



ELECTRICAL MEASUREMENTS  
TECHNIQUE AND ITS INDUSTRIAL APPLICATIONS

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TYPE 726-A VACUUM-TUBE VOLTMETER

● BECAUSE VOLTAGE MEASUREMENTS at communication frequencies usually require a voltmeter with an input impedance so high as to

have no appreciable shunting effect on the source under measurement, the vacuum-tube voltmeter is a laboratory necessity to the communication engineer. Commercially available thermionic voltmeters have in general been subject to one or more of the following defects: low sensitivity, limited voltage range, high-frequency error, and limited precision of reading at low values on the scale. The design of a voltmeter in which these defects are minimized has recently been completed, and, since it represents a new approach to the problem of a-c voltage measurements, a number of its design features are worthy of mention.

The voltmeter consists of a familiar combination — a diode-condenser rectifier circuit and a d-c amplifier. A condenser becomes charged by the rectifier



FIGURE 1. TYPE 726-A Vacuum-Tube Voltmeter

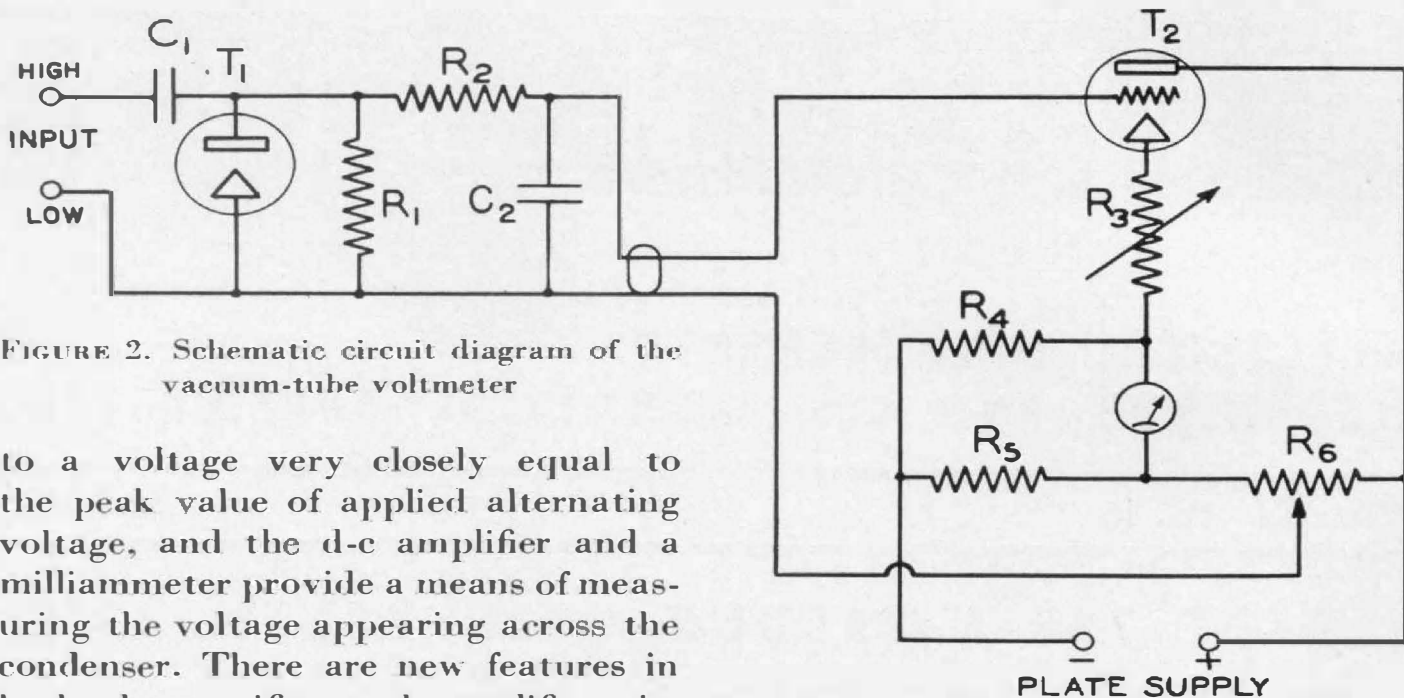


FIGURE 2. Schematic circuit diagram of the vacuum-tube voltmeter

to a voltage very closely equal to the peak value of applied alternating voltage, and the d-c amplifier and a milliammeter provide a means of measuring the voltage appearing across the condenser. There are new features in both the rectifier and amplifier circuits, however, which are very important in achieving high input impedance, permanency of calibration, and a calibration very nearly independent of the constants of the rectifier and amplifier tubes. These advantages are obtained, moreover, in an instrument covering a wide range of voltages.

### THE RECTIFIER CIRCUIT

The rectifier circuit<sup>1</sup> is shown on the left-hand side of Figure 2. The resistances  $R_1$  and  $R_2$  are of high value so that they do not affect the operation of the diode  $T_1$  and the condenser  $C_1$  in the input loop of the circuit. If  $C_1$  has sufficient capacitance so that no a-c voltage appears across it, its charge will build up until the voltage is equal to the peak value of the applied a-c voltage, after which time the anode will never be positive with respect to the cathode and no further rectified current can flow. When equilibrium is reached, in other words, the rectifier will approach the conducting condition only at the time of the positive peak of

