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Applications Of The Electrometer

By the Engineering Department, Aerovox Corporation

THE electrometer is an invaluable instrument in physics and electrical engineering when its potentialities and pecularities are understood. It finds use both in research and testing.

In one form or another, the electromechanical type of electrometer has been used in experimental physics for many years. Its familiar types include quadrant, binant, and fiber. Electrometers differ from electroscopes, to which they bear somewhat of a resemblance, in that the electroscope requires only the potential under test for its deflection, while the electrometer must be supplied with an auxiliary potential as well. The ancient gold-leaf electroscope and the modern electrostatic voltmeter are examples of the single-potential instrument.

The chief advantage of the electrometer is its extremely high input resistance. This characteristic enables the measurement of small currents. It also permits the measurement of voltages under conditions requiring only the minutest current drain. Small currents, such as the 10^{-10} microampere levels produced in gas ionized by radioactivity, have been measured with electrometers.

Electromechanical electrometers, being delicate instruments, are sensitive to vibration, shock, and to some extent to field effects and to air currents. They accordingly give their best performance in the laboratory under skilled handling. The modern vacuum-tube type of electrometer often can be used in environments unfavorable to electromechanical types. It utilizes a more rugged d'Arsonval type of indicating meter, instead of the delicate galvanometer, and is adapted readily to field use. Moreover, the vacuum-tube type allows the measurement of current by the steady-deflection method, rather than the rate-of-drift method required by other electrometers.

Configuration of the V. T. Electrometer

In principle and in general configuration, the vacum-tube electrometer resembles the well-known d. c. vacuum-tube voltmeter. The main difference is the extremely high input resistance of the former. V. T. voltmeters, for example, have input resistances commonly in the range 10 to 20 megohms. The input resistance of an electrometer can be of the order of 10^{10} *megohms.*

Figure 2 shows a typical skeleton circuit of a vacuum-tube electrometer. The circuit is battery-operated. V_1 is the filiment battery ,V_2 plate battery, and V_3 a bucking battery for zero setting. The "high" input terminal, X_1, is provided with a guard ring. Terminal X_2 may be grounded to X_3 or floated, as test conditions require. The indicating d. c. microammeter is connected in the "cathode" return circuit in series with resistor R_3 which is kept high in value for maximum degeneration. Stability and linearity are enhanced by this degeneration. The instrument is set to zero by means of potentiometer R_2 and the bucking battery, V_3. Switches S_1 and S_2 disconnect the batteries when the electrometer is not in use. No plate-battery switch is required, since disabling the filament circuit removes plate current.

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TYPE	MANUFACTURER	Filament Voltage	Filament Current	Plate Voltage	Plate Current	Grid #1 Voltage	Grid #2 Voltage	Grid #1 Current	Grid #2 Current	Plate Resistance	Trans-Conductance
VW41	Victoreen	1.5	0.015	6.0	10	----	1.0	250	$<10^{-8}$	125K	10
FP-54	Gen'l. Electric	2.5	0.09	6.0	60	4.0	4.0	10^{-9}	----	45 K	20 ②
CK571AX①	Raytheon	1.25	0.01	10.5	200	-3.0	----	$2X10^{-7}$	----	----	160
CK5697	Raytheon	0625	0.02	12	220	-3 0	----	$5X10^{-7}$	----	----	135
CK5889	Raytheon	1.25	0.0075	12	5.0	-2.0	4.5	$3X10^{-9}$	5.0	$18X10^{6}$	14
D-96475	Western Electric	1.0	0.27	4.0	85	3.0	4.0	10^{-9}		25K	40 ②
		VOLTS	AMP.	VOLTS	μa.	VOLTS	VOLTS	μa.	μa.	OHMS	μMHOS

① Data for triode-connected pentode.

