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# The AEROVOX Research Worker

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# High-Resistance Non-Electronic D. C. Voltmeters

*By the Engineering Department, Aerovox Corporation*

A VOLTMETER used to check high-resistance electronic circuits must have high internal resistance, in order to minimize circuit loading. The d. c. vacuum-tube voltmeter meets this requirement and has been obtainable in the service category for about 15 years. Most of these electronic voltmeters have input resistances of 11 megohms, constant for all ranges, although some service-type models go as high as 20 megohms.

The non-electronic d. c. voltmeter offers the advantages of complete portability, simplicity, freedom from drift and zero adjusting, and the ability to operate without any sort of power supply. These features often are definitely required in field testing and are desirable also in the laboratory when removal from power line and batteries is a requisite. But the common non-electronic voltmeter has relatively low input resistance.

It is of interest to note that a non-electronic d. c. voltmeter having high input resistance can be obtained with a sensitive d. c. microammeter and high-resistance multiplier. The full-scale deflection of the microammeter must be somewhat lower than is common in meters ordinarily used in conventional voltmeters. Thus, a 0-10 d. c. microammeter with a 25-megohm series resistor provides a 0-250 d. c. voltmeter. Note that the input resistance in this case is higher than that of the conventional d. c. vacuum-tube voltmeter. The instrument sensitivity is 100,000 ohms per volt.

Ultra-high-resistance, non-electronic d. c. voltmeters of this type are entirely practical. Multiplier resistors may be switched in the instrument circuit, in the conventional manner, to change ranges. D. C. microammeters are available with full-scale deflections of 2, 5, 10, 15, 20, and 30 microamperes.

*U. H. R. Voltmeter Circuits*

Figure 1 shows the circuit of a multirange ultra-high-resistance d. c. voltmeter having 100,000 ohms per volt sensitivity. A 0-10 d. c. microammeter is employed. The voltage

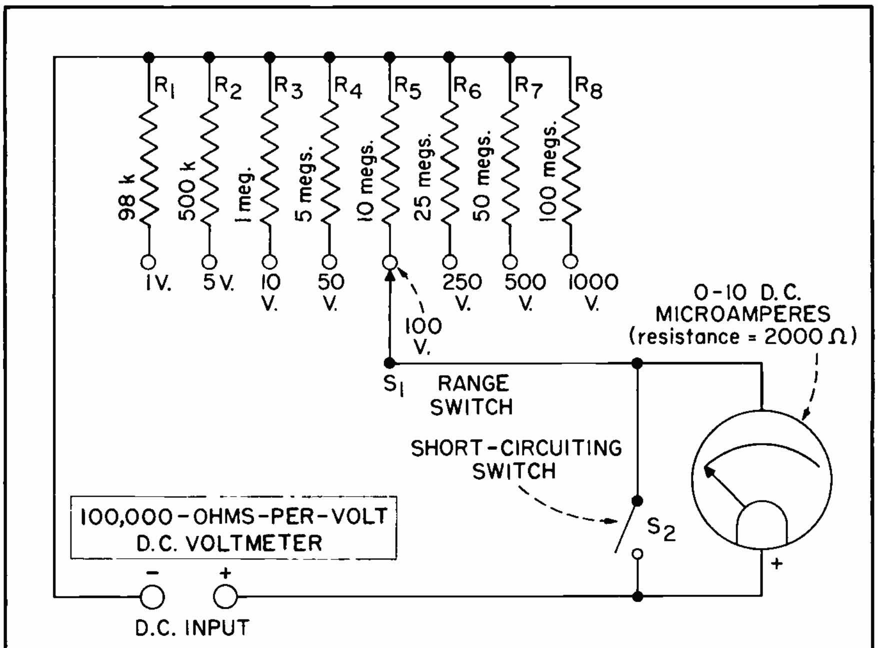


FIGURE 1



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ranges provided are 0-1, 0-5, 0-10, 0-50, 0-100, 0-250, 0-500, and 0-1000 volts. Other ranges, more desirable to the reader can be added or substituted for those shown. The multiplier resistor values are calculated by means of Ohm's Law, R = E/I where R is the required multiplier resistance in ohms, E is the desired full-scale voltage deflection in volts, and I is the full-scale current deflection of the microammeter *in amperes.* Figure 4 is a chart listing calculated multiplier resistance values for 23 common voltage ranges for use with sensitive microammeters of six different full-scale deflections.