the applied alternating voltage. For the rest of the cycle the plate will be negative with respect to the cathode. The voltage across the diode thus consists of a negatively-biasing direct voltage in series with the applied alternating voltage, and it will be seen that the average plate potential is negative with respect to the cathode.

The purpose of  $R_1$  is to permit the discharge of condensers  $C_1$  and  $C_2$  when the input voltage is reduced. This resistor is placed across the rectifier rather than across  $C_2$ , so that no direct current will flow through  $R_2$  except when the input voltage is varied and new equilibrium conditions must be established. No correction need be made, consequently, for voltage drop across this resistor, and the entire d-c voltage is applied to the amplifier tube. This feature contributes considerably to the stability of the instrument and the permanence of its calibration.

The direct component of the voltage across the diode is equal to the peak value of the applied alternating voltage. The resistance  $R_2$  and condenser  $C_2$  remove the alternating component

<sup>1</sup> For a discussion of diode circuits, see "Crest Voltmeters" by C. H. Sharp and E. D. Doyle, Trans. A.I.E.E., 35, pp. 99-107, February, 1916.

so that only the direct component is applied to the d-c amplifier. Elaborate filtering is not necessary due to the extreme linearity of the amplifier resulting from degeneration. Unless the alternating voltage is sufficient to swing the plate current to cut-off, only a negligible amount of rectification can take place. The simple filtering arrangement shown is, therefore, entirely adequate.

### THE AMPLIFIER CIRCUIT

The d-c amplifier circuit is shown in the right-hand section of Figure 2. The resistor in the cathode lead is particularly important. This provides degenerative coupling between the input and output circuits and not only accomplishes in the d-c case improvements analogous to those resulting from the use of degeneration in a-c amplification,<sup>2</sup> but also has other important results. Before the manner of operation is explained, the important improvements resulting from the use of degeneration in the present case will be outlined:

(a) The meter indication within very close limits is made proportional to the direct voltage introduced into the grid circuit.

(b) The sensitivity is made practically independent of the constants of the tube.

(c) The grid circuit is rendered capable of handling directly voltages hundreds of times greater than the normal cut-off bias. Hence no voltage-dividing network is required.

(d) The sensitivity can be changed for the various desired voltage ranges merely by changing the value of the cathode resistor and the value of the grid-bias voltage.

