THE THERMIONIC VOLTMETER AS APPLIED TO HIGH FREQUENCY MEASUREMENTS.

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Numerous articles have appeared in the last few years announcing types of vacuum tube voltmeters to be used in high frequency electrical measurements. Such a voltmeter should have the following characteristics: (a) it should be entirely independent of frequency; (b) it should not absorb power from the measuring circuit; (c) it should hold a calibration over a considerable period; (d) it should not require too much auxiliary equipment; (e) it should have a wide range in voltage, say from 0 to 100 volts; and (f) it should not change materially the constants of the circuit to which it is applied.

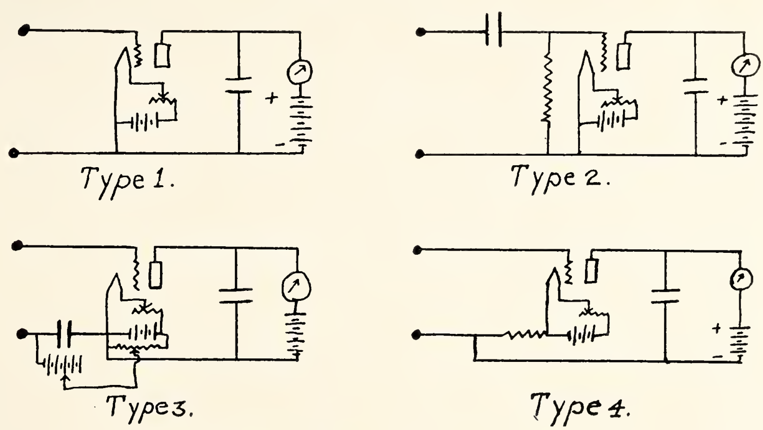

Fig. 1—Common Types of Thermionic Voltmeter.

The various types could be classified under four heads as in figure 1, namely, (1) direct deflection, readings directly proportional to voltage; (2) leaky grid or inverse, readings inversely proportional to voltage; (3) slide back, voltage measured by amount of grid bias to compensate for applied high frequency voltage; (4) reflex, a high range voltmeter having an automatic bias voltage proportional to input voltage.

The present discussion is limited to the two most widely used types, the direct deflection and the "leaky grid" or inverse type. As a further limitation only the application of such instruments to radio frequency circuits will be considered.

There is an abundance of information available in the literature concerning the construction, characteristics, and calibration of thermionic

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voltmeters. Very few articles[1] can be found dealing directly with the application of this device to actual measurements in high frequency circuits. The present paper is the result of an attempt to measure inductance, capacity, resistance, frequency and impedance at frequencies from 600 to 1,200 kilocycles. Voltages used varied from 0 to 80 R. M. S. volts and currents from 20 to 125 milliamperes.

A general method of procedure with such an instrument is to measure the voltage across the terminals of the impedance, (a capacity, resistance, inductance, etc.). Knowing the frequency and current, from the relations $E=ZI$, $Z=\sqrt{R^2+X^2}$, and $X=2\pi fLI$ or $\frac{1}{2\pi fC}$, R, L, and C may be determined. This method is accurate provided the voltages are low. Consequently the currents must be small through the impedances. Since small high frequency currents, less than ten milliamperes, are difficult to measure except with thermo-junctions and sensitive galvanometers, this method is practical only for small resistances, small inductances, or large condensers. (The voltage across a 398 mmf. condenser at 750 K. C. is approximately 26.6 volts with a current of 0.050 amp.). If a known small inductance say about 8 microhenries is placed in a high frequency circuit and the voltage measured across the inductance, from the relation $E=2\pi fLI$, f may be determined or the voltmeter could be calibrated directly in kilocycles at a constant current value. Either type 1 or type 2 voltmeter may be used for these measurements *provided the voltage measured does not exceed 1.8 volts for type 1, and 5.5-6 volts for type 2.* If these limits are exceeded the voltmeter input circuit absorbs enough power to change the current appreciably in the measuring resonant circuit. Figure 2 shows such a measuring circuit.

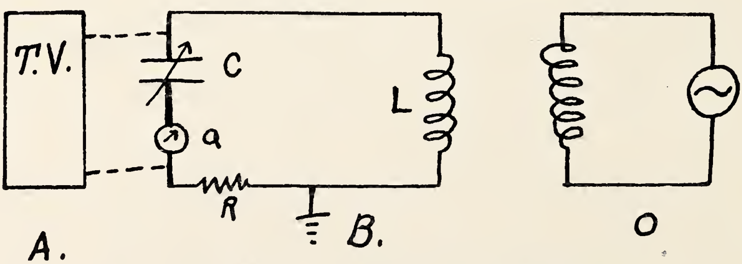

Fig. 2—Simple Measuring Circuit for Thermionic Voltmeter.

