The AEROVOX Research Worker

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Vacuum-Tube Voltmeters

PART 1

By the Engineering Department, Aerovox Corporation

VTVM CIRCUITS

THE vacuum-tube voltmeter is a meter which has not been used heretofore to the fullest extent of its capabilities. As the meter can be used so that it does not draw an appreciable current or power from the circuit being measured, the connection of the VTVM does not disturb the current and voltage relationship in the circuit. The VTVM is practically independent of frequency up to frequencies of the order of 10 megacycles per second.

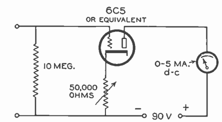

Figure 1

Moreover the VTVM can be designed to read peak, trough or average voltage so that the form factor of the voltage can be readily determined. The VTVM can be used, with a known condenser as a shunt, to measure current. This feature is especially valuable in the low-current high-frequency circuits where the power taken by a thermo-couple meter will seriously disturb the circuit.

There are several types of VTVM circuits available. The choice of circuit is determined by the particular measurements to be made. The simplest VTVM is the type which depends on plate rectification for its operation. The circuit of this type of meter is given in Figure 1. The meter can be used as an indicator without calibration but if the meter is to be used as a voltmeter it must be calibrated against another meter. The calibration can be done using d.c. (Figure 2A) which gives the average value for a sine wave. The average value multiplied by 1.5708 gives the effective or R.M.S. of the voltage measured. This is the value read on the usual type of a.c. voltmeter. The VTVM can be calibrated directly in R.M.S. values by the use of a.c. A circuit that can be used for this purpose is given in Figure 2B. The voltage at the terminals of the VTVM is the a.c. voltmeter reading multiplied by

$$\frac{R_2}{R_1+R_2}$$

This circuit is used because accurate low-range a.c. voltmeters are usually not available. The circuits shown in Figures 2A and 2B can be used for the calibration of all VTVMs.

The VTVM shown in Figure 1 is first adjusted to its zero point which is some low value of current on the milliammeter, such as 0.1 ma., by variation of the 50,000 ohm resistance in the cathode circuit. The VTVM must always be adjusted to this zero reading before taking any readings. The disadvantage of this circuit is that at the zero adjustment of the VTVM the current through the milliammeter is not zero. By means of a bucking circuit the zero current can be bucked out of the milliammeter. Such a circuit is used in the VTVM circuit of Figure 3. This VTVM has a range of 1.5 volts R.M.S. for the constants given and the smallest reading is about 0.2 volts.

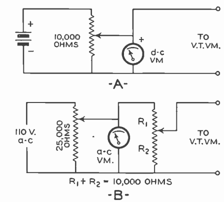

Figure 2

Another form of VTVM which is similar to the one described above is a battery-operated meter whose advantage is that it is not grounded and its capacity to ground can be made very small. The fundamental circuit is shown in Figure 4. With this circuit it is necessary to check and adjust all voltages to some fixed value

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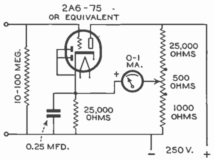


Figure 3

before using the VTVM. The filament voltage is set to its proper value, after which the grid bias is adjusted to its correct value. The plate milliammeter is set to zero by the adjustment of the 200 ohm potentiometer which is connected across the filament circuit. The range of this meter depends on plate voltage and the tube used. High ranges can be obtained by using higher plate and grid voltages. The switches S_1 and S_2 which are shown in the diagram of Figure 4 are ganged together and can be a double-pole single-throw switch. The switch S_1 opens the grid bias battery circuit to prevent the flow of current through the grid bias potentiometer when the meter is not in use.