The internal resistance ($r_m$) of high-sensitivity microammeters is comparatively high. In the 0-10 microammeter, for example, this value lies between 2000 and 4000 ohms, depending upon manufacture and model number. For best accuracy, the meter resistance value, $r_m$ must be subtracted from the calculated multiplier resistance, R, whenever R/r is 100 or less. Thus in Figure 1, the calculated value of the 1-volt multiplier would be 100,000 ohms. But the meter internal resistance is 2000 ohms and 100,000/2000 = 50, so we must subtract the meter resistance, giving the accurate multiplier value of 98,000 ohms. On each other voltage range, $R/r_m$ is higher than 100, so the calculated multiplier resistance values are used.

Figure 2 is a table showing pertinent data for commercially available sensitive d. c. microammeters with full-scale deflections between 2 and 30 microamperes. Displayed in this chart are the internal resistance ($r_m$) values and the voltmeter sensitivities (in ohms per volt) which the meters will provide in voltmeter circuits. All except the 2 microampere model are panel-type instruments. The 0-2 microammeter is a portable case-type, but can be mounted on the panel of an assembled u. h. r. voltmeter.

Figure 3 shows a useful variation of the u. h. r. volt-meter circuit. Here, a center-zero type of microammeter is employed. The right half of the scale is graduated from zero up to the maximum positive voltage, and the left half from zero down to the maximum negative voltage of the same value. When a test voltage is applied so that the upper input terminal is positive, the meter is deflected up-scale to read the voltage. If the voltage source is reversed, the meter is deflected down-scale and reads the same voltage but with negative sign. Thus, no changeover of test leads is needed.

| SCALE (µa.) | METER RESISTANCE, $r_m$ (ohms) | VOLTMETER SENSITIVITY (ohms per volt) |
|---|---|---|
| 0—2 | 10,000 | 500,000 |
| 0—5 | 8000 | 200,000 |
| 0—10 | 2000—4000 | 100,000 |
| 0—15 | 5000 | 66,666 |
| 0—20 | 1520 | 50,000 |
| 0—30 | 1520 | 33,333 |

TABLE OF MICROAMMETER DATA

FIGURE 2

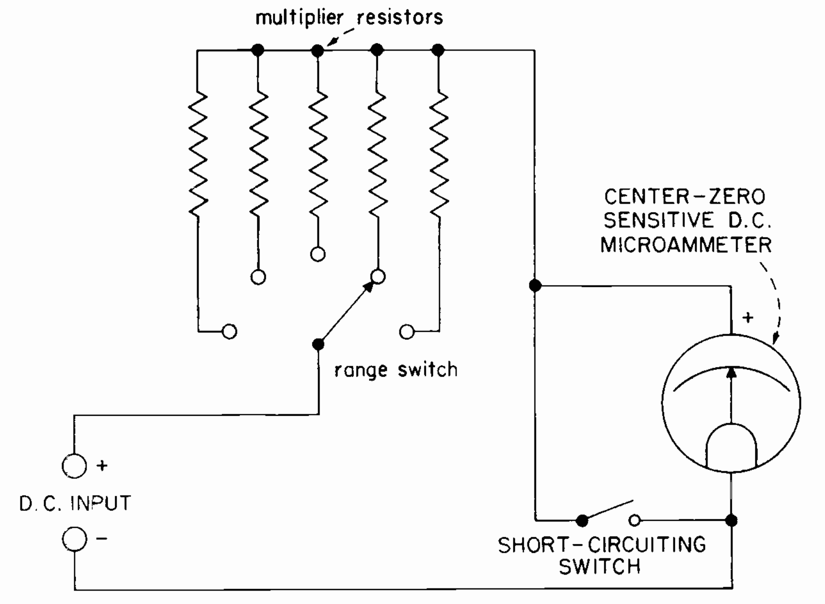
*Sensitivity and Resistance*

The last column in the chart in Figure 2 shows the voltmeter sensitivity which is afforded by available high-sensativity microammeters. These sensitivities are obtained on each range of voltmeters employing the meters.

