H T HOOVER

Radio Editors of magazines and newspapers are hereby given permission to reprint in whole or in part, with proper credit to the Aerovox Corporation, the contents of this issue of the Aerovox Research Worker.

The AEROVOX Research Worker

The Aerovox Research Worker is a monthly house organ of the Aerovox Corporation. It is published to bring to the Radio Experimenter and Engineer authoritative, first hand information on condensers and resistances for radio work.

Vol. 7, No. 8 | AUGUST, 1935 | 50c per year in U.S.A. 60c per year in Canada

The Proper Use of Resistors to Extend Meter Ranges

By the Engineering Department, Aerovox Corporation

MOST readers are familiar with the use of resistors as shunts and multipliers to extend the range of measuring instruments. However, inquiries show that there exists a good deal of confusion when it comes to determining the correct resistance values and the best circuits for multi-range instruments. It is the purpose of this article to show again the proper way of arriving at the correct value of shunts or multipliers for a given case and to show the different circuits now in use, discussing their respective merits.

VOLTMETERS

A voltmeter is nothing but a milliammeter with a high resistance in series with it. It should be clear that when the current is known which flows through this high resistance, the voltage at its terminals can be found by Ohm's Law. The user has been spared this computation since the instrument is calibrated directly in volts. The same meter movement will serve for instruments of different ranges because the voltage at its terminals at full scale deflection is proportional to the resistance of the meter plus its multiplier; so, by providing additional resistors, higher ranges can be obtained. The resistance value of the multiplier for each additional range depends on the sensitivity of the meter movement. This brings us to the important point of "sensitivity".

OHMS PER VOLT

The sensitivity of a voltmeter is expressed in "ohms per volt" and equals the total resistance of the meter divided by the number of volts indicated at full scale deflection. This figure indicates how much current it takes to operate the meter. For instance, if an 0-10 voltmeter has a resistance of 10,000 ohms, the sensitivity would be 1,000 ohms per volt, and from Ohm's Law it is easily found, that the meter requires a current of 1 ma at full scale deflection. Similarly, if the 0-10 voltmeter had a resistance of but 1,000 ohms, the sensitivity would be 100 ohms per volt and it would require 10 ma to move the needle to full scale deflection. This illustrates that: THE HIGHER THE RESISTANCE OF THE VOLTMETER—FOR A GIVEN RANGE—THE GREATER THE SENSITIVITY.

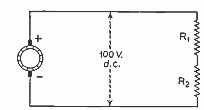

Fig. 1

The lack of sufficient sensitivity results in inaccuracy when the instrument is used in high-resistance circuits. This is shown best by an example. In Fig. 1, two resistors are connected across a d. c. generator delivering 100 volts. Neglecting for this purpose the resistance of the generator itself, the 100 volts will divide across the resistors in proportion to their resistance. Suppose R1 is 6000 ohms and R2 is 4000 oms. Then the voltage across R2 would be 40 volts. But what would a voltmeter show?

Employing a voltmeter of 100 ohms per volt sensitivity and having a 50 volt range, the voltmeter resistance would be 5000 ohms. Suppose this is connected across R2 to measure the 40 volts. The presence of the voltmeter places a resistance of 5000 oms in parrallel with the 4000 making a resultant resistance between B-C of

$$\frac{5000 \times 4000}{5000+4000} = \frac{20{,}000{,}000}{9000} = 2{,}222 \text{ ohms}$$

The total resistance in the circuit is now 6000+2,222=8,222 ohms and the voltage across R2 as shown by the meter is now

$$\frac{2{,}222}{8{,}222} \times 100 = 27 \text{ volts}$$

This does not mean that the meter itself is inaccurately calibrated because the voltage is actually 27 volts when the voltmeter has been connected. However, it was desired to know the voltage between B and C before the voltmeter was connected; and so the answer was unsatisfactory. It is obvious then, that the resistance of the voltmeter must be such that it will not materially alter the conditions in the circuit to be measured. This is satisfied by an instrument of higher sensitivity. Let us apply the same example to a meter of 1,000 ohms per volt sensitivity. Employing again a 50 volt range, the meter resistance becomes 50,000 ohms. When this is con-

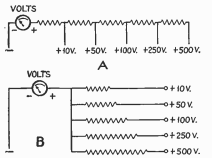

Fig. 2

nected across R2, the resistance between B and C becomes

$$\frac{4000 \times 50{,}000}{4000 \quad 50{,}000} = \frac{200{,}000{,}000}{\cdot\ 54{,}000} = 3700 \text{ ohms}$$

and the meter would show

$$\frac{3700}{9700} = 38.1 \text{ volt}$$

If the range of the voltmeter used had been the 100 volt range, it would have indicated 39 volts. This illustrates the trend of the reduction in error when the resistance of the meter is increased. It shows that even with