Figure 3 is a simplified diagram to illustrate the degenerative effect of the

cathode resistor. If a voltage  $E_1$  is introduced into the grid circuit, the plate current will tend to increase, causing a voltage drop  $E_R$  across the cathode resistor in opposition to the introduced voltage. The net change in grid voltage is the difference between the two. If the cathode resistor is large in value, only a very slight increase in plate current is required to develop a voltage equal to the introduced voltage. The net grid voltage, therefore, can change only slightly, and  $E_R$  must always be very nearly equal to  $E_1$ . The larger the value of the cathode resistor, the smaller must be the increment in plate current and the more nearly equal must  $E_R$  be to the introduced voltage  $E_1$ . Whenever the cathode resistor is large enough to bring about this condition, the change in plate current, indicated on the meter, will be directly proportional to the introduced voltage, and the tube constants will be of very little importance.

The same simple consideration shows that the sensitivity of the arrangement, considered as a d-c voltmeter, can be changed by varying the cathode resistor. If this resistor is increased in value ten times, only one-tenth of the change in plate current will be required

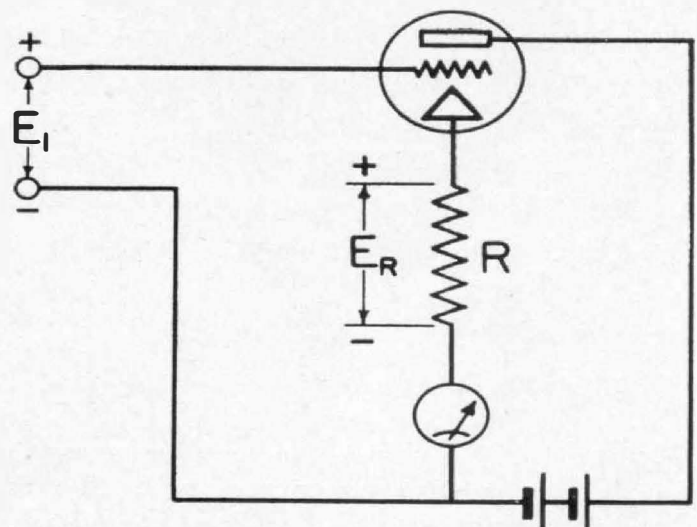


FIGURE 3. Schematic circuit diagram of a degenerative d-c amplifier

<sup>2</sup> See "Stabilized Feedback Amplifiers," H. S. Black, B.S.T.J. 13, pp. 1-18, January, 1934.

to develop a given opposing voltage. If the plate millimeter has a certain full-scale sensitivity, consequently, ten times the voltage must be introduced into the grid circuit to cause full-scale deflection. For sufficiently high values of the cathode resistor, the full-scale voltage is directly proportional to the cathode resistance and depends only on this quantity and on the sensitivity of the millimeter.

The polarity of the direct voltage developed by the rectifier circuit and applied to the d-c amplifier is such that the grid of the amplifier  $T_2$  is made negative with respect to the cathode. This is important in preventing damage to

