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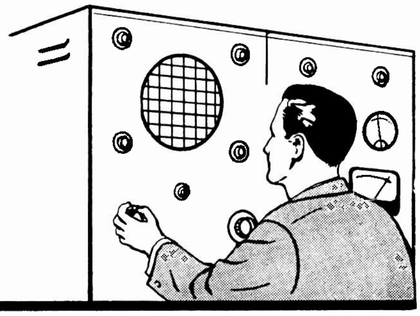

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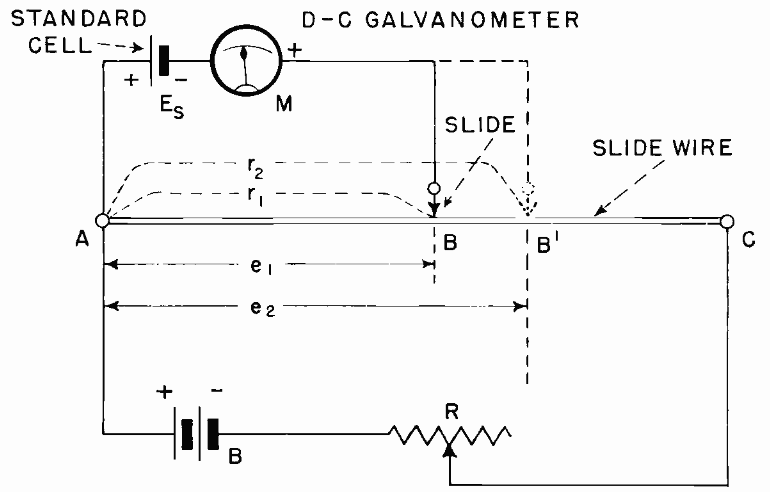
An Experimenter's Potentiometer

By the Engineering Department, Aerovox Corporation

THE **potentiometric method** provides accurate measurements of voltage in the laboratory. This method is employed extensively in the calibration of voltmeters and also particularly in the measurement of small d-c voltages. It has the superiority of all bridge-type measurements; i. e., the comparison of an unknown to a standard quantity.

Although the advantages of potentiometer-type voltage measurements are readily conceded by the experimenter, this method has not been generally available to him. The reason for this has been the costliness of potentiometer instruments.

This article describes an accurate, lower-priced potentiometer which may be assembled by the experimenter. This instrument will provide the precision which formerly has not been obtainable in low-budget laboratories and instrument shops.



PRINCIPLE OF POTENTIOMETER

FIG. 1

Basic Principle of Potentiometer

By means of the potentiometer circuit, the value of an unknown d-c voltage is determined by reference to an accurately-known standard d-c voltage. To perform the measurement, a null adjustment is made and the unknown voltage then is determined from a proportionality in which the unknown voltage is to the standard voltage as the ratio of the circuit resistances.

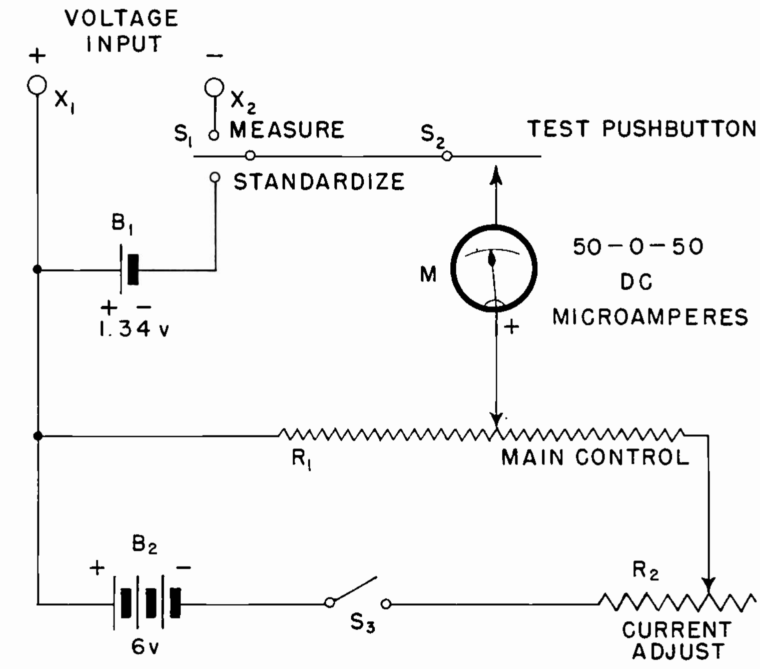
Figure 1 shows the basic circuit of the potentiometer. The principal adjustable component (main control) in this circuit is the slide wire, AC. This is a precision variable resistor which in its simplest form is a straight length of resistance wire stretched tautly between terminals A and C and provided with a slider and scale. In modern laboratory potentiometers, the slide wire is spirally-wound around a form, in order to get as long a strand as possible into a small space.