In this figure the oscillator O generates the high frequency current. The measuring circuit B is coupled loosely to O and the thermionic voltmeter A is connected across C, R, or L as the case requires. The voltmeter input circuit contains capacity varying from 4-20 mmf. and an effective resistance of 0.2-8 ohms, depending upon the circuit and type of tube used. These factors must be taken into consideration in making any accurate determination with such an instrument.

[1] See Bibliography.

We shall next consider a special method developed in this study for measuring higher voltages (0-80 volts), such as would be obtained using from 20-100 milliamperes at 600-1,200 kilocycles with ordinary radio coils and condensers.

The circuits used are shown in figure 3.

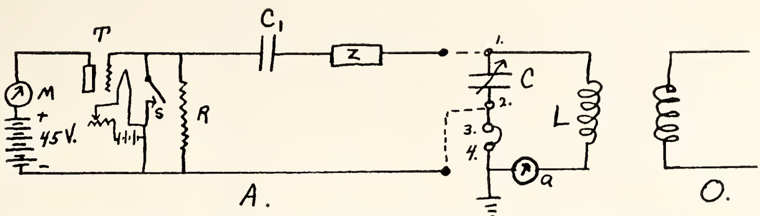

Fig. 3—Measuring Circuit for Multiplying Voltmeter, Arranged for Substitution Methods.

An inverse voltmeter (A) was used, having the following constants: M a (0-1) milliammeter; T, a UV-201 A tube; C, a 0.2 mf. mica insulated Western Electric condenser; S, a short circuiting switch to adjust filament to initial maximum reading; R, a 5 meg-ohm resistance; Z, an impedance 160,000 ohms approximately; C_1 is a variable air condenser; L, a low loss pickup coil; and O, a vacuum tube high frequency generator. The circuit was arranged with mercury contact points at 1, 2, 3 and 4 so that quick substitution of coils, condensers and resistances could be made. The purpose of the impedance Z in the input circuit was to multiply the reading of the voltmeter. A standard cartridge resistance of 500,000 ohms was first used for Z. With this resistance about a thousand readings and calculations were made to determine the multiplying factor M of such a voltmeter. Over a range of 600 to 1,200 K. C., M varied from 12.27 to 16.3, the increase in M being directly proportional to frequency. This suggested that the capacity of the ends of the cartridge and the holder was affecting the results. The resistance core was then removed entirely and the voltmeter still had a multiplying factor of about 8.

Since the impedance of 1 mmf. at 1,000 K. C. is about 160,000 ohms and since the capacity of the ends of such a cartridge is of this same order of magnitude it can easily be seen why such a voltmeter would have a varying multiplying factor. (An additional study is being made of this phenomenon.)

In applying such a voltmeter the following methods were used.

The voltage was measured across a standard coil and then across an unknown coil. If the frequency and current is kept constant by variation of coupling, and tuning to resonance, $E:E_x = L:L_x$ or with condensers $E:E_x = C_x:C$ C_x may be determined in terms of E, E_x and L. This method assumes that a curve has been made for the value of M against frequency.

The voltage across an unknown and a known coil may be made the same by varying the current through the circuit through a change of couplng. Then if f is kept constant $L_x:L = I:I_x$ or $C_x:C = I_x:I$. This method eliminates the actual value of voltage and M need not be known.

The following table gives some results obtained by these methods in comparison to other standard methods.

TABLE I. Value of Inductance and Capacity from the Voltmeter Method as Compared with Other Methods.

Inductance in Microhenries

E constant	I constant	$L = E/2\pi fI$	Wavemeter	Calculated
48.9	48.8	49.7	47.5	....
96.8	98.7	97.9	99.0	98.8
19.0	....	20.6	20.7	21.3

Capacity in Microfarads

E constant	I constant	Wavemeter	Bridge Measure
395	398	410	410
279	280	274	275
314	313	322	320

Frequency 750 K. C. Currents 30-100 milliamperes

During the course of this work many interesting and unexplained phenomena concerning high frequency measurements have come to light. It is not our purpose here to dwell at length on all the possibilities of such an instrument.

The most important conclusions that can be drawn are that for correct measurement: (1) The impressed voltages cause no appreciable current in the grid circuit of the voltmeter. (2) The negative filament terminal must be grounded. (3) The effective resistance and capacity of the voltmeter must be considered. (4) The grid must in no way be insulated from the filament by a high resistance grid return circuit. (5) Inductive effects should be avoided by shielding and short voltmeter leads. (6) At present there is no single type of thermionic voltmeter applicable to all conditions and voltages. (7) Application to audio frequency circuits is more easily accomplished because of greater power and current values and lower voltages.

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