VACUUM-TUBE VOLTMETERS

VACUUM-TUBE VOLTMETERS

2ND EDITION

by
John F. Rider

Revised by
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and
Alfred W. Barber

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Dedicated to
MY MOTHER
The longer I knew her,
the better I loved her.

PREFACE TO SECOND EDITION

This, the second edition, reflects almost ten years of expanding use of the vacuum-tube voltmeter. While the basic theories underlying these devices have not changed much since the very early days, the needs of electronic circuits found in television, radar, electronic computers and other devices, have made great demands upon electronic means of measuring voltage and current. Pulse techniques have become general practice and the rapid determination of magnitudes is a daily need.

To provide the answer to these needs, vacuum-tube voltmeter circuitry has undergone many revisions and to make them effective, engineering brains have devised the vacuum-tube voltmeter probe—the means which enable quantitative determinations of voltage and current at frequencies far up in the hundreds of megacycles.

Conditions of operation have become critical in all sorts of electronic devices. High-resistance circuits are more commonplace than ever before. They satisfied the demands for greater and greater sensitivity, but came into being only after tube design improvements resulted in more improved evacuation processes. The measurement of voltage and current in such circuits dictated substantial modifications in vacuum-tube voltmeter design.

This book attempts to portray the changes made in vacuum-tube voltmeters during the last ten years. Every effort has been made to satisfy all segments of the electronic art—from the student through the maintenance man, to the engineer. This book attempts to deal with the principles of the various types of vacuum-tube voltmeters, their design, application, and even repair. To accomplish this goal, every type of instrument is discussed and substantially every commercial version which has made its appearance on the market is noted in detail, even to the presentation of the schematic wiring diagram.

Several individuals are identified with the second edition. Mr. Alfred W. Barber revised a goodly portion of the original text. Mr. Charles Tepfer of the John F. Rider staff did most of the editing and contributed greatly to the contents of numerous chapters, especially the chapters relating to probes, applications, and maintenance.

Special thanks are extended to the manufacturers represented in this edition for their cooperation in furnishing photographs and other data. Acknowledgments are accorded each by means of courtesy lines but we feel that special mention should be made, hence these comments.

Every effort was made to make this edition up to the minute. It is realized, of course, that no book can embrace every new device which is a part of an art, for the time on the presses may be a period when something new makes its appearance. It is hoped that this edition will contribute knowledge about vacuum-tube voltmeters to the hundreds of thousands of users of these devices.

JOHN F. RIDER

March 19, 1951

AUTHOR'S FOREWORD TO THE FIRST EDITION

The vacuum-tube voltmeter, since its inception in 1895, has developed into one of the most valuable aids to the electronic research worker. Originally used to measure high-frequency voltages in connection with laboratory operations, it now has developed into an extremely valuable r-f, a-f and d-c voltage measuring device for the engineer and the maintenance man and for indicating purposes in complete communicating systems.

This book on the vacuum-tube voltmeter is intended as a practical exposition of the numerous types of such measuring devices, with the direct intention of providing a source of information for the engineer, student and serviceman, so that if he desires to compare different types, establish their principles of operation or construct them, all the facts are available from one source.

As is evident, a general understanding of the basic operation of the diode and triode types of tubes is taken for granted, although a brief review of each is furnished. This attitude is taken on the grounds that the man who works with vacuum-tube voltmeters is at least familiar with the vacuum tube. The beginner who is first learning elementary facts about radio theory, has no need for data on vacuum-tube voltmeters. At the same time, the use of equations relating to vacuum-tube voltmeter operation, such as are usually expected by the engineer, are also omitted because of the practical laboratory work that was done during the preparation of this text. The engineer who is interested in one certain type of vacuum-tube voltmeter, will find that type not only described, but presented in completed form with full constants for all of the components. Furthermore, since this is a practical book, rather than a theoretical book, there is no particular need for formulae.

As shown by the references and the bibliography, the text is a symposium of all the work which has been done in many countries upon vacuum-tube voltmeters. At the same time, however, original work also has been done, as attested by facts contained in this volume which are not available any place else.

In connection with the original laboratory work, we wish to express our gratitude to J. Avins who has done much research work upon vacuum-tube voltmeters, who has several valuable vacuum-tube voltmeter patents to his credit and under whose supervision the various finished units described in this volume were built. He was also greatly instrumental in the gathering of the numerous references contained in this book.

John F. Rider

February, 1941

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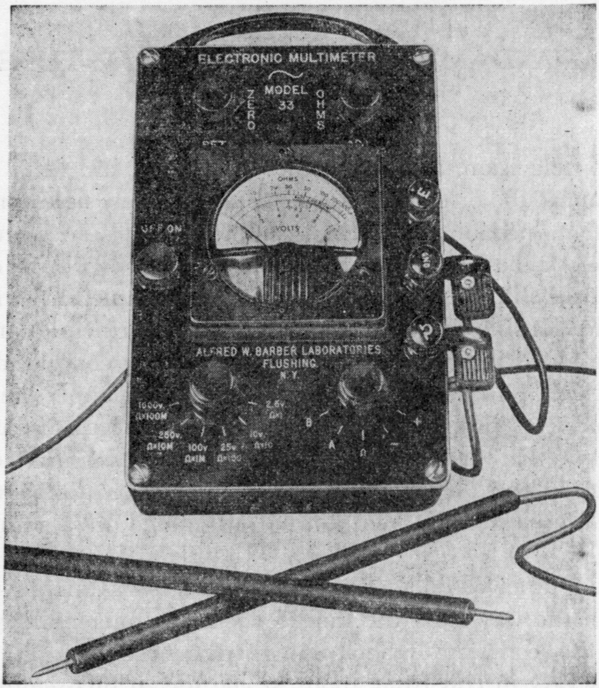
CHAPTER 1

FUNDAMENTALS OF VACUUM-TUBE VOLTMETERS

Radio, television, and electronics in general, are fields in which the vacuum-tube or electronic voltmeter is widely used for research and design, production testing, and servicing. The vacuum-tube voltmeter makes possible many measurements which otherwise could not readily be made and is easily adaptable to a wide range of applications. A thorough knowledge of its principles and modes of operation is important to anyone technically concerned with its fields of use. This knowledge will permit one to apply the vacuum-tube voltmeter properly thereby obtaining the greatest usefulness from it in the way of accurate results and maximum efficiency. Efficiency in the use of a piece of measuring equipment may be defined as the amount of information gained in a minimum of time.

Vacuum-tube voltmeters are commercially available in many forms all the way from the simple pocket voltmeter shown in Fig. 1-1 to the complete laboratory instrument shown in Fig. 1-2. VTVM's vary in cost from about $25.00 for an unassembled kit or $40.00 for a wired and tested unit, to over $300.00 for some laboratory type instruments. While the greatest number are general purpose, a-c operated types, there are many designed for special purposes, as well as many battery operated varieties. In addition to commercial voltmeters, there are many experimental or home-made meters which may be of interest and may be used in particular cases. Some of these latter will no doubt form the basis for commercial voltmeters of tomorrow.

Definition—The terms vacuum-tube voltmeter, VTVM, and electronic voltmeter are synonymous and refer to the combination of a thermionic vacuum tube and an indicating meter for the purpose of measuring current, voltage, or resistance. The vacuum tube (or tubes) are used for their rectifying or amplifying properties or both. A simple vacuum-tube voltmeter may use only a diode, while a complex voltmeter may utilize several amplifier tubes and a diode rectifier.



Courtesy Barber Laboratories

Fig. 1-1. A pocket-size vacuum-tube voltmeter for general purpose use.

Just as the vacuum tube has made possible high gain and a wide frequency coverage in communication circuits, so has its use in the vacuum-tube voltmeter resulted in measurements of greater sensitivity and wider frequency response than are possible by other apparatus. The development of the electronic voltmeter roughly parallels the development of other vacuum-tube circuits. The invention of the Fleming diode made possible the first vacuum-tube voltmeter consisting of a thermionic diode rectifier and an indicating meter. Present day high-frequency tubes provide voltmeters of great sensitivity and wide frequency response. In addition, advantage has been taken of the advances which have been made in sensitivity, ruggedness, and accuracy of indicating meters.

Courtesy Hewlett-Packard Co.

Fig. 1-2. Laboratory-type vacuum-tube voltmeter. This instrument is designed to measure a-c, d-c, and r-f voltages up to about 200 megacycles.

Advantages of the V-T Voltmeter

Since the vacuum-tube voltmeter was conceived to perform functions which were beyond the capabilities of other forms of measuring devices, it stands to reason that it must possess numerous advantages. These are many, but the one of prime importance and of greatest value to all those who have occasion to make voltage measurements under varying conditions, is that *the vacuum-tube* *voltmeter draws a negligible amount of current from the circuit under test.* In other words, it does not disturb or load the circuit under test to any appreciable extent. This is of especially great importance in radio circuits because so often the amount of power available in the circuit under test is measured in microwatts. Since a conventional meter would draw thousands of times the total available power, it is clear that it cannot be used to make measurements in such circuits.

With the v-t voltmeter, however, this limitation is largely overcome because the voltage under measurement is applied to a vacuum tube, rather than directly to a meter. Since the vacuum tube used in the measuring device draws very little current during normal operation of a v-t voltmeter, it follows that a very small current is drawn from the voltage source being measured.