The input resistance changes with each range of the voltmeter, however, since it is equal almost entirely to the resistance value of the multiplier. The multiplier values listed in the chart in Figure 4 show the input resistance which a given voltmeter will have on each range. If we take 10 megohms as the approximate input resistance of a d. c. vacuum-tube voltmeter, we find that this value will be equalled on the 20-volt range using a 0-2 microammeter, the 50-volt range with a 0-5 microammeter, 100-volt range with 0-10 microamperes, 150-volt range with 0-15 microamperes, 200-volt range with 0-20 microamperes, and 300-volt range with 0-30 microamperes. In each instance, all higher-voltage ranges will have higher input resistance than the v. t. voltmeter. These relationships point up the necessity for using the lowest-range microammeter that can be afforded for this application.

*Pointers on U. H. R. Voltmeter Construction*

The combination of extremely sensitive microammeter and very high multiplier resistance is not commonplace. Certain precautions are necessary in the construction of volt-




DUAL-DEFLECTION ULTRA-HIGH-RESISTANCE D.C. VOLTMETER

FIGURE 3

meters employing this combination, which do not arise in connection with voltmeters up to 20,000 ohms-per-volt sensitivity. These precautions are outlined below.

1. Special instrument-type resistors are required beyond 50 megohms. Be sure that the outer surfaces of these components are cleaned carefully after soldering into place. Try not to touch the surfaces with the bare fingers, to prevent depositing greasy or moist finger prints. After installation, wash the exterior portions of the resistors with carbon tetrachloride or any other solvent recommended by the resistor manufacturer. If the resistors have been coated with a special high-insulation wax, DO NOT TOUCH THE BODIES, and do not use solvent which might dissolve the wax.

2. Use the minimum of heat in soldering the resistors in place. Provide a protective heat sink by holding the pigtails with flat-nose pliers while soldering. Continue to grip the leads with the pliers until the soldered joint has cooled completely.

3. The range switch must be provided with excellent insulation to prevent leakage paths. Always use a ceramic-type switch for this application, and do not handle the ceramic insulation any more than necessary during assembly of the voltmeter. After installation, wash the ceramic with carbon tetrachloride or lacquer thinner to remove any contamination.

4. The input terminals of the voltmeter must be insulated from the panel material by ample washers or inserts of high-quality dielectric material, such as polystyrene or ceramic.

| VOLTAGE RANGE | BASIC METER RANGES | | | | | |
|---|---|---|---|---|---|---|
| | 0—2 μa. | 0—5 μa. | 0—10 μa. | 0—15 μa. | 0—20 μa. | 0—30 μa. |
| 0—1 | 500 K | 200 K | 100 K | 66.67 K | 50 K | 33.33 K |
| 0—1.5 | 750 K | 300 K | 150 K | 100 K | 75 K | 50 K |
| 0—2 | 1 meg. | 400 K | 200 K | 133.3 K | 100 K | 66.66 K |
| 0—2.5 | 1.25 meg. | 500 K | 250 K | 166.7 K | 125 K | 83.33 K |
| 0—3 | 1:5 meg. | 600 K | 300 K | 200 K | 150 K | 100 K |
| 0—5 | 2.5 megs. | 1 meg. | 500 K | 333.4 K | 250 K | 166.7 K |
| 0—7.5 | 3.75 megs. | 1:5 meg. | 750 K | 500 K | 375 K | 250 K |
| 0—10 | 5 megs. | 2 megs. | 1 meg. | 666.7 K | 500 K | 333.3 K |
| 0—15 | 7.5 megs. | 3 megs. | 1:5 meg. | 1 meg. | 750 K | 500 K |
| 0—20 | 10 megs. | 4 megs. | 2 megs. | 1.33 meg. | 1 meg. | 666.6 K |
| 0—25 | 12:5 megs. | 5 megs. | 2.5 megs. | 1.67 meg. | 1.25 meg. | 833.3 K |
| 0—30 | 15 megs. | 6 megs. | 3 megs. | 2 megs. | 1.5 meg. | 1 meg. |
| 0—50 | 25 megs. | 10 megs. | 5 megs. | 3.33 megs. | 2.5 megs. | 1.66 meg. |
| 0—75 | 37.5 megs. | 15 megs. | 7.5 megs. | 5 megs. | 3.75 megs. | 2.5 megs. |
| 0—100 | 50 megs. | 20 megs. | 10 megs. | 6.67 megs. | 5 megs. | 3.3 megs. |
| 0—150 | 75 megs. | 30 megs. | 15 megs. | 10 megs. | 7.5 megs. | 5 megs. |
| 0—200 | 100 megs. | 40 megs. | 20 megs. | 13.3 megs. | 10 megs. | 6.7 megs. |
| 0—250 | 125 megs. | 50 megs. | 25 megs. | 16.7 megs. | 12.5 megs. | 8.3 megs. |
| 0—300 | 150 megs. | 60 megs. | 30 megs. | 20 megs. | 15 megs. | 10 megs. |
| 0—500 | 250 megs. | 100 megs. | 50 megs. | 33.3 megs. | 25 megs. | 16.6 megs. |
| 0—750 | 375 megs. | 150 megs. | 75 megs. | 50 megs. | 37.5 megs. | 25 megs. |
| 0—1000 | 500 megs. | 200 megs. | 100 megs. | 66.7 megs. | 50 megs. | 33 megs. |
| 0—1500 | 750 megs. | 300 megs. | 150 megs. | 100 megs. | 75 megs. | 50 megs. |