A VTVM which does not require the separate adjustments of the one described above, is shown in Figure 5. An advantage of this circuit is that it can be used with either a d.c. or an a.c. power supply. After the initial adjustment of the resistors, the only adjustment necessary to compensate for battery voltage variation, is setting the milliammeter to zero by the adjustment of rheostat R. When an a.c. power supply is used the rheostat can be replaced by a fixed resistance and

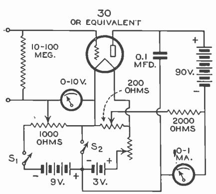
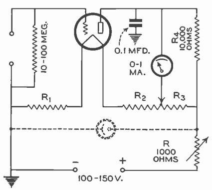


Figure 4

a voltage regulator tube such as a VR 90 or a two-watt neon lamp with the resistance in the base removed. This circuit can be adapted for use with a 6 or 9 volt battery so that a small self-contained VTVM is available. This form of meter is especially useful in radio frequency measurements when it is not desirable or possible to ground one side of the line.

All these VTVMs described above, read the average value of the applied a.c. voltage. If the voltage wave is sinusoidal the meter can be calibrated in R.M.S. values. For the measurement of peak voltages such as occur across filter condensers or when the form factor of the voltage wave is desired, a different type VTVM must be used. The circuit of Figure 4 can be adapted for peak voltage measurements. The meter is used as a slide-back voltmeter by first adjusting the plate current to some convenient value



	90 VOLTS 30 TUBE	9.0 VOLTS 30 TUBE
R_1 =	174 OHMS	17.5 OHMS
R_2 =	1500 OHMS	150 OHMS
R_3 =	200 OHMS	20 OHMS
R =	1000 OHMS	100 OHMS

Figure 5

when the meter is disconnected from the voltage to be measured. The reading of the grid bias meter is noted. The voltage is then applied to terminals of the VTVM and the potentiometer is adjusted so that the plate current is the same as with the VTVM disconnected from the voltage. The difference between the readings of two grid bias voltages is the peak voltage.

A direct-reading peak voltmeter which is very useful for reading high voltages is shown in Figure 6. In this circuit the rectifier passes only the positive peaks of the applied voltage to charge the condenser C. After the first cycle the current through the rectifier is only enough to replace the charge which has leaked off through the resistance R. This is the current which is read by the meter. The deflections of the milliammeter are directly proportional to the applied voltage and are practically independent of frequency over a wide range when

$$RC \geq 100 \frac{1}{f}$$

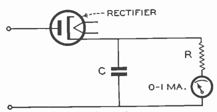


Figure 6

For reading the peak voltages on filter condensers used in receiver power supplies, the constants C = 2 mfd. and R = 1 megohm, give a satisfactory arrangement. For reading peak voltages of small magnitudes a d.c. amplifier is used to increase the sensitivity of the meter. The circuits of Figure 7 show two such peak voltmeters. The value of the capacity C depends on the frequency at which the meter is to be used. For power frequencies a capacity of .10 mfd. is usually satisfactory while at radio frequencies a .001 mfd. condenser is desirable. A VTVM of this type with the amplifier preceding the rectifier is used in the Aerovox Capacity and Resistance Bridge. This VTVM, see Figure 8, has a range of 2 volts and this can be reduced to .5 volt if the 3 megohm resistor is shorted. This VTVM can be used at power and audio frequencies only because of the choice of constants.

USES IN SERVICING RADIO RECEIVERS

Because of its high input impedance the VTVM gives the exact voltage of the points measured, and does not affect the RF or IF circuits when connected to them. Thus the VTVM

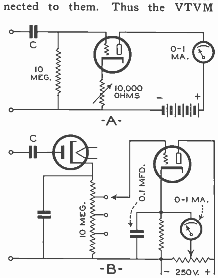


Figure 7

allows measurements of currents and voltages to be made directly.