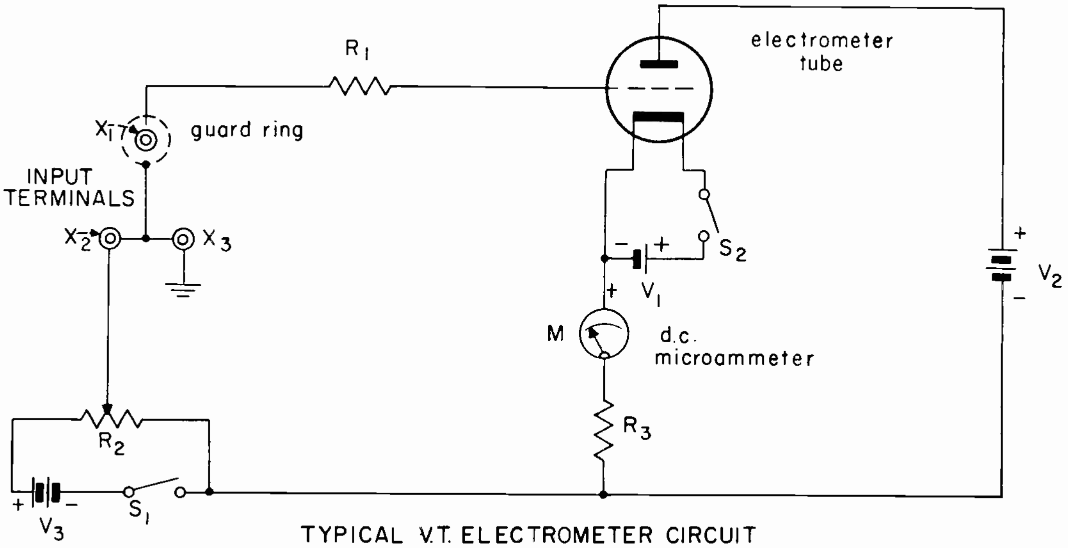
② Microamperes - per - volt.

CHARACTERISTICS OF ELECTROMETER TUBES

FIGURE 1.

A standard radio tube would be unsatisfactory in this circuit, since its input (grid-filament) resistance would be too low for electrometer use. Maximum current amplification demands that input resistance be high. Tube insulation usually is good, but internal charges reach the grid, increasing conductance. Special electrometer tubes have good evacuation and operate at low plate voltage to prevent ionization of whatever residual gas is present. They are operated also at low filament voltage and current, and some types are provided with an internal shield grid to isolate the control grid from positive ions from the filament. In some instruments, the second grid is used for the test-voltage input. In the electrometer, the tube is darkened to prevent spurious photoelectric effects, its envelope is washed carefully with a grease-removing solvent, and the outer surface of the envelope may be coated with a high-quality insulating material for additional protection against contamination from accidental touching or from the atmosphere. Figure 1 shows the characteristics of some electrometer tubes.

The electrometer usually is provided with several ranges. Range switching is accomplished by changing simultaneously the values of voltages V_1, V_2 (and sometimes V_3), and resistor R_3. A portion of R_3 is made adjustable for range calibration. The scale of meter M may be calibrated to read directly in volts. Resistor R_1 is a current-limiting component, the purpose of which is to limit tube input current when excessive signal voltages are applied.



TYPICAL V.T. ELECTROMETER CIRCUIT

FIGURE 2

trometer deflection in volts, and R_1 and R_2 (the voltage-divider resistance arms) are in ohms or megohms *each.*

Figure 4(B) illustrates measurement of the open-circuit voltage of a d. c. power supply having high internal resistance, R_G. The accurate measurement of such a terminal voltage (a resistor-limited constant-current transistor bias supply is an example) would pose a problem if only a v. t. voltmeter were available, since the internal resistance R_G would form a voltage divider with the voltmeter input resistance.

The arrangement in Figure 4(C) enables the measurement of the charged voltage and leakage rate of a sample capacitor, C. R_1 and R_2, if required, are chosen in value so that their total resistance is much higher than the leakage resistance of the capacitor. Switch S is thrown first to position A. This connects the capacitor across the polarizing-voltage source and charges it. The switch then is thrown to position B, connecting the charged capacitor to the electrometer through the voltage divider. The initial deflection of the electrometer shows the charged voltage of the capacitor, and the decline of this reading with respect to time indicates the discharge of the capacitor. This type of test perhaps is more indicative and valid when the external voltage divider (R_1, R_2) can be omitted. Then capacitor C looks into the very high resistance of the electrometer.