TABLE OF MULTIPLIER RESISTANCE VALUES

FIGURE 4

5. If a metal panel is used, be sure to specify metal-panel operation when ordering the microammeter.

6. Make an air-tight seal of the instrument case. to prevent the entry of dust, grease, and moisture which will tend to create high-resistance leakage paths on the range switch and multiplier resistors.

7. Ascertain from the meter manufacturer whether the microammeter can be used in all positions. If the meter is specified to operate in one position only (such as horizontal), make a practice of using the voltmeter only in that position.

8. Include a short-circuiting switch to short-circuit the microammeter itself when the voltmeter is not in use. Low-range microammeters often are susceptible to fields and transient phenomena, and the short circuit will protect the sensitive movement. Because of the high resistance of the multipliers, no damage will be done if a potential accidentally is applied to the voltmeter input terminals while the shorting switch is closed.

*Pointers on Use of the Voltmeter*

No special technique is required to measure voltages with the ultra-high-resistance meter. Manipulation of the instrument and its care are the same as with lower-resistance non-electronic voltmeters. However, it is appropriate to call attention here to a few precautions which should be observed to protect the meter and insure continued accuracy of the instrument.

1. When uncertainty exists as to the approximate level of a voltage, use the highest voltage scale first. Then, switch down successively to each lower range until deflection is obtained in the upper portion of the scale.

2. Switch the voltmeter to its highest range during idle periods, and also close the microammeter short-circuiting switch.

3. Always close the short-circuiting switch when the instrument is being transported. This provides efficient damping of the meter and will prevent mechanical damage due to shaking and vibration.

4. Do not expose an ultra-high-resistance voltmeter to magnetic fields, moisture, or corrosive fumes for long periods of time.

5. Keep the panel area around the input terminals scrupulously clean of dust, grease, and moisture.

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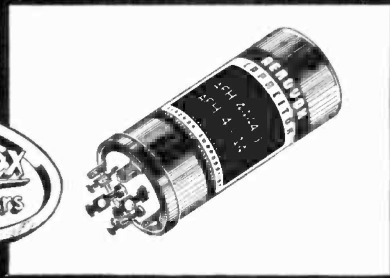

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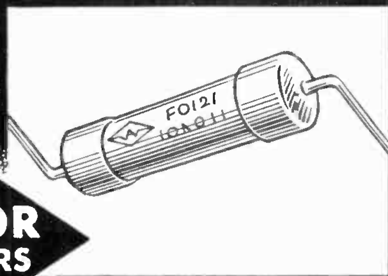

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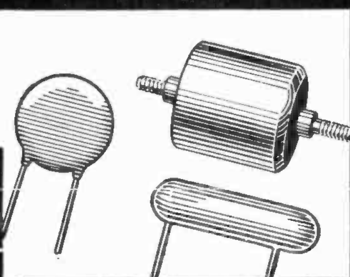

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