Battery B supplies a current to the slide wire through the adjustable limiting resistance, R. A standard cell supplying an accurate voltage, E_S, is connected to the slide wire through a center-zero d-c galvanometer, M.

As the slider is moved along the wire, the resistance between A and B, and B and C, is changed. Thus, the ratio of resistance between A and B to that between B and C may be altered as minutely as the slider can be positioned. Current flowing from Battery B produces a voltage gradient along the wire, so that the voltage drop between A and B is directly proportional to the distance from A to B. Thus, the voltage drop is e_1 (corresponding to an A-to-B resistance of r_1) when the slider is at B, and is e_2 (corresponding to an A-to-B' resistance of r_2) when the slider is set to B'. The resistance and voltage drop increase between A and B and decrease between B and C as the slider is moved to the right. The opposite is true when the slider is moved to the left.

To illustrate operation of the circuit, assume first that the slider is set to Point B (say, midway between A and C) and that the rheostat, R, is adjusted to pass a safe amount of current through the slide wire. A voltage drop, e_1, will be set up between A and B. This voltage will increase as R is lowered, and vice versa, and its polarity will be the same as that of the standard cell. When e_1 equals the standard cell, voltage, E_s, it will buck the latter and no current will flow in the circuit AMB. Consequently, the galvanometer, M, will not be deflected. Thus, the meter may be zeroed initially by adjustment of Rheostat R. At this point, the circuit is nulled and the resistance setting of the slide wire is indicated by r_1.

Now, if the standard cell is removed from the circuit and an unknown voltage (E_x) substituted for it, the circuit can remain balanced (nulled) only if the unknown voltage is equal to the standard cell voltage; i. e., $E_x = E_s$. If this equality does not exist, the meter will be deflected upscale if E_x is smaller than E_s, or downscale if E_x is larger than E_s. To restore null, the slider must be moved to a new point (B') at which the voltage drop (e_2) equals the unknown voltage. Voltage e_2 then will buck E_x, and the meter will be returned to zero. The new resistance, between A and B', now is r_2. (The slider would be moved to the right to B', as shown, if the unknown voltage were higher than the standard cell voltage. It would be moved to the left if the unknown were lower). If the slide wire is accurately calibrated in resistance settings and the standard cell voltage is known closely, the unknown voltage (E_x) may be determined from the initial and final resistance settings (r_1 and r_2) and the standard cell voltage (E_s): Thus, $E_x = (E_s r_2)/r_1$. This is true because the ratio of the voltages is equal to the ratio of the resistance settings. That is, $E_x/E_s = r_2/r_1$.



COMPLETE CIRCUIT OF EXPERIMENTER'S POTENTIOMETER

FIG. 2

The precision of voltage measurement by this method depends upon the accuracy of setting of the slide wire, the accuracy to which the standard cell voltage is known, and the sensitivity of the galvanometer.

Details of Experimental Instrument

In commercial, high-precision, laboratory potentiometers, the slide wire is replaced by a bank of precision resistors adjusted by rotary switches. The standard cell is of the special cadmium type and has a nominal voltage of 1.01830 v.

The experimenter's potentiometer (Figure 2) employs a 10-turn helical potentiometer, R_1, for the slide wire. This 1000-ohm unit has a linearity of 0.1%. It is provided with a direct-reading dial (supplied by its manufacturer). Since the resistance of this component is directly proportional to the shaft rotation, the dial reads direct in ohms. The standard cell (B_1) is an inexpensive mercury cell. The cell voltage remains constant at 1.34 v nominal throughout the cell life, almost to the exact instant of burnout. Before installation into the circuit, the exact voltage of this cell may be determined by means of separate precision voltage measurement.