High Sensitivity—The v-t voltmeter provides a greater sensitivity than a meter, because the VTVM combines the amplification provided by the tube with the inherent sensitivity of the meter. Thus in Fig. 1-3a, which is a schematic of a simple v-t voltmeter, a small change in grid voltage—without the flow of grid current—is capable of changing the plate current by a considerable amount. If a sensitive meter is used to measure this change in plate current, it is clear that the VTVM by utilizing the amplification of the tube, is capable of measuring much smaller voltages than could be obtained if the meter were coupled directly to the circuit being measured.

Greater Ruggedness—For a given measurement, the meter required in conjunction with a v-t voltmeter can be much less sensitive than a meter which could be employed directly. Because of this, meters which are used in VTVM's are more rugged, and so are better able to withstand accidental overload than conventional meters of the same sensitivity. In addition to permitting the use of a less sensitive meter, v-t voltmeter circuits are usually designed so that additional protection is afforded the meter. These refinements will be discussed in detail later, but for the present it is sufficient to note that the current through the meter can never rise above the maximum plate current of the vacuum tube with which it is associated, no matter how large an input voltage is applied to the grid.

Wider Frequency Range—An extremely important advantage of the v-t voltmeter over conventional meters is the fact that it makes possible measurements of a-c voltages over an extremely wide frequency range. Special v-t voltmeters have been developed which permit measurements to be made at frequencies of the order of several thousand megacycles, but even the well-designed commercial v-t voltmeter can measure up to several hundred megacycles. Because of the increasing importance of the ultra high frequencies in many branches of the electronic art, this is an important advantage of this type of instrument. As new tubes are developed and higher frequencies are exploited, these same tubes and circuits are being employed in v-t voltmeters to enable measurements at these higher frequencies.

Use of Ordinary Meters—Although the v-t voltmeter can be used with equal facility for all measurements, whether in high- or low-impedance circuits, the conventional meter still retains advantages when d-c or low-frequency (power) measurements are to be made in *low-impedance circuits.* These advantages are greater portability and (usually) greater accuracy, because of the fewer variables involved in using a single meter as against using a meter which is combined with a vacuum tube, power supply, and other components. **In high-impedance circuits, however, the v-t voltmeter is unquestionably superior to the conventional meter.** Whereas conventional voltmeters for direct-current measurements usually have input resistances of from 1,000 to 20,000 ohms per volt, 10 megohms is more or less standard for electronic voltmeters, i.e., at least 1,000 times that of the nonelectronic voltmeter for a full-scale range of 0–5 volts. Generally, alternating-current voltmeters have about one-half the input impedance of direct-current meters, but the a-c electronic voltmeter still offers the greater impedance.

We must recognize however, that the conventional d-c voltmeter rated at 20,000 ohms per volt and adjusted for measurement of 1,000 volts or higher will present a higher impedance load across a circuit than the usual run of VTVM's. Therefore the paramount advantages of the vacuum-tube voltmeter are found in its low voltage measurement capabilities on ac and dc, its ability to function at high frequencies, and its ability to read average, rms, and peak-to-peak values.

Electronic circuits operate over a very wide range of voltage and frequency and significant points are often at a high impedance. The electronic voltmeter offers the only general solution to measurements in these circuits. Modern developments have provided a number of different basic types of VTVM's, each particularly suited to a certain type of measurement.

Classification of Electronic Voltmeters

The following chapters will deal with the various types of voltmeters in detail. Here is a brief summary of the major types:

Direct-current voltmeters comprise a vacuum-tube circuit using one or more vacuum tubes, and an indicating meter. They utilize the important characteristic of the triode in which a relatively large plate current change is produced by a relatively small change in grid voltage. The direct-current vacuum-tube amplifier circuit is the basis for a whole series of measuring instruments including direct-current voltmeters covering a wide range of voltages; very sensitive, electronic current meters; ohmeters, capable of measuring resistances to thousands of megohms; pH meters, capable of making measurements through glass electrodes; electrometers drawing almost immeasurably small currents from the circuit under test; and many others.

Alternating-current voltmeters may utilize a simple circuit embodying a single diode or triode rectifier, but usually are a combination of a rectifier and a direct-current amplifier. The rectifier is usually a thermionic diode, although crystals and even metallic rectifiers are used. Another important class of a-c voltmeters are those in which an alternating-current amplifier is placed ahead of the rectifier. The latter are more sensitive but cover less frequency range than the directly rectifying types.

Thus, any vacuum-tube voltmeter circuit may be broken down into one or more of the three basic circuits consisting of direct-current amplifiers, rectifiers, and alternating-current amplifiers. Each of these circuits will be treated in detail in the following chapters.

In some cases the rectifying and amplifying functions may be of secondary importance. In the slide-back voltmeter, described later, a rectifier is used merely to furnish peaks of the voltage to be measured. In the electrometer, the electrometer tube is primarily an impedance transforming device for following or detecting changes in an extremely high-impedance circuit and producing a corresponding change in a relatively low-impedance circuit where the effect may be indicated by a meter.

A Simple D-C V-T Voltmeter

The basic operation of a vacuum-tube voltmeter is comparatively simple. The instrument in elementary form is a combination of a vacuum tube, the required operating voltages, and a plate-current meter used as an indicator. Two types of tubes are used in VTVM's: the triode, as the basic type of multiple-element tubes, and the diode. In view of the fact that the latter is discussed later in a separate chapter, we shall at this time consider the preliminaries of just the triode type.

The essence of operation of the triode type of v-t voltmeter lies within the amplifying property of the tube. This is so even when the tube is used as a triode rectifier or detector, rather than as an amplifier. As a result of this amplifying property, a small voltage applied between the control grid and the cathode or filament, whichever type of electron emitter is used, results in a large variation of the plate current. In Fig. 1-3a is shown the circuit of an elementary type of triode v-t voltmeter, which is in many respects similar to the more elaborate instruments described later. A d-c milliammeter is located in the plate circuit, between the plate battery and the plate to indicate the plate current. The unknown voltage to be measured is applied to the input of the tube between the grid and the grid bias terminal.

Suppose now that the bias voltage is adjusted so that, with no voltage applied to the input, the plate current is reduced to zero. Then if a positive voltage is applied to the input terminals it offsets all or part of the negative bias and the plate current will increase from zero. The greater the positive voltage, the greater will be the increase in the plate current. As shown in Fig. 1-3b, the plate current increase is almost proportional to the voltage applied to the input terminals so that the plate current can be taken as a measure of the voltage applied to the grid.

In practice, the milliammeter scale is marked in terms of the input voltage (E_x) which must be applied to the grid to cause a given plate current to flow. Thus when $E_x = 2$ volts the plate current $I_p = 4.0$ ma. This interpretation of the plate current in terms of the corresponding grid voltage is called *calibration* of the instrument. The meter scale shown in Fig. 1-3c has the original milliampere scale, while the appearance of the scale on the same meter after it has been calibrated for use in this simple VTVM is shown at Fig. 1-3d. It is customary to omit the plate current designations since these are not of interest to the user of the v-t voltmeter.

The application of such a simple v-t voltmeter to the measurement of direct voltages is immediately clear. To measure any positive d-c voltage between 0 and 5 volts, it is only necessary to connect this voltage to the input terminals of the VTVM and the value of the unknown voltage can be read on the meter scale.

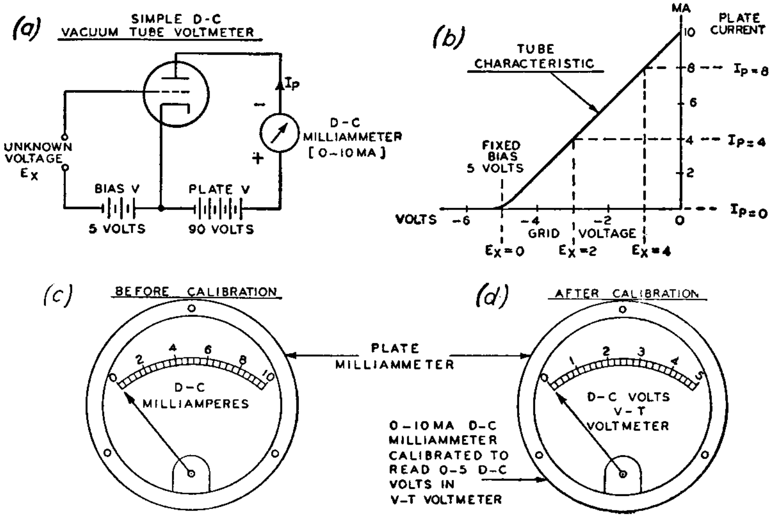


Fig. 1-3. The schematic and operation of a simple d-c v-t voltmeter. The appearance of the milliammeter scale before and after calibration illustrates the manner in which the plate-current reading is interpreted in terms of the unknown voltage applied to the grid.

Needless to say the v-t voltmeter which we have just described is a very simple voltmeter indeed, but because of its simplicity its usefulness is greatly limited. Thus such a v-t voltmeter can be used only for the measurement of d-c voltages over a limited range. To overcome this limitation, however, circuits have been developed which permit the measurement of all d-c voltages, regardless of polarity, and all a-c voltages over a wide range of frequencies. These VTVM's will be described in detail later.

A Simple A-C V-T Voltmeter

We have previously described the basic manner in which a vacuum tube and d-c milliammeter are arranged to measure *d-c* voltages. We shall now describe how a similar simple setup is arranged for the measurement of *a-c* voltages, in which classification we include of course all alternating voltages, so that the simple v-t voltmeter to be described can be used for measuring 25-cycle, 60-cycle, audio-frequency, and radio-frequency voltages.

