RCA MANUFACTURING COMPANY, INC.
A RADIO CORPORATION OF AMERICA SUBSIDIARY
Harrison, New Jersey

RCA RADIOTRON
DIVISION

APPLICATION NOTE No. 47
May 20, 1935.

APPLICATION NOTE
ON
THE USE OF THE 954 AS A VACUUM-TUBE VOLTMETER

The method employed for the measurement of a direct or an alternating voltage depends almost entirely upon the accuracy desired, and the accuracy of any particular method, in turn, depends upon the nature of the source. Thus, a d-c voltmeter having a sensitivity of 1000 ohms per volt is suitable for determining the voltage of a source having a resistance of the order of one-tenth the voltmeter resistance, but the error of measurement becomes appreciable when the resistance of the source is much above this value, because of the loading of the source by the voltmeter. The accurate measurement of a high-frequency alternating voltage also requires an instrument that has a negligible loading effect on the circuit being measured; in general, high-frequency voltages appear across high-impedance circuits.

The vacuum-tube voltmeter has been used for voltage measurements of radio circuits for many years. However, because of constructional difficulties and the comparative inaccessibility of voltage sources, especially in complex modern chassis, long leads are usually required from the voltmeter to the source. At high radio frequencies, the impedance of these leads becomes so important that the calibration of the vacuum-tube voltmeter is no longer applicable. Thus, the usefulness of the instrument may be severely curtailed or, in some instances, entirely lost due to the high impedance of the connecting leads. Without such leads, the input impedance of the instrument is compacitative for audio and medium radio frequencies when the peak value of the voltage to be measured is less than the bias voltage. An essential requirement of a vacuum-tube voltmeter, therefore, is low input capacitance and a construction which obviates the necessity for long probing leads.

The recently announced type 954 "Acorn" tube is especially adaptable for use in a vacuum-tube voltmeter because of its small size, low input capacitance (about 1.4 μμf when connected as a triode), and the accessibility of its control-grid terminal. The very small size of the 954 permits it to be housed near the end of the test probe; the control-grid terminal, which protrudes from the tip of the tube, then acts as the terminal of the probe. Hence, the use of the 954 in a vacuum-tube voltmeter can result in a much wider range of reliable operation than heretofore has been possible with older tubes, because the connecting leads between instrument and source have been practically eliminated.

A vacuum-tube voltmeter using the 954 in the manner suggested has been constructed. Its schematic diagram and a sketch showing the mechanical arrangement of the components are appended. As may be seen by referring to the circuit, the 954 is connected as a triode and is self biased by resistors R_1 and R_2, which provide the instrument with two ranges; low range, 1, and a high range, 2. The network composed of resistors R_3, R_4, and R_5 is used in conjunction with a 10-20 volt battery to buck out the initial reading of meter M with the input terminals short circuited. Calibration curves for ranges 1 and 2 of the particular voltmeter constructed are also given. These curves, of course, are not to be used with any other instrument, and are intended merely to depict the characteristics of the vacuum-tube voltmeter described in this Note. The voltage range of the instrument is determined by the sensitivity of the meter and the value of the grid bias. On range 1, an input of about 2 volts rms can be applied before grid current flows; on range 2, approximately 14 volts rms can be applied. These voltage ranges apply for the particular microammeter used, which has three scales, A, B, and C, and the resistance for each scale is 50 ohms.

The value of the resistors used in the plate-current balancing network depend upon the magnitude of the plate-current to be bucked, the resistance of the meter, and the potential of the bucking battery. In general, R_3 should be large compared to the resistance of M; R_4 and R_5 should be chosen to permit coarse adjustment by R_4 and fine adjustment by R_5. For values of meter resistance and bucking-battery voltages other than those specified, the ratio of R_3 to the resistance of M and the ratio of R_4 to R_5 may be the same as those given. It is also necessary to make R_4 and R_5 sufficiently large so that the current drain from the bucking-battery is not excessive.

The d.p.s.t. switch opens and closes the filament, plate, and bucking circuits simultaneously. Filament current (150 ma.) may be supplied either from four No. 6 dry cells for d-c operation or from a filament transformer for a-c operation. In the latter instance, it is necessary that the a-c source be free from wide fluctuations in voltage if the calibration is to remain substantially constant. Plate and bucking voltages are best obtained from batteries.

It is quite essential that the circuits be adequately by-passed if a low-frequency calibration is to hold at much higher frequencies. The bias resistors, R_1 and R_2, must be well by-passed at the lowest and at the highest frequencies at which the instrument is to be used. To satisfy the low-frequency requirement, the value of the bias resistor by-pass condenser should be about 16 μf. A condenser of this capacitance is best obtained in electrolytic form; if its working voltage is about 200 volts or more, leakage will not be excessive. However, since the capacitance of an electrolytic condenser decreases with frequency, another condenser C_1, of low power factor, in parallel with C_2 is necessary to take over the by-passing action at high frequencies. The practicability of this dual by-passing arrangement is demonstrated by the fact that a calibration made at 60 cycles was found to be essentially the same as that made at 25 megacycles.