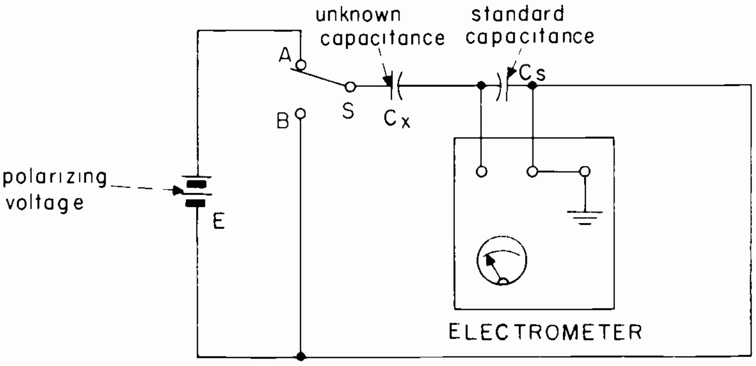
The static potential at a vacuum-tube electrode in series with a high resistance is measured accurately with the electrometer. The control grid is an example. Figure 4(D) shows the connections for checking static grid potential across a high value of grid resistance, R_G.

Other applications involving the use of an electrometer to measure potentials include checking of (1) piezoelectric crystal voltage, (2) output of slightly heated thermocouples, (3) contact potentials, (4) static electricity, and (5) physiological potentials in biological and medical research.

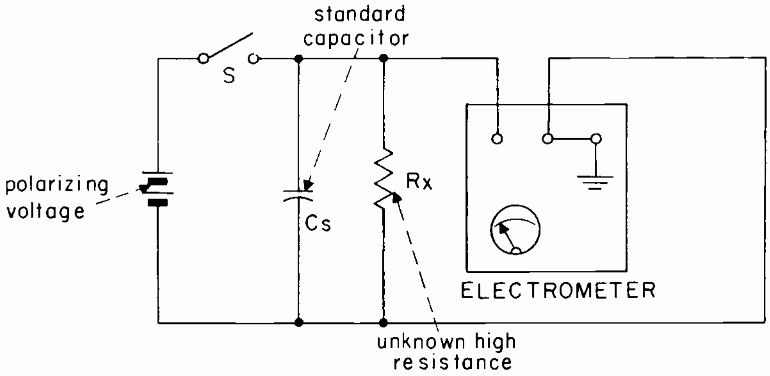
Capacitance and Resistance Measurements

The high input resistance of the electrometer permits determination of capacitance by d. c. methods. Figure 5(A) is an example. Here, C_S is a high-grade standard capacitor of accurately-known capacitance and excellent leakage characteristics. The polarizing voltage, E, also is known accurately. The capacitor shunts the electrometer input terminals. Capacitor C_X is the unknown unit. Capacitance is determined in terms of charge division between the standard and unknown. With switch S in position A, the capacitors charge in series. The voltage reading, e, of the electrometer is noted. The unknown capacitance $C_X = (C_S e)/(E - e)$.

High resistance values may be determined from the measured time constant of a circuit containing the resistance (R_X) and a charged capacitor (C_S) of accurately-known capacitance, as shown in Figure 5(B). When switch S is closed, capacitor C_S is charged to the potential of the polarizing voltage, and this value is indicated by the electrometer. When the switch is opened, the capacitor begins to discharge through R_X. The discharge rate then is accurately timed up to the point at which the electrometer voltage deflection has fallen to 37% of its initial value. The unknown resistance R_X (in megohms) $= t/C_S$, where t is the discharge time (in seconds) and C_S the standard capacitance (in microfarads).



(A) CAPACITANCE MEASUREMENT BY SERIES-C METHOD.

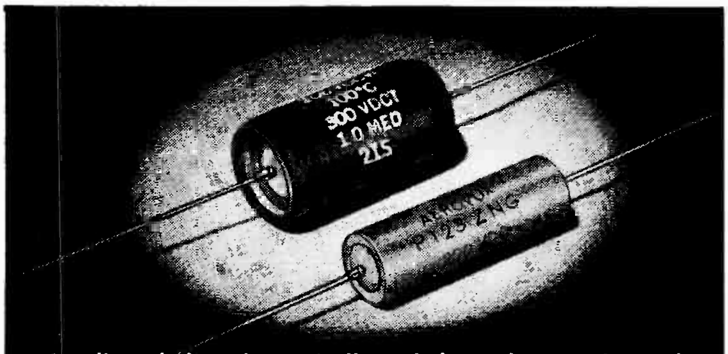


(B) RESISTANCE MEASUREMENT BY RC-DISCHARGE METHOD.