The schematic is shown in Fig. 1-4a. You will observe that this circuit is essentially the same as that shown in Fig. 1-3a; however the manner in which the circuit operates for the measurement of a-c voltages is different than for d-c voltages.

As Fig. 1-4b shows, the tube is initially biased to cutoff so that no plate current flows when there is no a-c voltage applied to the grid. When an input a-c voltage is applied, however, the grid will be swung alternately positive and negative. On the negative grid swings, which make the grid more negative, there can be no further decrease in the plate current because the tube is already biasd to cutoff. On the positive grid swings, however, the bias is offset and the plate current will follow the grid voltage so that there will be a pulse of plate current which is similar in shape to the positive half of the input a-c voltage applied to the grid.

As a result of this action, the current flowing through the plate milliammeter will consist of a series of pulses. But the plate current meter cannot follow these pulses—unless they are very slow—perhaps 1 cycle per second. At all frequencies above a few cycles per second, which means all audio, commercial ac, and high frequencies, the meter indicates the *average* value of the plate current that flows through it. The dotted line in Fig. 1-4b shows that the average plate current is 3.2 milliamperes, or 32 per cent of the peak plate current.

As in the case of the d-c vacuum-tube voltmeter which we previously described, it is possible to calibrate the scale of the d-c plate milliammeter used in the a-c VTVM in terms of the a-c voltage applied to the grid. When no voltage is applied, the plate meter will read zero and so this point on the scale can be marked zero volts. As the a-c voltage is increased from zero, the plate current will increase, and the meter reading will increase in proportion to the magnitude of the applied a-c voltage. In this way each point on the scale can be assigned that value of input a-c voltage which is required to produce the particular value of d-c current through the meter for that scale reading. A typical calibration for an a-c vacuum-tube voltmeter of the type we have been describing is shown in Fig. 1-4c.

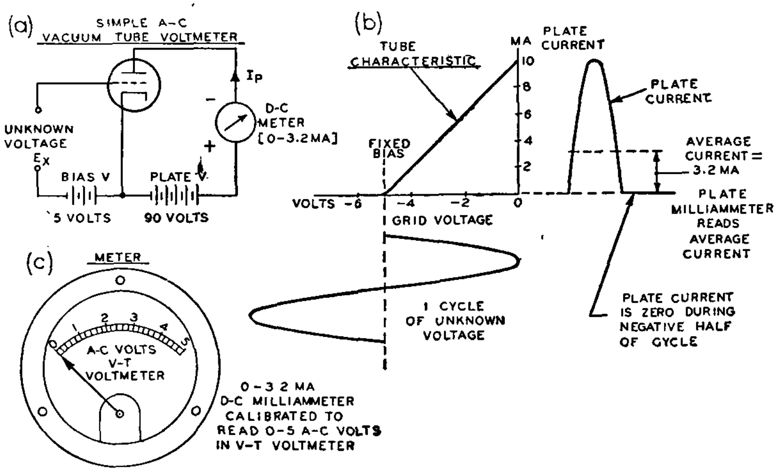


Fig. 1-4. In this simple v-t voltmeter for the measurement of a-c voltages the grid is biased to cutoff. Thus, only the positive halves of the input voltage cause a flow of plate current through the d-c milliammeter which is calibrated to read a-c volts.

Importance of Waveform—Peak, RMS, and Average Values

One of the significant details associated with vacuum-tube voltmeters, belonging in this discussion of fundamentals, is that relating to waveform. Thus v-t voltmeters are often referred to as being of the *peak* type, as being calibrated to read *rms* values, as having a response proportional to the *average* value of the input voltage, etc. All of these comments are related to the *waveform* of the voltage being measured and to the *response* of the v-t voltmeter used for the measurement.

D-C Voltage Wave—The simplest type of waveform is that of a direct voltage such as is shown in Fig. 1-5a. It is a straight line. Here there is no possibility of confusing the *peak, rms,* and *average* values because all are equal.

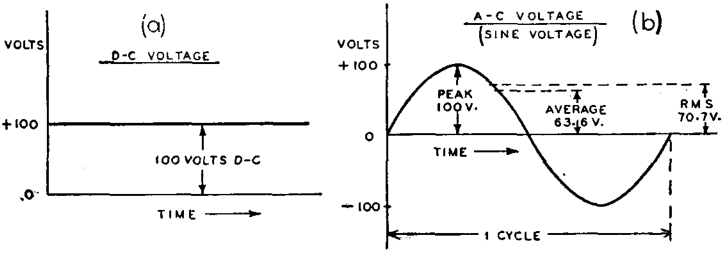


Fig. 1-5. The simplest waveform, direct current, is a straight line; the fundamental a-c waveform is a sine wave. Note the designations of the *peak, average,* and *rms* values.

Sine Voltage Wave—When we refer to an a-c voltage, it is usually understood that the waveform of that voltage is similar to the smooth *sine wave* shown in Fig. 1-5b. When an a-c wave has this sine shape, it is said to be pure or undistorted, and is entirely free of harmonics. The voltage wave which is supplied by the power companies usually has a waveform which is very nearly a sine wave.

However not all waves have a sine waveform. Whenever a wave is not pure sine in shape, the change in waveform is due to the presence of harmonic frequencies. Thus the "complex" waves shown in Figs. 1-6, 1-7, and 1-8 are made up of a fundamental frequency plus a number of harmonic frequencies. In general the more the waveform departs from a sine wave, the greater are the number and amplitude of the harmonics present.

Peak Value—In describing the waveform of various types of voltages and currents being measured, it is often necessary to refer to the *peak* value of the wave. As the name implies, the peak value is the highest voltage which the wave reaches. For the sine wave shown in Fig. 1-5b, the peak value is clearly equal to 100 volts. The peak values of the complex waves shown in subsequent figures are indicated in each drawing. Note that regardless of the complexity of the waveform, the peak value is in all cases the highest value reached by the voltage.

For some distorted (complex) waves, the positive peak value is different from the negative peak value. This occurs when the wave is not symmetrical and in such cases it is necessary to refer to the *negative-peak* voltage as well as the *positive-peak* voltage. An example of such a wave is shown in Fig. 1-6. Recognition of this condition is important in v-t voltmeter measurements because of the difference in measured values under different conditions.

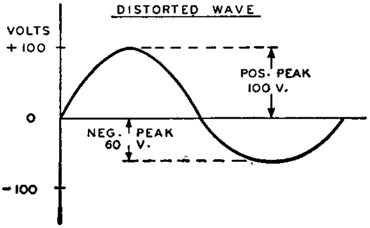
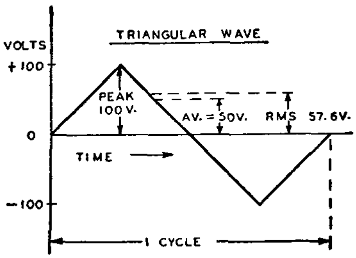
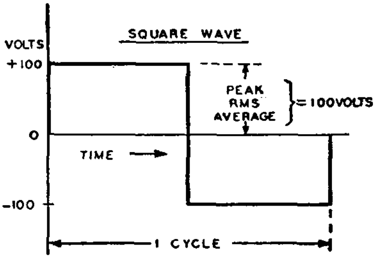


Fig. 1-6. An unsymmetrical complex wave which is distorted because its positive and negative peaks are unequal.

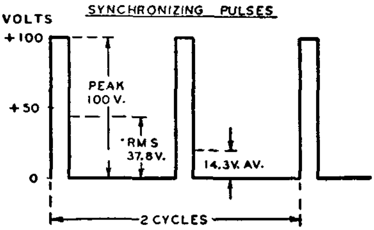
Average Value—Another term used in connection with a-c voltages and currents is the *average* value. Just as the name implies, the average value of an a-c voltage is equal to the value obtained by averaging the instantaneous values of voltage over the whole positive or negative half-cycle. When this averaging process is carried out for a sine wave, it turns out that the average value of the half-wave is equal to 63.6 per cent of the peak value. As shown in Fig. 1-5b, the average value of a sine wave of voltage having a peak value of 100 volts is 63.6 volts.

The average value is not always equal to 63.6 per cent of the peak value. It all depends upon the waveform. For a sine wave it is 63.6 per cent; for a triangular wave like that in Fig. 1-7, it is 50 per cent (for a half-wave). For a square-top wave like that shown in Fig. 1-8 it is 100 per cent for each half-cycle. For the special type of wave which represents the synchronizing pulse in a television system and shown in Fig. 1-9, the average value is only





Above Fig. 1-7, above right Fig. 1-8, and right Fig. 1-9. Three representative types of complex waves. Although the *peak* value is the same, the *average* and *rms* values are different for each of these voltage waves.



14.3 per cent of the peak. The reason for this low average value is that the peak value of the wave lasts for only a small fraction of the cycle. During the remainder of the cycle the voltage is zero, so that the average value is brought down to a figure very much lower than the peak. In the case of rectified waves, the average value of a half-wave rectified pulse is 31.8 per cent of the peak, as shown in Fig. 1-10, and is 63.6 per cent of the peak in a full-wave rectification system, as shown in Fig. 1-11.