The galvanometer is a standard 50-0-50 d-c microammeter, M. A normally-open pushbutton switch, S_2, is connected in series with this meter. Both the meter and the standard cell are protected, since current can flow in the meter circuit only during short intervals when the pushbutton is tapped for test. (The current drain could be considerable when the circuit is unbalanced, hence should not be allowed to flow continuously under off-null conditions).

The spdt switch, S_1, is the function switch. When it is thrown to its STANDARDIZE position, the standard cell, B_1, is connected to the potentiometer circuit for initial null adjustment. When S_1 is thrown to its MEASURE position, the standard cell is disconnected and an unknown voltage, applied to the input terminals, X_1 and X_2, may be measured with the potentiometer.

The 6-volt battery, B_2, supplies current to the slide wire potentiometer through the CURRENT ADJUST rheostat, R_2. A spst switch, S_3, is provided for disconnecting this battery when the instrument is not in use. Both R_1 and R_2 must be wirewound units. No graduated dial is needed for R_2.

The 10-turn potentiometer, R_1, has been specified for compactness, simplicity, accuracy, and convenience. However, in less critical versions of this instrument, a single-turn wirewound potentiometer may be employed if it is provided with an accurately-calibrated, direct-reading ohms dial.

Operation of Instrument

Initial Balance. (1) Set Switch S_1 to STANDARDIZE. (2) Set Potentiometer R_1 to some convenient point near the center of its range. (3) Close Switch S_3. (4) Tap Pushbutton switch S_2 repeatedly while adjusting Rheostat R_2. Continue to do this until Meter M no longer deflects in either direction. To prevent damage to the meter, the button should not be held down continuously for any length of time, only tapped, until deflection of the meter no longer is beyond either full-scale limit. (5) The circuit is balanced (nulled) when the meter does not deflect either upscale or downscale when the pushbutton is depressed. (6) At this point, note the resistance setting of R_1 and record this value as r_1.

Voltage Measurement. After the balancing operation is completed according to the instructions given in the preceding paragraphs, proceed immediately with d-c voltage measurement in the following manner: (1) Do not disturb the setting of R_2, and keep S_3 closed. (2) Connect the source of unknown voltage to VOLTAGE INPUT terminals X_1 and X_2, carefully observing the correct polarity. (3) Throw Switch S_1 to its MEASURE position. (4) Tap Pushbutton S_2 repeatedly while adjusting Potentiometer R_1. (5) The null point is reached in the adjustment of R_1 when Meter M no longer is deflected when S_2 is closed. At this point, record the resistance setting of R_1 as r_2. (6) Calculate the unknown voltage (E_x) in terms of the 1.34 v standard cell (B_1) voltage: $E_x = (1.34r_2)/r_1$. (The resistance value r_1 was obtained from the potentiometer setting in the initial null adjustment). If it was determined by pre-installation measurements that the voltage of B_1 differs from the nominal 1.34-volt value, substitute the true value in the formula.

Measurement of High Voltage. When the unknown voltage is much higher than that of the standard cell, a null point will not be found at any setting of Potentiometer R_1. Such a voltage must be stepped down before it can be accommodated by the instrument.

The stepdown is provided by an external potentiometer termed a **volt box.** Figure 3(A) shows the basic arrangement of the volt box: A series a resistors are connected in a step-type potentiometer circuit to provide various voltage step-down ratios such as 1000:1, 100:1, 10:1, etc. Figure 3(B) shows the connections between voltage source, volt box, and potentiometer. The potentiometer is balanced for the unknown voltage in the usual manner. The unknown voltage (E_x) then is calculated: $E_x = (1.34mr_2)/r_1$, where **m** is the multiplication ratio of the volt box. (For example; if the volt box "steps the applied voltage down" to 1/300 of its original value, m = 300).

The experimenter may build his own volt box from a properly chosen set of precision fixed resistors selected for desired step-down ratios. Recommended ratios are 1000:1, 300:1, 100:1, 30:1, and 10:1. The use of a calibrated smooth-type potentiometer is to be discouraged, since the reset precision of this type may be poor.

