratio of resistance to voltage at full scale deflection is 100 ohms per volt.

Greatest accuracy in making voltage measurements is obtained when the current taken by the voltmeter is very small. If the current taken by the voltmeter (consisting of ammeter and series resistance) is large, the additional current taken from the circuit affects the regulation of the system, resulting in an appreciable difference of voltage across the points measured when the voltmeter is connected or disconnected from the circuit.

For this reason, voltmeters having a high ratio of resistance to full scale reading, or what amounts to the same thing, voltmeters which use a sensitive, low range milliammeter as the indicating instrument are preferred for measurements in battery eliminator systems or other circuits where voltages in the circuit are affected by additional current drains.

From the two examples that have been given we see that it is possible to determine the current range of the milliammeter used in the voltmeter if the voltage range of the voltmeter and the total resistance or ohms per volt are known.

If the resistance is 1,000 ohms per volt, we know that the maximum current through the meter is one divided by 1,000 or .001 ampere (1 milliampere). If the resistance of the voltmeter is 100 ohms per volt, the maximum current reading is one divided by 100 or .01 ampere (10 milliamperes).

It is also possible to determine the range of milliammeter which must be used to give a voltmeter of any desired "ohms-per-volt" characteristics. If for instance we wish a voltmeter having a range of 0 to 500 volts with characteristics of 2000 ohms per volt, the total resistance in the circuit (resistance of milliammeter and series resistance "R", in Fig. 7,) must be 500 times 2000 or 1,000,000 ohms. This means that the current at full scale deflection will be 500, the full scale voltage reading, divided by the total resistance in the circuit which is 1,000,000 ohms. The answer is .0005 ampere or .5 milliampere. A voltmeter constructed by using a 0 to .5 milliammeter (0 to 500 microamperes microammeter) in series with a resistance to bring the total resistance to 1,000,000 ohms would give the required characteristics of 0 to 500 volt scale with a resistance of 2,000 ohms per volt.

In most cases, when the voltage scale runs fairly high and the ratio of meter resistance to total resistance is low, the internal resistance of the meter, may be neglected, and the required series resistance may be taken as the value of the total resistance required in the circuit. In making a voltmeter to measure low voltages however, the ratio of meter resistance to total resistance may run fairly high and would introduce an appreciable error. In

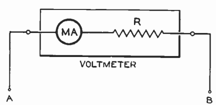

Fig. 8

such cases therefore the internal resistance of the milliammeter should be known and the value of external resistor chosen should be such that the sum of both the meter resistance and external resistor will be equal to the total resistance required in the voltmeter circuit.

If for instance we require a high resistance volmeter having a range of from 0 to .2 volts and a resistance of 1,000 ohms per volt, the total resistance required in the circuit would be .2 multiplied by

1,000 or 200 ohms. The range of meter required to give full scale deflection on .2 volts with a resistance of 200 ohms would be .2 divided by 200 or one divided by 1,000, both of which give a value of .001 ampere (1 milliampere) as the range of milliammeter required.

If a Jewell Pattern 88, 0 to 1 milliammeter having a resistance of 30 ohms is used, the resistance R of Fig. 7 should have a resistance

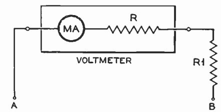

Fig. 9

of 170 ohms to make up the total of 200 ohms required. If the resistance of the meter is disregarded and a 200-ohm resistance is used at R, the total resistance in the voltmeter circuit will be 230 ohms instead of the required 200 ohms. This means that for full scale deflection, .001 ampere, with 230 ohms in the circuit, a voltage of 230 times .001 or .23 volts will be required. A full scale deflection in that case would actually be .23 volts instead of the required .2 volts and would constitute an appreciable error.

In the case of a 0-50 volts arrangement however, using a 0 to 1 milliampere meter, the required 1,000 ohms per volt characteristics can be obtained by using an external resistor R of 49,970 ohms which with the 30 ohms of the meter would give a total resistance of 50,000 ohms.

If the resistance of the meter were disregarded in this case, and a 50,000 ohm resistor were used at R of Fig. 7, the total resistance in the circuit would be 50,030 ohms and the voltage at full scale deflection would be 50,030 times .001 or 50.03 volts. The .03 volt error in this case would be negligible.