Among other reasons, the average value of an a-c wave is important because the reading of a d-c meter is proportional to the average value of the current or voltage. Thus in explaining the operation of the simple a-c VTVM shown in Fig. 1-4, we mentioned that the d-c meter responded to the *average* value of the current wave in the plate circuit. Another example where the average value is important is in the reading of a milliammeter which measures the plate current of a class-A amplifier tube. With a signal applied, the plate current of such a tube is similar to that of the *pulsating* wave shown in Fig. 1-12. The reading of the d-c meter is the *average* value of this wave; if the waveform is undistorted, the reading will not change when the signal is removed because the average value of the wave is the same as the steady value of plate current. In this connection, if the tube were not biased to cutoff, the current flowing through the meter would be influenced by both the positive and negative halves of the cycle.

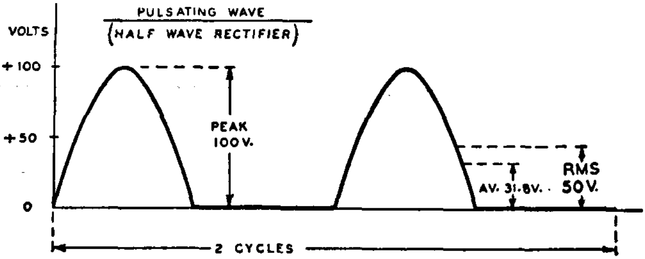


Fig. 1-10. The voltage output of a half-wave rectifier.

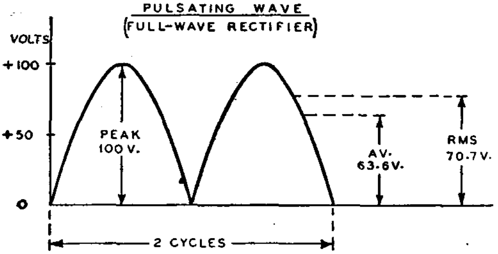


Fig. 1-11. The output voltage of a full-wave rectifier. The *average* and *rms* values of the output of a full-wave rectifier are twice as great as those of a half-wave rectifier, when the *peak* values are equal.

RMS Value—The *rms* or *root-mean-square* value is more often used in connection with a-c voltages and currents than either the average or peak values. Usually when we refer to a line voltage as being 117 volts, or a heater voltage as being 6.3 volts, it is the *rms* value which is designated. The rms value, often called the *effective* value, is a measure of the power in the current or voltage wave. It thus involves the average of the *squares* of all of the instantaneous values, for the same reason that the heating effect of a current is proportional to the square of the current.

In the case of a sine wave, the rms value turns out to be equal to 70.7 per cent of the peak value of the wave, as is indicated in Fig. 1-5b. As in the case of the average value, *the rms value is a different percentage of the peak value for different complex waves.* An examination of Figs. 1-7, 1-8, and 1-9 will show how the rms value varies for different typical waveforms; these waveforms range

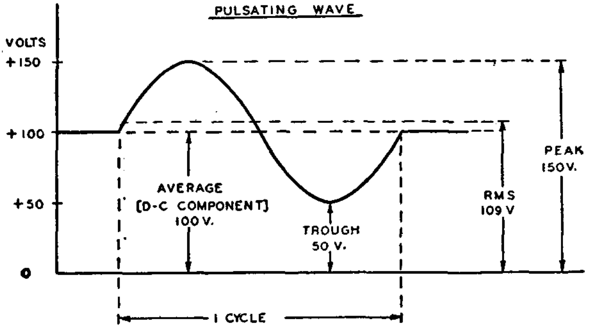


Fig. 1-12. The *peak, rms, average,* and *trough* voltages of a pulsating wave typical of those found in the plate circuit of an amplifier tube. Note that the *average* value is equal to the d-c component of the wave.

from a triangular-shaped wave to the series of pulses used for synchronizing sweep circuits.

V-T Voltmeters Respond to Peak, Average, or RMS Values

Depending upon its design, the reading of a v-t voltmeter is a function of either the *peak* value, the *average* value, or the *rms* value (or some combination of these values) of the voltage applied to the input. As we have just seen there is no fixed relationship between these values, and so it is important to know just what type of VTVM one is using. The v-t voltmeter described in connection with Fig. 1-4 is an "average-reading" meter because its reading depends upon the *average* value of the positive half-cycles. Other VTVM's, which will be described later, are different from this meter in that their indication is proportional to the *peak* or the *rms* values.

Calibration of V-T Voltmeters—Vacuum-tube voltmeters are not always calibrated in terms of the value to which they respond. For example, it is very commonplace for commercial *peak-reading* v-t voltmeters to be calibrated so that the scale indicates the *rms* value of the input voltage. Whenever this is done, however, it is understood that this calibration holds true only for a sine wave in which the rms value is 70.7 per cent of the peak value. If a VTVM of this type is used to measure the synchronizing pulse waveform in Fig. 1-9, for example, the instrument would respond to the peak value of 100 volts, and being calibrated in terms of a sine wave, would indicate 70.7 volts rms. The true rms value of this wave, however, is 37.8 volts, so that there is an error of 32.9 volts—an error of 87 per cent!

Fortunately the voltages most frequently encountered are for the most part closely similar to a sine wave so that errors of the type mentioned above are the exception rather than the rule. However the preceding example emphasizes the fact that it is not sufficient to know that a vacuum-tube voltmeter is calibrated to read rms values. When working on voltages other than pure sine waves, that is, complex voltages, it is necessary to know whether the voltmeter is of the peak-reading type; whether it responds to the positive or negative peaks, or both; whether it is an rms type; and so forth. These considerations will be taken up in detail in the chapters where these meters are considered.

Balancing or "Bucking" Circuits

In the v-t voltmeters which have been described up to this point, the vacuum tube was operated at plate-current cutoff. As a result, no current flowed through the plate milliammeter (or microammeter) with no voltage applied to the input of the VTVM. In practice it is frequently very desirable to operate on a point of the vacuum-tube characteristic where the plate current has an appreciable value. In such instances the resulting no-signal plate current flow is a disadvantage because (1) the full meter scale cannot be utilized for measurement, and because (2) the sensitivity of the meter is limited to a value which is less than the no-signal plate current.

To permit the use of a more sensitive plate-current meter and to utilize the entire plate meter scale so as to increase the over-all sensitivity of the v-t voltmeter, it is customary to balance or "buck out" the no-signal plate current. The methods for accomplishing this will be explained in detail in Chapter 3. Here, it is sufficient to say that in the balanced circuit one tube receives the signal to be measured or its rectified components, while a second tube acts as a balancing circuit to neutralize the no-signal plate current of the first tube. Most commercial v-t voltmeters use balanced circuits which are more stable and satisfactory than "bucking" circuits, both however, make possible the utilization of the full scale of the meter for calibration, and result in a meter sensitivity of five, or more, times the no-signal plate current.

REVIEW QUESTIONS

CHAPTER 1

1–1. What is a vacuum-tube voltmeter?

1–2. How has the development of the vacuum tube contributed to electrical measurements?

1–3. The v-t voltmeter draws negligible current from the circuit being measured. Give three types of circuits where this characteristic of the v-t voltmeter allows it to make measurements impossible with other type meters.

1–4. What are the basic circuits of the typical a-c v-t voltmeter?

1–5. A-c v-t voltmeters are designed to respond either to the peak, the rms, or the average value of an a-c voltage. What information about the measured voltage is given by each of these values?

1–6. What is the difference between the *response* of a meter and its *reading*?

1–7. How may a meter read rms values of measured voltage if it responds to the peak values?

1–8. Why is it desirable to bias the vacuum tube in the amplifier section of a VTVM at a value where plate current is appreciable for no voltage input?

1–9. Why are "balancing" or "bucking" circuits used in a-c VTVM's?

1–10. Design a simple "bucking" circuit which could be used in a v-t voltmeter to counteract the no-signal plate current.

CHAPTER 2

DIODE VACUUM-TUBE VOLTMETERS

Although many improvements have been made in vacuum tubes since the diode was invented, diode v-t voltmeters are still widely used today because of certain advantages which they afford. Apart from their own usefulness, they are of special interest because certain complicated VTVM's also employ diode circuits; among these may be mentioned v-t voltmeters of the rectifier-amplifier, the amplifier-rectifier, the slide-back, and the logarithmic types. In this chapter we shall explain the operation of the diode rectifier since it is fundamental and necessary to an understanding of all diode VTVM circuits. In addition, we shall describe practical circuits of the various types of diode v-t voltmeters, including their operation and characteristics.

The Diode Characteristic

The property of the diode which makes it useful in v-t voltmeter circuits is its ability to conduct current in only one direction. When a positive voltage is applied to the plate of a diode, the resulting current increases as the plate voltage is increased, see Fig. 2-1. However, if the polarity of the voltage is changed so that the plate is made negative with respect to the cathode, then no current flows. With zero plate voltage we assume the absence of plate current.[1]

If we examine Fig. 2-1b, the plate voltage-plate current characteristic of the diode, you will note its nonlinearity—the fact that there

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[1] A more complete description of the behavior of diodes with zero input voltage is given later in this chapter.

is no uniform relationship between the plate current and the plate voltage. The reason for this is that the resistance of the diode is not constant—it decreases for an increase in plate voltage.

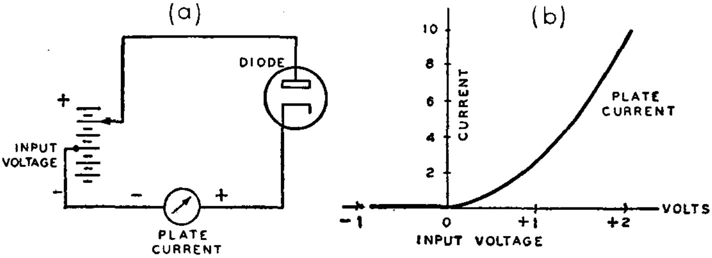

Fig. 2-1. A diode arranged so that positive and negative voltages can be applied to the plate is shown in (a). The plate-current characteristics at (b) shows that current flows only when the plate is made positive with respect to the cathode.