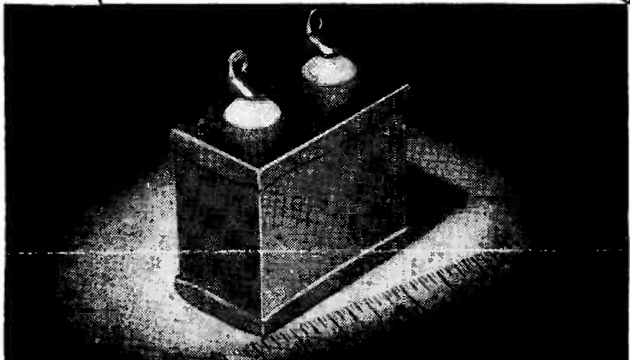
CAPACITANCE AND RESISTANCE CIRCUITS

FIGURE 5

It's the *exclusive* **AEROLENE** impregnant that makes the difference . . .



Aerolite tubulars—hermetically-sealed metal-case units, with or without insulating jackets. Featuring vitrifed terminal seal.



Space-saver metal-case Aerolites are available in rectangular-can and in bathtub housings, in widest range of terminals and mountings.

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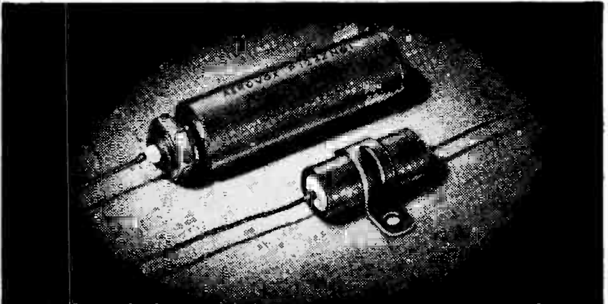
metallized-paper
CAPACITORS*

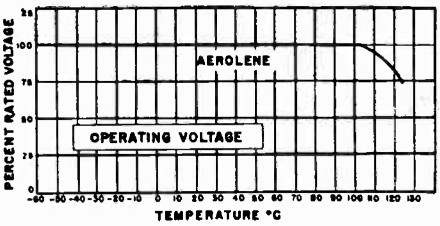
Don't overlook that *plus* factor—*Aero*lene. This unique, Aerovox-exclusive, solid-setting impregnant accounts for the higher temperature ratings of Aerolene units For in addition to the usual advantages inherent in metallized-paper capacitors, there are further gains when the sections are solidly, ruggedly, permanently imbedded in solid Aerolene impregnant for maximum protection against heat and cold, moisture, vibration and roughest handling. Also hermetically-sealed to protect against leaks.

Aerolite (metallized-paper) capacitors with Aerolene impregnant, offer longer service life, lower radio-frequency impedance, and extended electrode construction with soldered connections at all electrical contacts. The accompanying graphs tell their own story of superior performance.

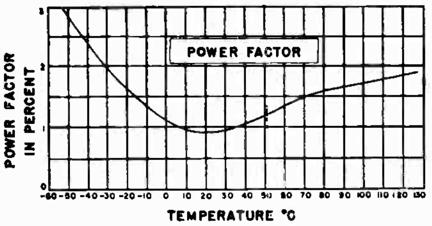


Threaded terminal mounting and tangential bracket Aerolites, with or without wire leads.

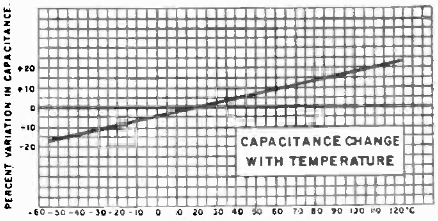
**FUNCTION-FITTED!* Because Aerovox pioneered the metallized-paper development in this country, our engineers can provide outstanding application-engineering service. Let us collaborate with you on your circuits, associated components, operating conditions. Literature on request.



Temperature Range: Operating at working voltage equal to rated voltage over temperature range of minus 55° C to plus 100° C; and at working voltage equal to 75% of rated voltage up to 125° C.



Power Factor: 1.5% or lower at 25° C, when measured at or referred to a frequency of 1000 cycles per second on capacitors up to and including 1.0 mfd.; and when measured at or referred to frequency of 60 cycles, on capacitors greater than 1.0 mfd.



Nominal Capacitance up to and including 1.0 mfd. is measured at or referred to at frequency of 1000 cycles per second at 25° C. Capacitors above 1.0 mfd., measured at or referred to frequency of 60 cycles per second at 25° C.

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