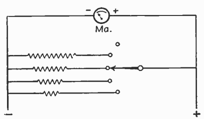

Fig. 3

a 1,000 ohms per volt instrument there is still an error of 5 per cent. The example did not contain as high resistance as one often uses in radio work. It should therefore be clear that there are many cases in radio circuits where the voltage cannot be measured with any degree of accuracy with any voltmeter which draws any current at all. This happens in resistance coupled amplifiers. In those circuits it is necessary to arrive at the voltage by measuring the current through the resistances in question and then calculate the voltage by Ohm's Law. Instruments which do not take any current from the circuit can also be used; these are: vacuum tube voltmeters and potentiometers.

EXTENDING VOLTMETER RANGES

In order to extend the range of a voltmeter, a multiplier resistor is placed in series with it. Although it seems almost needless to say so, one cannot extend the range of a meter downward, neither can the sensitivity be increased by resistors. If it is possible to get at the inside of the meter and take a tap directly from the meter movement it may sometimes be possible to obtain a lower range.

The proper value of the multiplier resistor is found from the equation:

$$R = (n-1)\ Rm$$

where Rm is the meter resistance and n is the factor whereby the range is to be multiplied. When a 10 volt range is

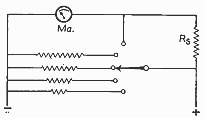

Fig. 4

to be increased to a 100 volt range, the multiplier should equal 9 times the meter resistance. When the meter resistance is not known it will have to be measured.

If the sensitivity of the meter is known, the following rule may be found convenient. The multiplier range should be equal to the sensitivity in ohms per volt, times the volts which are to be added to the range. For instance, a 1000 ohms per volt meter requires 1000 ohms, for every volt added. Increasing the range from 10 to 100 volts (adding 90 volts) requires

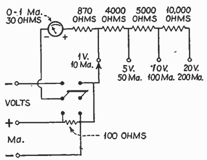

Fig. 5

a 90,000 ohm multiplier. Changing a range from 150 to 750 volts, takes 600,000 ohms for a 1000-ohms-per-volt meter.

MULTI-RANGE VOLTMETERS

It is obvious that a multi-range instrument can be made by tapping the multiplier resistors and to connect the circuit to the taps by means of a switch or by separate terminals. Two possible circuits are available. They are shown in Fig. 2A and 2B. In Fig. 2A the most economical use is made of the resistors, but it has the drawback that if the multiplier for a low range burns out accidentally, all the other ranges are useless. In Fig. 2B, more resistors are needed, but if one multiplier is defective all other ranges can still be used.

MILLIAMMETERS

The range of a milliammeter can be extended by shunting it with a resistor. The proper size of the shunt is found from the following consideration: Suppose the shunt was equal to the meter resistance. Equal currents would then flow through the two branches, or, the meter would show half of the current and the range has been multiplied by two. For similar reasons, a shunt equal to one-half of the meter resistance will multiply the range by three. A shunt of 1/3 of the meter resistance multplies the range by four, etc.

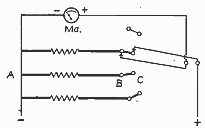

Fig. 6

A milliammeter of low range can be converted to a multi-range milliammeter by the addition of several such shunts. Large errors may be introduced and the instrument may be damaged unless proper precautions are taken when designing the switching circuits. The most obvious circuit for the purpose is shown in Fig. 3. In the first position, no shunt is in the circuit, therefore the original range of the meter is now in use. In the other positions one of the shunts is employed. Suppose that one switches from one range to another and the switch arm breaks contact with one terminal before it makes contact with the next. During the time that the shunt is open the lowest range is in use and if this is done while measuring relatively heavy current the meter will burn out. Also, should the switch fail to make con-

tact at any point, this point will represent the lowest current range and the unsuspecting user may again overload and damage the meter.

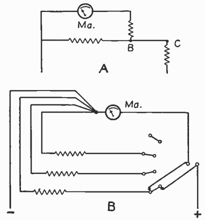

Fig. 7

There is still another drawback to this arrangement. The switch contact is a part of the shunt and if a switch should make a bad contact, the resistance of the shunt is increased with a consequent error in reading. Since shunts have very low resistance, especially for high ranges, the contact resistance does not have to be very high before it becomes large enough to cause errors. On high ranges it will be difficult to get the same reading twice if the switch contact is anything less than perfect.