However, it is possible by a very simple expedient to alter the characteristics of the diode circuit so as to nullify this variable resistance effect of the tube. This is done by the use of a load resistance, as shown in Fig. 2-2.

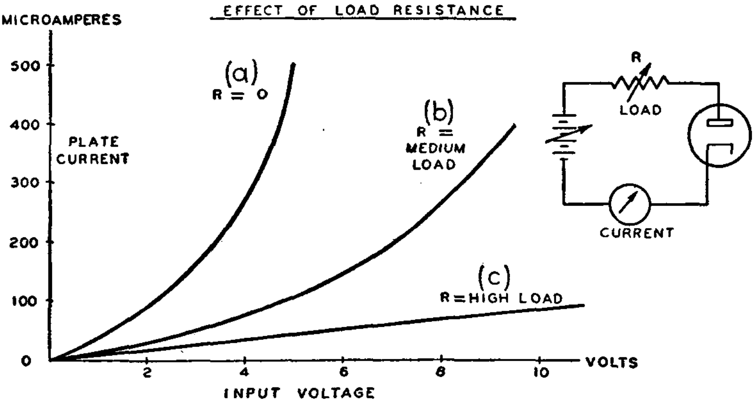

Fig. 2-2. The effect of load resistance on the plate current-plate voltage characteristic of a diode. A linear plate current variation can be secured by using a high value of load resistance as shown at (c).

If a resistor is inserted in the diode circuit, the curved characteristic is straightened somewhat, as is shown by curve (b) in Fig. 2-2.

If a still higher value of resistance is used, the characteristic becomes practically a straight line (c); however, the line is lowered appreciably because the current obtained for a given voltage is decreased by the load resistance. Note that the use of a high value of load resistance permits higher input voltages to be applied without excessive current being drawn by the diode.

The straightening effect of the load resistance demonstrated in Fig. 2-2 is a consequence of the fact that the nonlinear diode resistance is small in comparison with the load resistance. Thus although the diode resistance itself varies with the applied voltage, these variations are negligible in comparison with the total constant resistance in the diode circuit.

In practice, values of load resistance above 100,000 ohms must be used to obtain a high enough value of input resistance when the diode rectifier is used as a v-t voltmeter. These values are sufficiently high so that the diode characteristic is essentially straight for values of input voltage above a few volts. A straight characteristic is desirable for two reasons: (1) the scale of the v-t voltmeter is then uniform, and (2) the calibration becomes independent of variations in the resistance of the diode. Such variations may occur because of "aging" of the tube or changes in the heater voltage.

Diode Rectifier Operation

The behavior of the diode when an a-c voltage is applied to the circuit is fundamental to an understanding of diode VTVM's. In Fig. 2-3a, we show a circuit in which an a-c voltage is applied to a diode in series with a load resistor and a microammeter. To illustrate the action which takes place, we have shown at (b) the diode characteristic which was just described. For negative voltages we assume no current flow,[2] while for positive voltages the diode current increases uniformly as the applied voltage is increased.

The applied a-c voltage is shown below the voltage axis and consists of a sine wave of voltage which has a peak value of 4 volts. Starting with the positive half of the cycle, the plate current increases from zero to a maximum of 400 microamperes and then returns to zero as the voltage drops to zero. As the applied voltage

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[2] Later in this chapter there is a discussion concerning current flow with zero plate voltage.

goes through the negative half of the cycle, no current flows. The same action takes place on each of the succeeding cycles of applied voltage.

D-C Plate Microammeter Reads Average Value of Current—The current wave through *R*, the load resistor, shown in Fig. 2-3, is also the current through the d-c microammeter or milliammeter. Being a d-c meter, this instrument will not respond to the fluctuations in the rectified current but will respond only to the d-c component of the rectified current. This d-c component is precisely the same as the average value of the rectified current. It is indicated in the figure by the dotted line which shows that the reading of the d-c microammeter will be 31.8 per cent of the peak value of the current.

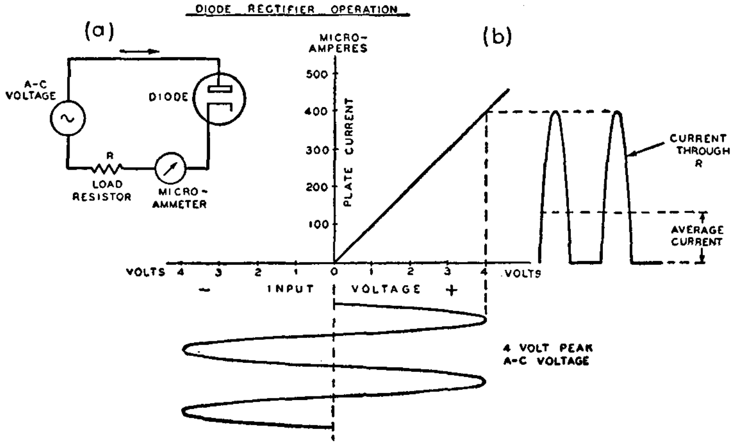


Fig. 2-3. The operation of a simple diode rectifier circuit. When an a-c voltage is applied to the plate, the positive half cycles are rectified and the d-c meter indicates the average value of the rectified plate current.

D-C Current Is Proportional to Applied A-C Voltage—If we vary the a-c voltage applied to a diode rectifier, then the reading of the d-c meter will increase proportionately as the a-c voltage is increased. This is illustrated by the typical curve in Fig. 2-4, which shows that a 4-volt input will produce a d-c current of 130 microamperes, an 8-volt input will produce twice as much current, or 260 microamperes, etc. This curve shows that it is possible to calibrate the d-c microammeter in terms of the a-c input voltage, so that the diode circuit can be used as a v-t voltmeter. As can readily be seen by a study of Fig. 2-3, the reading of this type of VTVM depends upon the average value of the *positive half-cycles* of the applied a-c voltage.

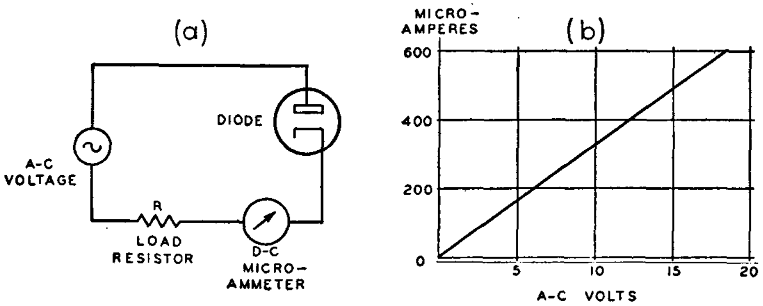


Fig. 2-4. When an a-c voltage is applied to a diode circuit, the rectified plate current increases as the applied a-c voltage is increased. A typical curve showing the relation between the d-c plate current and the applied a-c voltage appears at (b).

Simple Diode V-T Voltmeter

A v-t voltmeter using the circuit just described is shown in Fig. 2-5. This diode VTVM uses a 200-microampere meter, a 100,000-ohm load resistor and an ordinary receiving diode such as one section of a type 6H6 tube. When used for measuring a-c voltages it will give a full-scale deflection for an input voltage of some 45 volts rms. Although we mention the sensitivity of the voltmeter in terms of rms values, it is understood as previously explained that the meter reading is proportional to the *average* value of the positive half-cycle of the wave being measured. This however, does not preclude calibration of the meter in rms values.

Input Resistance—The input resistance of this type voltmeter is equal to the value of the series or load resistor. In practice very high values of *R* cannot be used because of the resulting reduction in sensitivity. Thus if the input resistance were to be raised to 1 megohm, then a 20-microampere meter (instead of 200 microamperes) would be required in order to secure approximately the same sensitivity.

Frequency Response—The frequency response is limited to the lower radio frequencies because there will always be some shunt capacitance which will tend to bypass the r-f currents around the series resistor, *R*. This will make the meter read high as the frequency is increased, since a larger current will flow through the meter than if the current were completely limited by the series resistor, *R*. In general the higher the value of *R*, the more limited will be the frequency response.

Limited Application—Because of its comparatively low input resistance and limited frequency range, the "series-resistor" type of diode v-t voltmeter has a limited use. This simple series circuit is seldom used to measure an alternating voltage superimposed on a direct-voltage component due to the difficulty of interpreting the reading. Other diode v-t voltmeters which are superior to this circuit for practically all applications will be described in this chapter.

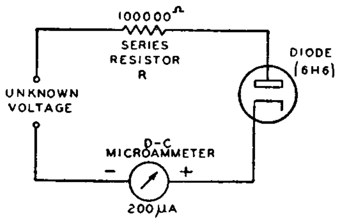


Fig. 2-5. A simple diode v-t voltmeter in which a series resistor is used in order to raise the input resistance and obtain a linear response.

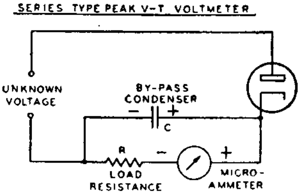


Fig. 2-6. A diode v-t voltmeter in which a peak response is obtained by shunting the load resistance *R* with a large capacitor *C*.