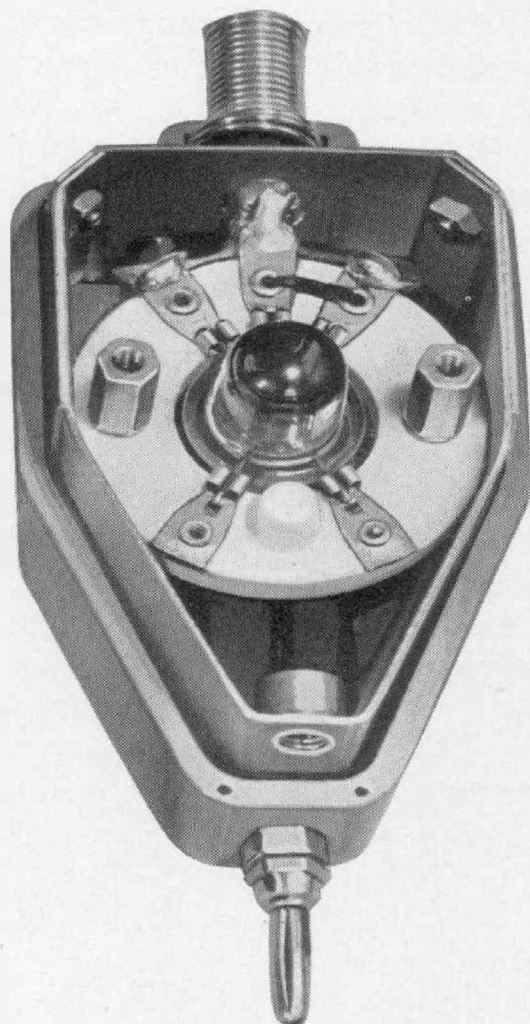


FIGURE 4. This shows the rectifier, mounted in the probe with cover removed. The extremely short leads and low shunt capacitance obtained are responsible for the excellent frequency characteristic

the meter due to overload. The plate current decreases when voltage is applied and can be reduced only to zero. The maximum possible change in plate current does not greatly exceed the millimeter full-scale current, so that serious overload is not possible, no matter what input voltage is applied. The millimeter, of course, is connected in the circuit backwards, so that a decrease in plate current is indicated as a positive deflection.

The three resistances,  $R_4$ ,  $R_5$ , and  $R_6$  shown in Figure 2, but not in Figure 3, make it possible to balance out the initial plate current and to furnish the desired grid bias. The resistance  $R_3$  and the position of the tap on the resistance  $R_3$  are changed simultaneously when the range of the instrument is changed.

#### POWER ABSORPTION

The power which must be drawn from the voltage source can readily be calculated from the known voltages appearing across the resistors  $R_1$  and  $R_2$ . In the filter circuit  $R_2C_2$  just considered, the entire alternating voltage appears across  $R_2$ . The same voltage appears across  $R_1$  as appears across the rectifier, namely, the full alternating voltage in series with a direct voltage equal to its peak value. The a-c fraction of the power loss is the same which would result if  $R_1$  and  $R_2$  in parallel were placed directly across the voltage source. In addition, sufficient power must be drawn to supply the d-c loss in  $R_1$  corresponding to the peak value of the a-c voltage. Short pulses of current flow through the rectifier to supply this power, so for this component of the loss the voltage source is loaded relatively heavily during a very small part of the cycle, and not at all during the rest of the cycle.

Due to the shortness and intensity of the pulses through the rectifier any resistance in the input branch reduces seriously the flow of rectified current and lowers correspondingly the meter reading. It is this reduction in meter reading due to the impedance of the voltage source, rather than the total power consumption, which is important in most applications. This effect can be made negligible only by reducing the d-c power absorbed to the lowest possible value. In the TYPE 721-A Vacuum-Tube Voltmeter the resistor  $R_1$  has the value 50 megohms. About 4 megohms in series with the applied voltage is sufficient, however, to halve the voltmeter reading. From the voltage reduction standpoint the input resistance, therefore, can be said to be 4 megohms. The power absorption, however, is determined mainly by a-c losses in  $R_2$  (10 megohms), and from this standpoint the input resistance is appreciably greater — about 6 megohms. At high frequencies other factors become important, so that the simple analysis here given is no longer applicable. These factors are discussed below.

### OPERATION AT HIGH FREQUENCIES

To achieve satisfactory operation at high frequencies, the elements which make up the rectifier circuit are made as small as possible and are mounted in a separate housing at the end of a flexible cord. Probe terminals are provided so that the measuring circuit may be placed close to the voltage source. A 955-type acorn tube is used as the diode rectifier. The probe terminals can be removed to reduce still further the inductance of the input loop.