The VTVM can be used to measure the ripple and the peak voltage at

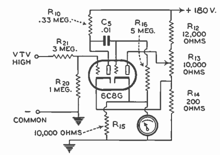


Figure 8

Note: *The numbered circuit components shown in the above diagram refer only to part numbers of the Aerovox Capacity and Resistance Bridge Model 75.*

various points of power supplies and audio amplifiers. If a VTVM such as is shown in Figure 1 or Figure 3, with a .1 mfd. condenser in series with the grid lead, is connected across the filter condensers of a power supply such as shown in Figure 9, the meter will read the average a.c. voltage across each condenser. A d.c. voltmeter connected to the same points will give the d.c. voltage. As the wave shape is not sinusoidal the average value of the a.c. voltage across the condensers is not as important as the R.M.S. values and the peak values. The peak voltage can be measured by means of a VTVM such as shown in Figure 6. The R.M.S. value cannot be measured by the VTVM but its value can be closely approximated by finding the ratio of the peak to the average value of the voltage. With the VTVM connected

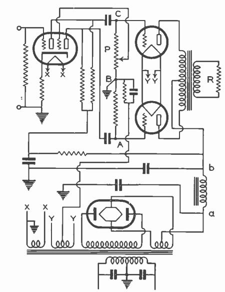


Figure 9

from the point b to ground, the effect of the filter capacity on the ripple of the power supply as the capacity is varied can be determined. The dynamic regulation of power supply can be determined by measuring the voltage appearing across the second filter condenser when a constant amplitude signal is applied to the amplifier input. The magnitude of the voltage measured is directly proportional to the impedance of the power supply at the frequency used.

A phase inverter can be checked for balance of the signal on the grids of the push-pull stage by connecting the VTVM from the points *A to B* and from the points *B to C* as shown in Figure 9. The voltages read should be equal and the voltage across the points *A to C* should be twice the voltage *A to B* or *B to C*. The voltages can be made equal by adjustment of the slider or potentiometer P. If the voltage across *AC* is not twice the voltage *AB* or *BC*, the voltages are not in phase. The phase shift is usually very small at low frequencies but at higher frequencies it may become quite large. Unequal capacities to ground will cause both unbalance of voltage and different phase positions for the grid voltage, thus introducing distortion which varies with frequency. Any unbalance that occurs in the push-pull stage can be determined by connecting the VTVM across the cathode bias resistor with its by-pass condenser disconnected. When the amplifier is balanced, no a.c. voltage should appear from the point *B* to ground. This unbalance may be caused by mismatched tubes or an unbalanced transformer.

The over-all gain, or better, the signal voltage required to deliver maximum output can be measured by first determining the power output limit. The simplest way of doing this is as follows: The amplifier is connected as in Figure 10 with an oscillator and a calibrated potentiometer. The input to the amplifier is varied from zero up. The power output of the amplifier is calculated from

$$\frac{E^2}{R}$$

and plotted against the input voltage. The rated load of an audio amplifier can be found by drawing a straight line from the origin tangent to the voltage curve. At the point from which the voltage curve drops away from the straight line the distortion begins, the amount being proportional to the displacement of the curves. The allowable distortion depends on the particular use of the amplifier and the corresponding allowable displacement of the curve from a straight line and can be determined from these conditions. Figure 11 shows such a curve for an amplifier whose constants are given in the diagram. This is a simple method of approximating the power output of an amplifier without the use

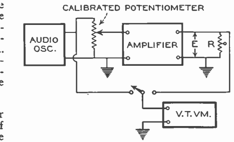


Figure 10

of an expensive distortion meter or harmonic analyzer. The ratio $\frac{P}{e}$ at the load limit is the sensitivity of the amplifier. P is the power output in watts and e is the input voltage required to produce this output. The hum level in db below maximum power output is given by

$$-10 \log_{10} \frac{P_p}{P_y}$$

P_p is the rated power output of the amplifier and P_y is the power output with zero power input. Actually the curve in Figure 11 does not go to zero input, but the noise level at an input of .001 volts is much greater than the output for the input voltage. This is shown by the flattening of the curve at that point.

If the range of the VTVM is less than the voltages to be measured a voltage divider may be used to extend the range of the voltmeter.

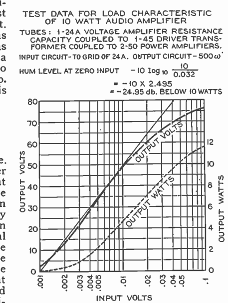


Figure 11

The next issue of the Research Worker will discuss the measurement of IF and RF circuits with the VTVM.