Peak Diode V-T Voltmeter—Series Type

The VTVM shown in Fig. 2-6 will be recognized as similar to the familiar diode-detector circuit used in superheterodyne radio receivers. In this circuit a bypass capacitor is used across the load resistor. The effect of this capacitor is to make the circuit respond to the *peak* value of the positive half-cycle of the applied a-c voltage. If the capacitor is removed, then the circuit becomes similar to Fig. 2-5, and it then responds to the *average* rather than the *peak* value.

Operation—As in all diode circuits, no current flows through the diode on the negative half of the cycle. On the positive half however, the plate becomes positive with respect to the cathode so that electrons flow into the plate end of *C* and out of the cathode end. The result of this action is to charge *C* to a voltage which is only slightly less than the peak value of the applied voltage.

To take a definite example, let us assume that a 100-volt peak a-c voltage is being measured. On the positive peak of the signal, *C* will charge up to 100 volts. Because of the shunt resistor *R*, however, the capacitor will at all times be slowly discharging through the resistor. The effect of this action is to make the voltage across *C* drop from about 100 volts to about 95 volts during the time between positive peaks of the applied voltage.

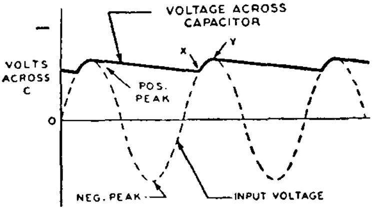


Fig. 2-7. The shunt capacitor *C* in Fig. 2-6 becomes charged negatively by an amount equal to the positive peak of the applied voltage. During the interval between positive peaks, *C* discharges slowly as indicated by the sloping solid line.

The manner in which the voltage across *C* varies is shown in Fig. 2-7. From a study of this figure it is apparent that current flows in the diode circuit only for the small interval *x*-*y* near the positive peak of the applied voltage. Throughout the remainder of the cycle the charge on *C* keeps the plate negative with respect to the cathode so that the diode is nonconducting. When *R* and *C* have the proper value however, the amount of charge which is replenished while the diode is conducting is sufficient to compensate for the slow discharge of the capacitor through *R* and the meter. For proper operation the time constant of the circuit (*RC*) should be large in comparison with the time of 1 cycle. Typical values of *R* and *C* for different frequency ranges are given in the Table 2-1.

Sensitivity—The sensitivity of the series-type peak v-t voltmeter is limited by the value of the load resistance and the sensitivity of the d-c microammeter or milliammeter. Since *C* charges to the peak value of the input voltage, the average current through the meter will be equal approximately to the peak input voltage divided by

TABLE 2-1

R AND *C* VALUES FOR PEAK V-T VOLTMETERS

Frequency	*RC*	*Typical Values of R-C** *R* *Megohms*	 *C* *Microfarads*
above 25 cycles	0.4	1	0.4
above 60 cycles	0.17	1	0.2
above 1,000 cycles	0.01	1	0.01
above 100 kc	0.0001	0.1	0.001
above 10 *mc*	0.000001	0.1	0.000005

* For any frequency range, different values of *R* and *C* can be used provided that the product *RC* is not less than the value specified in the *RC* column. ($RC = 10/f$).

the resistance of *R*. Thus if *R* has a value of 1 megohm, full-scale deflection on a 100-microampere meter will be obtained for a peak input voltage of slightly more than 100 volts.

Input Resistance—The input resistance depends upon the value of *R* and is approximately equal to one-half the resistance of *R*. The input capacitance depends upon the capacitance of the diode and the leads, and is not affected by the large value of capacitance used for *C*. The reason that *C* does not shunt the input of the v-t voltmeter is that *C* is isolated from the input circuit by the diode *which does not conduct current except for a small fraction of the cycle on the very peak of the input voltage.*

Frequency Error—The series-type peak VTVM has a negligible frequency error over a range extending from a low frequency determined by *R* and *C* to a very high frequency determined by the type of tube used and the length of the leads. Unless the proper values of *R* and *C* are used however, the calibration will not be the same for all frequencies. The values of *R* and *C* which must be used for low frequency accuracy are described later in this chapter.

D-C Path Is Required—This type of v-t voltmeter, as well as that shown in Fig. 2-5, cannot be used for measurements unless a complete d-c path is present for charging the capacitor *C*. For example, it cannot be coupled to another circuit through a blocking capacitor since there would then be no complete d-c path in the diode circuit. When this type of circuit is used as a detector, a complete d-c path is always present through the secondary winding of the r-f or i-f transformer. When it is necessary to measure a-c voltages in a circuit where a d-c component must be blocked off, it is preferable to use the diode circuit shown in Fig. 2-8.

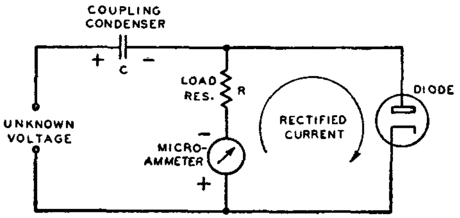


Fig. 2-8. A diode v-t voltmeter in which the unknown a-c voltage is coupled to the diode circuit through a blocking capacitor *C*. The rectified current circulates through the diode, meter, and *R* as indicated by the arrow.

Peak Diode Voltmeter—Shunt Type

One of the most useful of the diode VTVM circuits is the shunt-type circuit illustrated in Fig. 2-8. With this circuit the voltage to be measured is coupled to the diode by means of a capacitor *C* which also blocks any d-c voltage that may be present. The performance of this circuit is generally similar to that of the series-type peak v-t voltmeter (Fig. 2-6), although the arrangement of components is different.

Operation—When an a-c voltage or signal is applied to the input terminals, the diode draws current on the positive peaks. As a result of this action, capacitor *C* becomes charged, with the polarity indicated in Fig. 2-8, to a voltage which is almost equal to the positive peak of the signal. The plate of the diode is thus maintained at a d-c voltage equal to the peak value of the signal, so that a steady d-c current flows through the meter. The value of this current is equal to the peak signal voltage divided by the resistance of *R*.

A diagram of the current flowing through the diode is shown in Fig. 2-9. As this figure shows, the diode is nonconducting except for a brief interval near the positive peak of the applied voltage. At this point there is a surge of current, and this, averaged over the entire cycle, provides the d-c current which actuates the meter.

Although the meter is shown in series with the load resistor *R*, it is also possible to place it in series with the cathode of the diode. In this connection it is worth noting that the d-c current measured by the meter circulates around the resistor and diode and thus has the same value in either the resistor leg or the diode leg. It is preferable to insert the meter in series with the resistor, since the r-f current through the meter is then smaller than if the meter were placed in series with the cathode leg of the circuit.

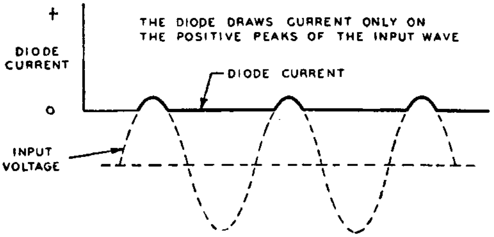


Fig. 2-9. In the circuit shown in Fig. 2-8, a pulse of current is drawn by the diode on each of the positive peaks of the input voltage. The reading of the d-c meter is equal to the average value of these current pulses.

Loading—The loading of this type of diode v-t voltmeter is determined by *R* and is equal approximately to one-half the resistance of *R*. For this reason it is desirable to keep *R* as high as is possible. The limiting factor is the required sensitivity which is reduced as *R* is increased.

Frequency Error—The shunt-type peak VTVM's frequency error is similar to that of the series-type, and is determined by the same factors.

Sensitivity—The sensitivity is determined by the resistance of *R* and the sensitivity of the d-c microammeter or milliammeter. The peak voltage required for full-scale deflection can be determined by multiplying the full-scale current by the load resistance. For example, if *R* is 1 megohm, and a 100-microampere meter is used, then slightly more than 100 volts peak is required for full-scale deflection. The sensitivity can be increased by either lowering *R* or using a more sensitive meter. Either one of these alternatives is undesirable because the one reduces the input resistance, while the other raises the cost. A more practical alternative is to amplify the output of the diode. Rectifier-amplifier v-t voltmeters are widely used; they are described in Chapter 4.

Linearity—The calibration of the shunt-type peak v-t voltmeter, like that of all diode voltmeters, is usually linear for voltage ranges higher than several volts. On the low-voltage ranges, however, a nonlinearity is introduced because of imperfect rectification.

D-C Path Is Not Required—Unlike the series-type v-t voltmeter, no direct-current path is required with the shunt-type VTVM.

This is apparent from the fact that the rectified current circulates through the load resistance *R* and the diode, so that an external path through the circuit being measured is not required. This is an important advantage of the shunt-type circuit, as is also the fact that the capacitor *C* blocks any d-c voltage which may be present. The blocking action of the input capacitor is often a great advantage since there are many occasions where a small r-f voltage must be measured at points where a large d-c voltage is present. A typical example of such a case is the problem of measuring the signal voltage at the plate of an amplifier tube. In this instance *C* permits only the signal (the a-c component of the voltage at the plate) to reach the rectifier circuit.

A Shunt-Type Diode Voltmeter Circuit

A practical shunt-type diode peak v-t voltmeter circuit using a 6H6 diode rectifier is shown in Fig. 2-10a. As the calibration curve of Fig. 2-10b shows, the range covered with the constants shown is 50 volts for full-scale deflection on a 100-microampere meter. The input resistance is approximately half the load resistance or about 250,000 ohms.