The vacuum-tube voltmeter may be constructed in three separate units:

(1) The probe, consisting of a metal housing, which contains the 954, its socket, C_1, C_3, and a shielded four-wire cable terminating in a five-pin plug. These four leads, labeled b, c, d, and e, connect the housing to the control unit (2); lead a is the shield surrounding the cable.

(2) The control unit, containing C_2, R_1, R_2, R_3, R_4, R_5, S_1, and the d.p.s.t. switch. This unit is equipped with a five-contact socket into which unit (1) is plugged.

(3) The power unit, consisting of the filament, plate, and bucking batteries. The control unit may connect to the power unit by a plug and socket arrangement similar to that employed between units (1) and (2). In fact, two voltmeters can be powered by the same batteries by merely having two sockets connected in parallel in unit (3).

If the voltmeter is to be connected to a source through a series condenser, no bias will be applied to the grid of the 954. It is necessary, therefore, to connect a high resistance across the input terminals of the tube to permit the application of bias. The value of this resistance depends upon the permissible loading, but for most cases a 0.5 or 1 megohm resistor is satisfactory.

The voltmeter described in this Note was operated at frequencies up to 25 megacycles without serious loading effects or changes in calibration. However, somewhat higher frequencies may be measured, the upper limit depending upon the permissible loading.

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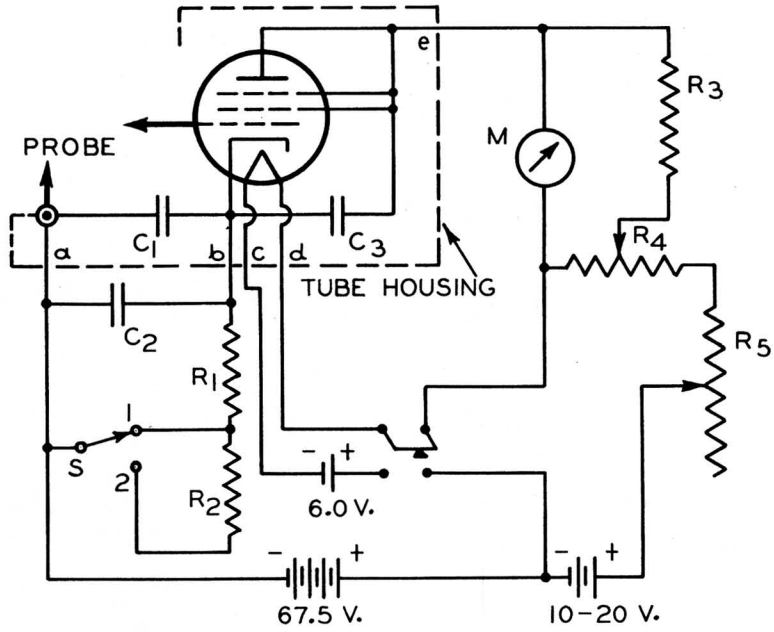
TYPICAL TUBE-VOLTMETER CIRCUIT
SPECIALLY ADAPTED FOR PROBE ARRANGEMENT

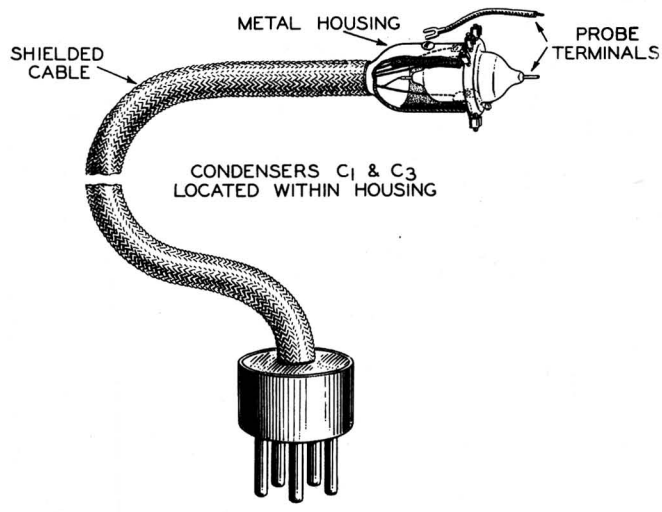
TYPE 954 (AS TRIODE)



C_1 = 500 μμf CONDENSER (MICA)
C_2 = 16 μf COND. FOR CALIBRATION WITH AND MEASUREMENT OF LOW FREQUENCIES
C_3 = 500 μμf CONDENSER (MICA)
M = MICROAMMETER (50 OHMS APPROX.)
R_1 = 2000-OHM RES. (WIRE WOUND)
R_2 = 50000-OHM RES. (WIRE WOUND)
R_3 = 10000-OHM RES. (WIRE WOUND)
R_4 = 40000-OHM POTENTIOMETER FOR COARSE ADJUSTMENT IN BALANCING OUT PLATE CURRENT
R_5 = 2000-OHM RES. (VARIABLE)
S { ON POSITION 1 GIVES RANGE OF 2 VOLTS RMS
S { ON POSITION 2 GIVES RANGE OF 14 VOLTS RMS

NOTE: LEADS b, c, d AND e RETURN INSIDE CABLE. LEAD a IS CONNECTED TO GROUNDED HOUSING.