So far we have considered merely the ranges required in a milliammeter to give any desired ohms-per-volt characteristic and the series resistances necessary to give the required voltage range to the voltmeter.

In many cases a high resistance voltmeter of a certain range is available and it is desirable to know how to increase the voltage range of the instrument to measure higher voltages. When the maximum voltage reading of the voltmeter and the ohms-per-volt characteristic of the meter are given, it is a simple matter to calculate the additional series resistance which must be used with the voltmeter in order to increase its range to any desired reading.

Any given high resistance voltmeter can be considered as a milliammeter connected in series with a resistance R as shown in Fig. 8. Only two terminals are brought out in a meter which has a single range.

If the milliammeter used has a range of 0 to 1 milliampere, and a total resistance of 50,000 ohms due to the resistance of the meter and the series resistance R, the range of the meter will be 0 to 50 volts with a rating of 1,000 ohms per volt.

If an additional external resistance of 50,000 ohms is connected in the circuit as shown at R1 in Fig. 9, the total resistance in the circuit is increased to 100,000 ohms. The voltage required now to give the full scale deflection of 1 milliampere (50 volts reading on the voltmeter scale) will be 100,000 (the resistance in the circuit) times .001 (the current in the circuit at full scale deflection) or 100 volts.

If a resistance of 100,000 ohms is used at R1, the total resistance in the circuit will be 150,000 ohms and the voltage required to give full scale deflection will be 150 volts.

To obtain the value of resistance required at R1, Fig. 9, to increase the maximum scale reading of a voltmeter it will be found that all that is necessary is to multiply the total resistance of the voltmeter (ohms-per-volt rating times the maximum voltage on the scale) by one less than the multiple by which it is desired to increase the maximum reading of the present scale.

Thus if the present range of a voltmeter is 50 volts and its rating is 1,000 ohms per volt, the total resistance of the voltmeter is 50,000 ohms. If it is desired to increase the range to 100 volts the multiple is 2 since 50 must be multiplied by 2 to obtain 100. The external resistance required at R1 is found by multiplying the resistance of the meter (50,000 ohms) by one less than the multiple i. e., 1, since 2 less 1 is 1. This means that the resistance required at R1 is 50,000 ohms. If it is desired to increase the range from 0 to 50 up to 0 to 250, the multiple is 5. The resistance of the meter, 50,000 ohms must therefore be multiplied by one less than the multiple or 4, (5—1). R1 would therefore have to be a resistance of 200,000 ohms.

With a total resistance of 250,000 ohms (50,000 ohms of the voltmeter and 200,000 ohms in the external resistor R1) the voltage required to give a full scale deflection of 1 milliampere will be 250,000 times .001 or 250 volts, which proves the above method of finding the external resistance required to be correct.

There are two general methods of connecting external resistors to make a multirange voltmeter out of a milliammeter or to increase the range of a standard voltmeter.

The method shown in Fig. 10 uses single or individual external resistors for each separate range. If the present scale of the voltmeter is 0 to 50 volts with a total resistance of 50,000 ohms in the voltmeter, when the A and B terminals of the voltmeter are used, a resistance of 50,000 ohms at R1 will increase the voltage range to 0 to 100 when terminals A and B1 are used. A resistance of 100,000 ohms at R2 will increase the range to 0 to 150 volts using terminals A and B2. A resistance of 150,000 ohms at R3 will increase the range to 0 to 200 volts using terminals A and B3 while a resistance of 200,000 ohms at R4 will increase the range to 0 to 250 volts using terminals A and B4. In each case the full scale deflection will cause a current of 1 milliampere to flow in the circuit because a 0 to 1 milliampere meter is used in the voltmeter proper.

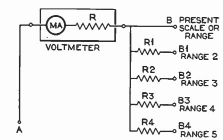

Fig. 10

With a current of 1 milliampere flowing through them, the 50,000 ohm resistor, R1, will dissipate .05 watt, the 100,000 ohm resistor, R2 will dissipate .1 watt, the 150,000 ohm resistor, R3, will dissipate .15 watt and the 200,000 ohm resistor, R4, will dissipate .2 watt.

In the arrangement shown in Fig. 11 however, the watts dissipation of each resistor, due to the fact that each resistor has the same value of resistance, is the same.