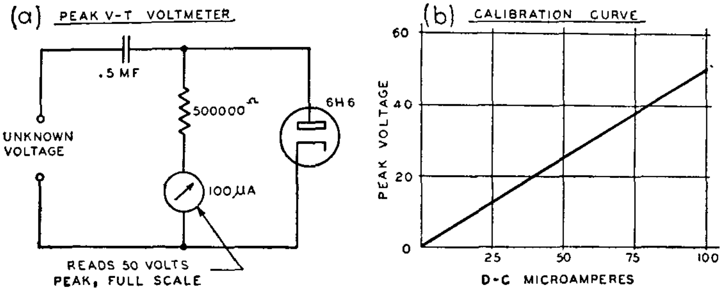


Fig. 2-10. A simple peak v-t voltmeter using a 6H6 diode. An approximate calibration for this v-t voltmeter is shown at (b).

If it is desired to improve the high frequency response, the base of the 6H6 tube may be removed and connections may then be made directly to the tube leads, or a high-frequency type diode such as the 9005 may be used. Where voltage handling capacity is more important than high-frequency response, power rectifier tubes such as the 6X5GT or 6X4 are sometimes used.

Although greater sensitivity can be obtained by decreasing *R* or by using a more sensitive meter, it is more desirable where greater sensitivity is required to use either a triode or a rectifier-amplifier type VTVM. Both of these types are described in subsequent chapters.

As mentioned in Chapter 1, it is possible to calibrate a *peak* v-t voltmeter in terms of *rms* values by multiplying each one of the peak values shown in the calibration curve at (b) by 0.707. Although the scale can be calibrated in rms values in this manner, the indication is not a true rms reading and is accurate only for a sine wave of voltage.

A High-Voltage Shunt-Type Peak V-T Voltmeter

A diode v-t voltmeter suitable for the measurement of high values of a-c voltage is shown in Fig. 2-11. The circuit is the same as the preceding one with the exception that the type 6H6 tube has been replaced by a television high-voltage rectifier tube of the 2X2-A type. This latter tube, although its envelope is no larger than that of an ordinary receiving tube, will withstand peak voltages up to 6,700 volts and has a low input capacitance because of the large separation between the plate and cathode. With the constants shown, full-scale deflection is obtained on the 500-microampere meter when a peak voltage somewhat greater than 5,000 volts is applied. The calibration curve on this range is very nearly linear, although for lower voltage ranges the calibration is curved slightly because of the comparatively high internal resistance of the diode. This high internal resistance is due to the large separation between the cathode and plate.

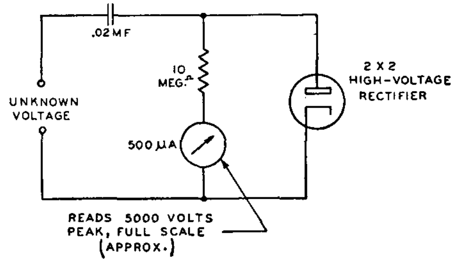


Fig. 2-11. A diode v-t voltmeter suitable for the measurement of high values of a-c voltage. A type 2x2-A high-voltage rectifier tube is used.

The coupling capacitor should be rated to withstand twice the highest peak voltage to be measured. Similarly the load resistor should be capable of withstanding this same value of voltage. A special high-voltage resistor can be used or several low-voltage resistors can be placed in series in order to obtain the required rating. The meter and filament transformer are at the low-potential side of the input circuit so that no special precautions are required, *provided the low side of the input is always connected to ground.*

By varying either the load resistance or the sensitivity of the meter, it is possible to obtain other voltage ranges such as 1,000 volts full scale. For voltages below several hundred volts it is preferable to use a receiving-type diode so as to obtain a more linear calibration. A receiving-type diode is preferable because it has a lower internal resistance than a high-voltage diode.

In the case of high-voltage diode v-t voltmeters it is especially desirable to run a calibration curve and not to rely on the computed calibration. If this procedure is not followed there will be an appreciable error because the high internal resistance of the diode prevents the capacitor from charging up to the full peak value of the applied voltage.

Values of R and C for Peak V-T Voltmeters

The low frequency operation of both the series and shunt type of peak VTVM depends upon the choice of proper values of R and C. The criterion to be followed in picking suitable values for R and C is that the *time constant* of the R-C combination must be large in comparison with the time of one cycle. The *time constant* is a measure of the time required for a capacitor to charge or discharge through a resistor; specifically, it is the time required to charge a capacitor to 63 per cent of its final voltage, or the time required for it to lose 37 per cent of its initial voltage. To obtain the time constant in seconds, multiply the value of R *in megohms* by the value of C in microfarads. For example, the time constant of a 2-megohm resistor and a 0.5-μf capacitor is $2 \times 0.5 = 1$ second.

A useful rule is that the time constant RC of a peak v-t voltmeter should be equal to about $10 \times 1/f$, where f is the lowest frequency to be measured. Since $1/f$ is the time of one cycle, this is only another way of stating that R and C should be large enough so that their product is at least ten times the duration of 1 cycle of the lowest frequency. Another way of expressing this same relationship is by the equation:

$$RCf = 10.$$

Typical values of R and C for different frequency ranges is given in Table 2-1. If it is desired to cover down to about 25 cycles, the action of the meter will become sluggish because the capacitor takes an appreciable time to change its voltage when the applied voltage is changed. For this reason it is often preferable to use a medium value of C for all r-f and a-f work. When it is necessary to measure low-frequency voltages, an additional capacitor of 1 μf or more can be connected in shunt with the internal capacitor. The regular calibration will then apply to 25 and 60 cycles, as well as to the higher frequencies.

"Contact Potential" Effect in Diode V-T Voltmeters

In the preceding description of diode v-t voltmeters we deferred a discussion of the action taking place when small voltages are measured by means of a diode rectifier. This action is complicated by the fact that the initial speed with which the electrons leave the cathode is sufficient to carry them to the plate even when no external voltage is applied. And even when the circuit is incomplete, the speed with which the electrons arrive at the plate is sufficiently great so that the plate assumes a potential or voltage which is about 1 volt negative with respect to the cathode. Both of these interrelated effects will now be described.

Zero-Signal Current—When the plate and cathode of a diode are connected together through a resistor, Fig. 2-12a, it is found that a small current flows because of the high speed with which many of the electrons leave the cathode. (The arrow is shown toward the plate because the conventional direction of current flow is taken to be opposite to the direction of electron flow.) For the type 6H6 diode, a current of about 300 microamperes flows when the plate and cathode are connected together directly; the exact current depends to a great degree upon the heater voltage and the condition of the cathode.

The manner in which this zero-signal current varies as the load resistance is increased is shown in Fig. 2-12b. Starting with a resistance value of 100 ohms, the curve shows that the current decreases from about 300 microamperes for a resistance of 100 ohms, to about 0.1 microampere for a resistance of 10 megohms.

When a diode rectifier is used in a VTVM circuit, a current will thus flow even when no voltage is applied; the magnitude of the current which can be expected is given by the curve at (b). In high-range v-t voltmeters this initial or zero-signal current is ordinarily so small that it is negligible. However, in low-range diode v-t voltmeters, it is necessary either to balance out the initial current or to make allowance for it in some other way.

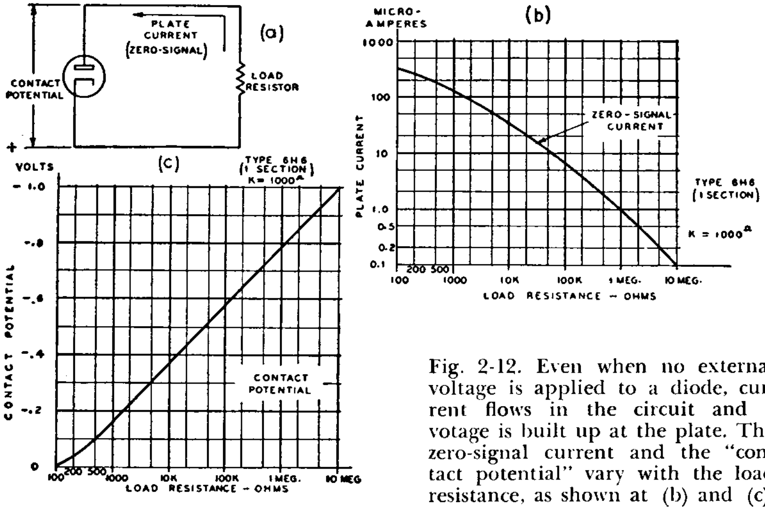


Fig. 2-12. Even when no external voltage is applied to a diode, current flows in the circuit and a votage is built up at the plate. The zero-signal current and the "contact potential" vary with the load resistance, as shown at (b) and (c).

"Contact" or Zero-Signal Potential—Depending upon the value of load resistance connected to a diode, the zero-signal plate current will cause a voltage drop to take place between the cathode and the plate. This drop is in such a direction as to make the plate negative with respect to the cathode. This effect is illustrated by the curve shown in Fig. 2-12c. For values of load resistance less than about 100 ohms the contact potential is effectively short-circuited, so that the voltage difference between plate and cathode is reduced to practically zero. As the load resistance is increased, however, the plate becomes steadily more negative until it reaches a potential of about 1 volt negative with a load resistor of about 10 megohms. For still higher values of load resistance, the potential at the plate

becomes only slightly more negative than the 1-volt value for a 10-megohm load.