CAPTION FOR FIGURE 2

B_1—1.34 v mercury cell — Mallory RH3R

B_2—Midget 6-volt dry battery — Burgess 2F4

M—50-0-50 d-c microammeter — Triplett Model 327T

R_1—1000-ohm, 10-turn, helical potentiometer — Borg Model 205 with direct-reading dial — Borg Model 1307

R_2—7500-ohm, 3-watt, wirewound rheostat — I. R. C. Type 58

S_1—Spdt wafer switch — Centralab 1460

S_2—Spst, normally-open, pushbutton switch — Grayhill Series 4000

S_3—Spst toggle switch

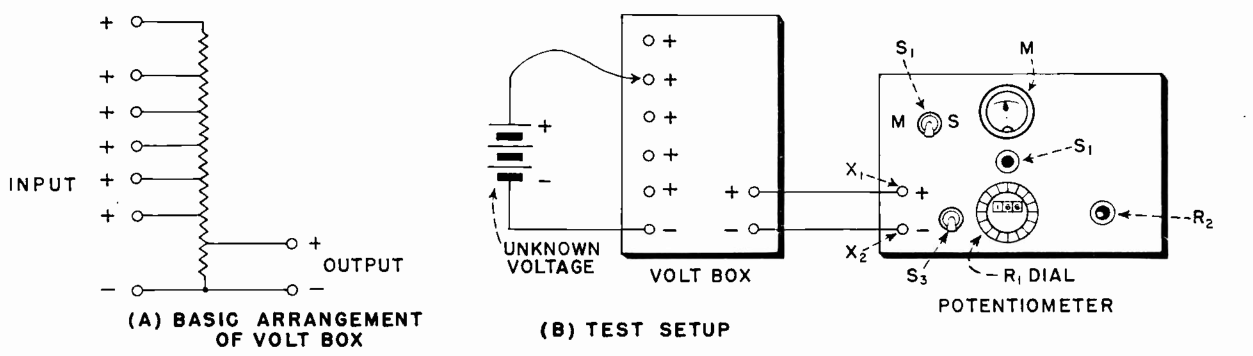
ERRATA

November-December 1958 Research Worker, Volume 28, Numbers 11-12.

Equation (1) should read

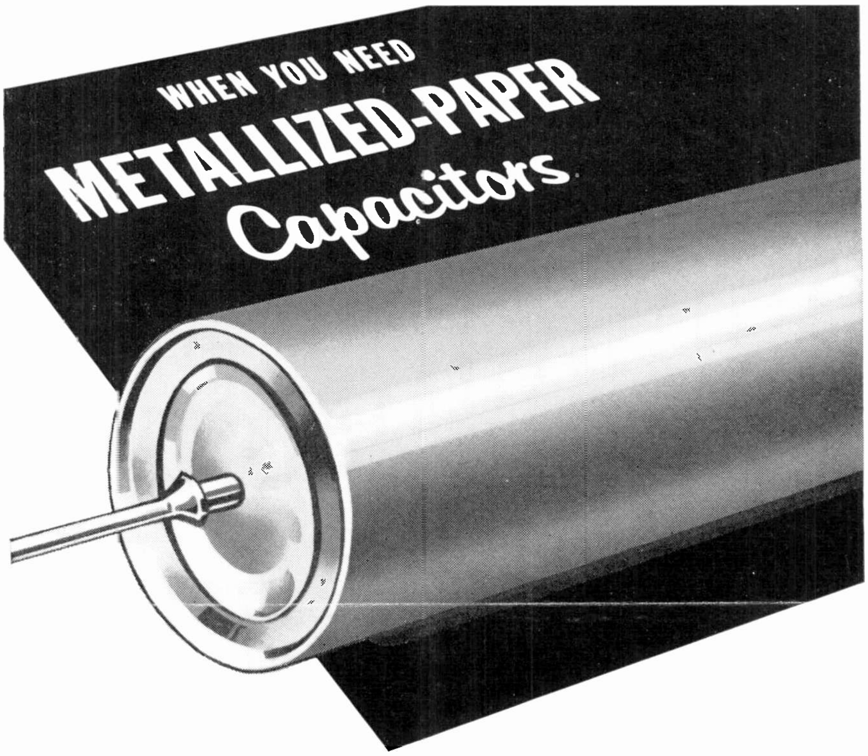
$$\cos \theta = \frac{E_a^2 + E_r^2 - E_c^2}{2E_aE_r}$$

The paragraph immediately above Equation (1) should begin: "If E_a and E_r are sinewaves of the same frequency, etc."



USE OF VOLT BOX TO MEASURE HIGH VOLTAGE

FIG. 3



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