CONSTRUCTION OF PROBE



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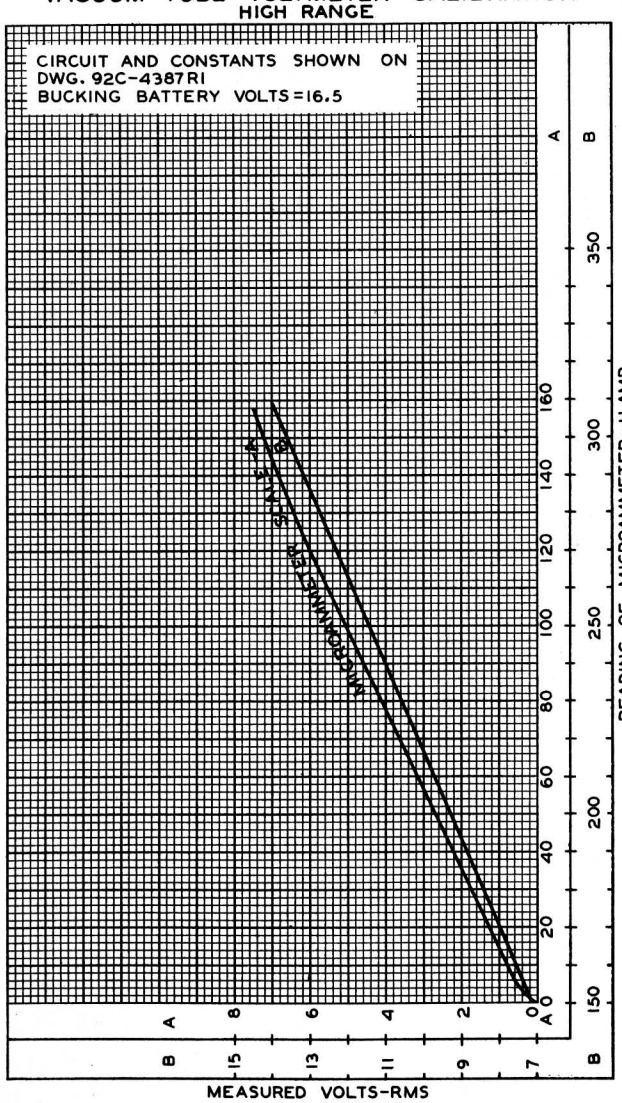
VACUUM-TUBE VOLTMETER CALIBRATION
HIGH RANGE



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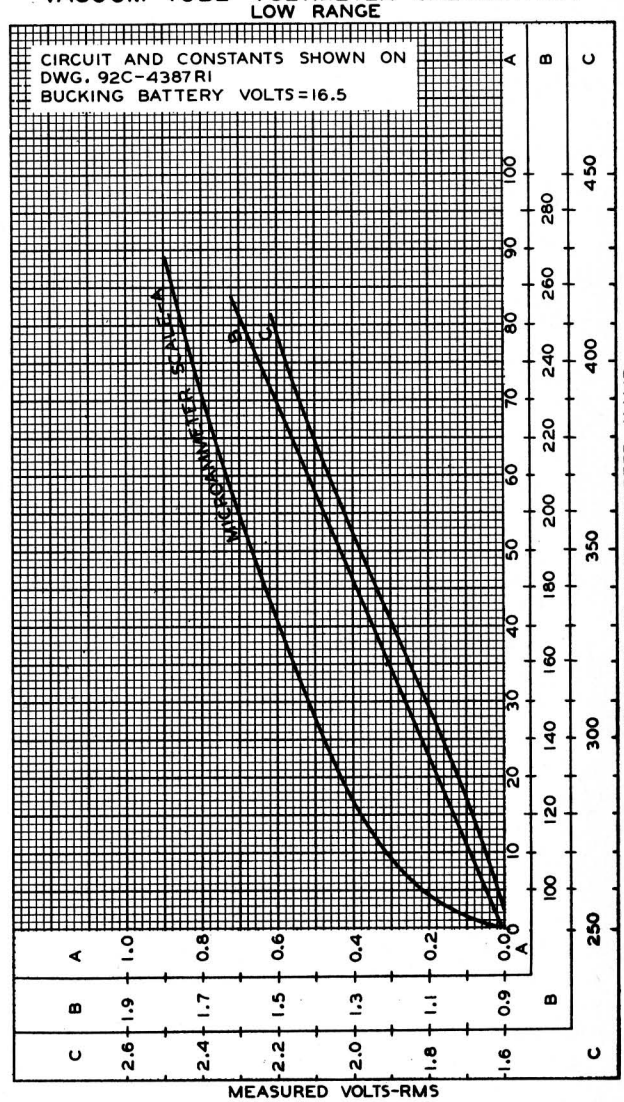
VACUUM-TUBE VOLTMETER CALIBRATION
LOW RANGE



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