A "shorting" type switch will eliminate the first objection but the second and third disadvantages remain unless a perfect switch is found. Several schemes are in use for eliminating these troubles. One of these is illustrated in Fig. 4. A series resistor is used in the meter branch; in order to multiply the meter range by n, the shunt must now be

$$R = \frac{Rm + Rs}{n-1}$$

If Rs is chosen sufficiently large, the shunt does not have to be of so low a resistance. The importance of perfect switch contacts then becomes less but the milliammeter will have a higher resistance. This has the same effect as a voltmeter of low sensitivity; it changes conditions in the circuit and may give an erroneous reading. Radio circuits generally have rather high resistance which makes the high-resistance milliammeter still useable. In the circuit of Fig. 4 the lowest range has the normal resistance of the meter only because Rs is shorted in that position.

It is now possible to keep the shunt constant and to obtain different ranges by providing different values of Rs. These series resistors can often be the same ones which are used when the meter is employed as a voltmeter. Fig. 5 shows an example of this type of circuit. A common error is to neglect the current flowing through the meter itself and to consider that the meter with the series resistor is a voltmeter measuring the drop across the shunt. Fig. 5 shows values for an 0-1 ma meter with an internal resistance of 30 ohms.. If the value of the shunt is taken as 100 ohms, the value of Rs should be 100 ohms less than its corresponding voltmeter multiplier value. This is accomplished economically with the d.p.d.t. switch. No doubt this circuit is very economical on precision resistors but it has the drawback of too high resistance; and it is not used very much today.

Fig. 6 shows a switching system which overcomes all the dangers of open switch contacts and the effects of bad contacts. It requires a double-deck switch. Considering an individual range, the shunt extends from A to B. If the contact at B is open, the meter circuit is open and the instrument will not indicate. If the contact at C is open, the main circuit is open and the meter again is not in a dangerous position.

The switch contacts at B and C are not a part of the shunt. If any resistance exists at these points, the circuit becomes as in Fig. 7. These added resistances are in such parts of the circuit that their effect on ac-

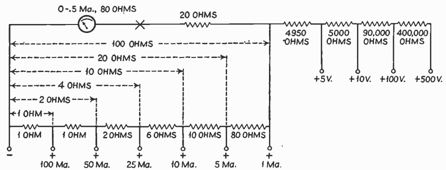

Fig. 9

curacy is unimportant. In this circuit it is important to make the wires which are shown heavy, as short as possible and to use bus bar. The shunts should all be connected together to a short piece of bus bar and they should not have individual wires running to the meter because these wires become a part of the shunt. Fig. 7B shows the wrong way, Fig. 6 shows the right way.

A third system, now becoming popular employs a tapped shunt and does away with the switch altogether. It eliminates burning out dangers when moving from one range to another and it introduces no errors due to faulty contacts. The circuit is shown in Fig. 8. When the test prods are connected to A and E, the entire resistor A-E becomes the shunt. When the test circuit is connected to A-C, the resistor C-D-E becomes a part of the meter branch and A-C is the shunt. When the sum of all the resistors plus the meter is some round number, such as 100 ohms, the taps come at even values of resistance and no odd-value shunts are required.

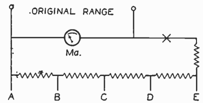

Fig. 8

This is why: It was shown that, in order to multiply the range by any number, n, the resistance of the shunt should be 1/(n—1) times the resistance of the meter branch. Or, the resistance of the meter branch is (n—1) times the resistance of the shunt. The sum of the two branches, or the total resistance of the circuit A-B-C-D-E and back through the meter to A equals n times the resistance of the shunt; or, the shunt equals 1/n of the total resistance. In Fig. 8 the sum of all resistances remains the same for all ranges, so the values A-B, A-C, etc., are easily found. As an example, suppose the meter had a resistance of 80 ohms and a range of .5 ma. It is desired to obtain ranges of 1, 5, 10, 25, 50 and 100 ma. The total values of the tapped resistor is now taken as 120 ohms, making with the 80 ohms meter resistance a total of 200 ohms.

For a range of 1 ma., n=2, so the shunt should be 100 ohms. This gives us the value of the tapped resistance in Fig. 9. The range of 5 ma. makes n=10, so the shunt should be 20 ohms. For 10 ma the shunt is 10 ohms, for 25 ma, 4 ohms, 50 ma, 2 ohms and for 100 ma, 1 ohm. This gives us the solution for the complete circuit. All resistance values are standard, no special shunts required.