As a result of these details of con-

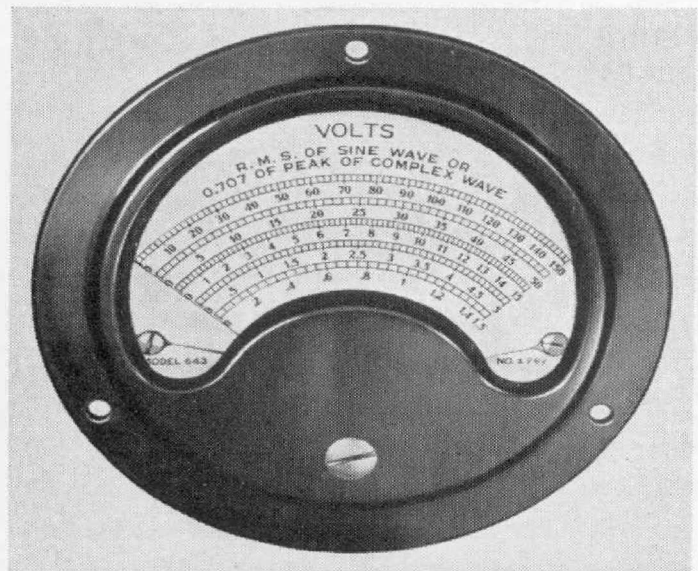


FIGURE 5. Five ranges of voltage are provided. It will be seen that the scales are nearly linear

struction, the resonant frequency of the input loop is about 380 megacycles, and 500 megacycles with the probe terminals removed. The frequency error in the reading is only 3 per cent at 100 megacycles.

The power consumed from the source at high frequencies is no longer determined by the values of resistances  $R_1$  and  $R_2$  but by the total stray capacitance across the input and the losses in this capacitance. The total capacitance is about  $6 \mu\mu\text{f}$  and the power factor about 2.5 per cent, the losses occurring principally in the envelope and socket of the tube and in the material surrounding the resistance elements  $R_1$  and  $R_2$ . It is interesting that at high frequencies the input impedance is not affected by turning on or off the heater of the diode  $T_1$ .

### OTHER ADVANTAGES

By including a power-supply voltage regulator, the meter indication has been made as stable as that of a d-c instrument. Fluctuations in line voltage have no effect, nor do long period drifts which would otherwise change the read-

ing through changes in filament temperature.

Although the diode rectifier is mounted in a probe, the probe can be mounted inside the cabinet for low-frequency measurements, if desired, and the voltage source under measurement connected directly to terminals on the panel.

The Low terminal on the panel is not connected directly to panel, but is isolated by a blocking condenser. This is convenient in measuring voltages

across plate tank circuits, for instance, where the voltmeter can be grounded without damage.

The meter reads directly the r-m-s value of a sinusoidal voltage. As has been shown above, however, it is the peak value of the waveform which determines the reading. The instrument is very useful for determining the peak values of complex waveforms, these values being obtained by multiplying the reading by 1.414.

— W. N. TUTTLE

### SPECIFICATIONS

**Range:** 0.1 to 150 volts in five ranges (1.5-5-15-50-150 volts).

**Accuracy:**  $\pm 2\%$  of full scale at all five ranges, on sinusoidal voltages.

**Waveform Error:** The instrument is essentially a peak voltmeter calibrated to read r-m-s values of a sine wave, or 0.707 of the peak value of a complex wave. On distorted waveforms the percentage deviation of the reading from the r-m-s value may be as large as the percentage of harmonics present.

**Frequency Error:** Less than 1% between 20 cycles and 50 megacycles. At 100 megacycles, the voltage indicated is about 3% larger than the voltage across the probe terminals when the tips are removed. With the tips in place the error is about 7%.

**Input Impedance:** About 5 megohms at low audio frequencies. Since the capacitance between input terminals at the probe is 6  $\mu\mu\text{f}$ , the input impedance will be lower at higher fre-

quencies. The resonant frequency of the input circuit is about 380 megacycles but can be increased to 500 megacycles by removing the plug tips of the probe.

**Power Supply:** 100 to 130 volts, ac, 60, 50 or 42 cycles and 200 to 260 volts, 50 cycles (see price list). The instrument incorporates a voltage regulator to compensate for supply variations over this voltage range. The power drain is less than 20 watts.

**Tubes:** One 955-type, one 75-type, and one 1v-type rectifier, supplied with the instrument.

**Accessories:** A seven-foot attachment cord, a pilot lamp, and the three tubes are supplied with the instrument.

**Mounting:** Black crackle-finish aluminum panel mounted in a shielded walnut cabinet.

**Dimensions:** (Width) 9 $\frac{1}{2}$  x (depth) 14 x (height) 8 $\frac{1}{2}$  inches, over-all.

**Net Weight:** 17 $\frac{1}{2}$  pounds.

#### Power Supply

| Type  | Frequency | Voltage    | Code Word | Price    |
|-------|-----------|------------|-----------|----------|
| 726-A | 60 cycles | 100 to 130 | ALLOT     | \$165.00 |
| 726-A | 50 cycles | 200 to 260 | ALTER     | 165.00   |
| 726-A | 50 cycles | 100 to 130 | ABAFT     | 165.00   |
| 726-A | 42 cycles | 100 to 130 | AMASS     | 165.00   |

## MISCELLANY

● ON MAY 1, Martin A. Gilman joined the Engineering Department of the General Radio Company. Mr. Gilman receives his S.M. degree in electrical engineering from M.I.T. in June of this year.

● ON APRIL 20, R. F. Field spoke before the Pittsburgh section of the I.R.E. on the subject of "Direct-Reading Instruments." He plans to deliver this paper before the Indianapolis section on May 13.

● FOR SEVERAL MONTHS, Arnold Peterson of M.I.T. has been engaged in a research project at General Radio Company studying ultra-high-frequency oscillators. Some of the results of this project were presented by Mr. Peterson at the April 30 meeting of the International Scientific Radio Union at Washington, D. C. The title of the paper was "The Frequency Stability of Ultra-High-Frequency Oscillators." We hope to publish some of this material in a forthcoming issue of the *Experimenter*.

● A. E. THIESSEN returned early in April from a several weeks' visit to our Pacific Coast offices in Los Angeles and San Francisco. During this time he addressed several technical society

meetings. At the February 23 meeting of the Physics Club of Chicago, Dr. Arthur H. Compton, Chairman, his subject was "Stroboscopes and High-Speed Photography."

"Direct-Reading Instruments" was the title of Mr. Thiessen's paper at the Los Angeles section, I.R.E. The talk was supplemented by a few reels of high-speed motion pictures. Douglas Kennedy is chairman of the Los Angeles section, and the speaker was introduced by W. W. Lindsay, Jr., of the Meetings and Papers Committee.

This same paper was also delivered at the San Francisco section, V. J. Freiermuth, Chairman.

The subject of "Wave Analysis" was discussed before the Electronics Club of Los Angeles, Dr. J. F. Blackburn, Chairman.

A number of invitations to address other I.R.E. sections were received, and it is regretted that the schedule did not permit the acceptance of these.

● IN ORDER TO TEST the performance of the TYPE 726-A Vacuum-Tube Voltmeter at high frequencies, it was necessary to develop an accurate method of high-frequency voltage measurement. In next month's *Experimenter*, L. B. Arguimbau will describe the high-frequency voltage standard used for these measurements.

# I. R. E. HONORS GENERAL RADIO PRESIDENT



who has been responsible for an important advance in the science or art of radio communication. This advancement may be a single development or it may be a series of developments which in the aggregate have resulted in substantial improvements in radio communication. . . . ”

Mr. Eastham has been active in radio engineering societies since the early days of wireless telegraphy, and a member of the Institute since the first year of its existence. He served as a director of the Institute for several years, and has been its treasurer since 1927. He now holds the membership grade of Fellow. As founder and president of the General Radio Company, he has contributed much to the development of instruments and methods for radio measurements.

Presentation of the medal will be made at the annual convention banquet of the Institute on May 12. The citation reads as follows:

“To Melville Eastham for his pioneer work in the field of radio measurements, his constructive influence on laboratory practice in communication engineering, and his unfailing support of the aims and ideals of the Institute.”

● **THE MEDAL OF HONOR** of the Institute of Radio Engineers has been awarded to Melville Eastham, President of the General Radio Company since its founding in 1915.

This gold medal “is given in recognition of distinguished service in radio communication. It is awarded to one

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