With the circuits which have been thus far described, the zero-signal current is of greater interest than the contact potential. Later, however, we shall describe rectifier-amplifier types of v-t voltmeters in which the voltage developed at the plate is taken as a measure of the input voltage. In this type of VTVM, the zero-signal voltage or contact-potential curve may be of primary interest.

The curves which we have shown are for the representative 6H6 receiving-type diode. Other tubes, such as triodes used as diodes, also show the same effect. In high-voltage diodes, such as those of the 2X2-A type, the same effect is present but to a much smaller degree. Thus in the type 2X2-A, the zero-signal current with zero load resistance is only about 0.1 microampere as against 300 microamperes for the type 6H6. This tremendous difference is due to the much wider spacing between the cathode and plate in the high-voltage diode. Although the zero-signal current of high-voltage rectifiers is much smaller, the contact potential is still appreciably large because of the high diode resistance. Thus the contact potential of the type 2X2-A is about 0.4 volt as against about 1 volt for the type 6H6.

Effect on Calibration—The effect which we have been describing is of greatest importance only on the low-voltage ranges of diode v-t voltmeters. On ranges less than about 10 volts, the zero-signal current can be bucked or balanced out. Even though this initial current is balanced out, however, the calibration will not be linear for inputs of less than several volts because of the high internal resistance of the diode.

From the previous discussion it would seem that the contact potential can be decreased or eliminated by reducing the cathode operating temperature through a decrease of the heater voltage. This procedure is of little real benefit due to its effect on rectification efficiency and hence, sensitivity. Fig. 2-13 shows how the contact potential and the rectification efficiency of two typical diodes, the 6H6 and the 6AL5, vary with heater voltage. It will be seen from these curves that as soon as the contact potential is reduced significantly, the sensitivity starts to fall. Furthermore, operation at reduced heater voltage is undesirable since the sensi-

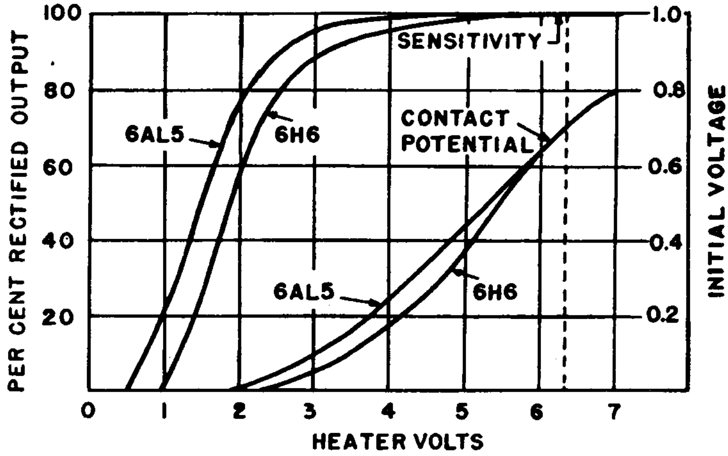


Fig. 2-13. The variation of contact potential and rectification efficiency with heater voltage for the 6AL5 and the 6H6.

tivity soon becomes highly dependent on heater voltage, an obviously undesirable condition.

Crystal Diodes

Crystals are often used in place of diode tubes in the circuits described in this chapter. In general, a crystal diode of silicon or germanium may be substituted for the vacuum tube with little change in the voltmeter operation. The use of the crystal diode eliminates the contact potential effect and also results in a good high frequency response with a low shunt capacity. Crystal diode circuits are often used in high frequency "plumbing" as indicators of standing waves and other conditions.

Crystal probes used in combination with vacuum-tube amplifiers will be treated in more detail in Chapter 9.

REVIEW QUESTIONS

CHAPTER 2

2–1. Why does the addition of a large resistor in the plate circuit of the diode improve the linearity of the plate voltage-plate current characteristic?
2–2. What is the limiting factor on the size of the diode load resistor used in a simple diode v-t voltmeter?
2–3. What element in the circuit of Fig. 2–6 makes the meter a peak-responsive one?
2–4. What factors affect the input impedance of the peak diode VTVM?
2–5. Explain the difference between the operation of the series and shunt types peak diode voltmeters.
2–6. Compute the time constant of a series circuit containing a resistor of 200,000 ohms and a capacitor of 2 μf.
2–7. What is "contact potential" in a diode?
2–8. Why does the contact potential of the diode in a diode VTVM increase when the load resistance is increased?
2–9. On what measurement range is "contact potential" of primary interest? Why?
2–10. How may "contact potential" effects be eliminated in diode v-t voltmeters?

CHAPTER 3

TRIODE VACUUM-TUBE VOLTMETERS

Triodes are widely used in a-c vacuum-tube voltmeters where they function as d-c amplifiers, coupling tubes, or impedance changers in combination with diode rectifiers, as well as in d-c v-t voltmeters. In these applications, the property of being able to convert from a high impedance, low current circuit at the grid to a low impedance, high current circuit at the plate or cathode makes the triode extremely useful. Triodes are also used to some extent in single-tube circuits where they are used both for rectification and amplification at the same time. Grid-circuit or plate-circuit rectification may be employed and either *linear, average,* or *square-law* rectification obtained. However, the use of the triode alone in a VTVM limits the voltage range of the instrument.

In this chapter many of the basic triode v-t voltmeters will be described as well as their affiliated circuits.

Plate Detection V-T Voltmeters

The plate current-grid voltage curve shown in Fig. 3-1 is typical of triode vacuum tubes. Vacuum-tube voltmeters which utilize this characteristic are called *plate detection* or *plate rectification* v-t voltmeters and depend for their operation on the fact that the unknown voltage applied to the grid causes an increase in plate current on the positive half cycle which is greater than the decrease on the negative half cycle. As a result, a net increase in plate current takes place and this increase is a measure of the unknown voltage applied to the grid. Voltmeters of this type are referred to as being of the *peak, half-wave,* or *full-wave* types—depending upon whether the operating bias is greater than cutoff, at cutoff, or less than cutoff.

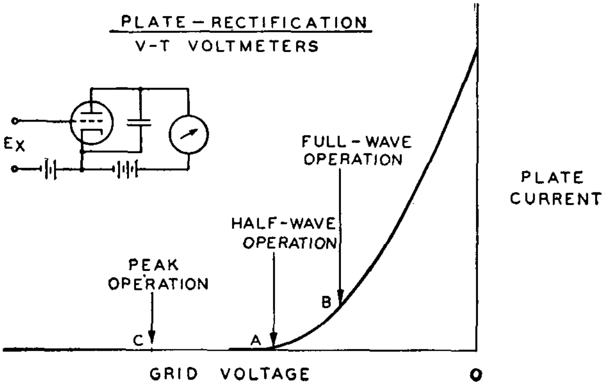


Fig. 3-1. Plate rectification v-t voltmeters are classified as *peak, half-wave* or *full-wave*,—depending upon the position of the operating point on the plate current—grid voltage characteristic.

Half-Wave Square-Law V-T Voltmeter

The basic circuit and operation of the half-wave square-law VTVM are shown in Fig. 3-2. As the designation *half-wave* implies, the operating grid bias is chosen close to cutoff so that the plate current is essentially zero when no signal is applied to the grid. When a signal is applied, the plate current increases during the positive half of the cycle, as is shown at (b). On the negative half, however, no appreciable decrease in the plate current takes place because the plate current is practically zero to begin with. As a result of this rectification, the average value of the plate current increases when a signal is applied, and this increase can be taken as a measure of the voltage applied to the grid.

Square-Law Response—The outstanding characteristic of this type of v-t voltmeter is the fact that the plate current is approximately proportional to the *square* of the voltage applied to the grid. This makes the calibration independent of the waveform, although there may still be some waveform error which is dependent upon the phase of the harmonics present in the unknown voltage. The compensation for variations in waveform cannot be complete in the half-wave type of VTVM because no current flows in response to the negative half-cycles of the input voltage; as a result the waveform of the negative half-cycles cannot directly affect the reading of the voltmeter.

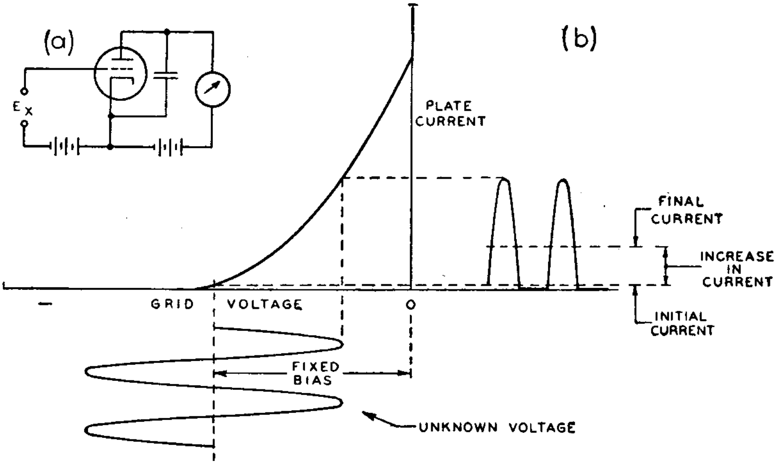


Fig. 3-2. The half-wave v-t voltmeter is operated just above plate current cutoff, so that only the positive half cycles of the applied voltage are effective in causing the plate current to increase. The meter indicates the increase in the average plate current.

Weak-Signal Operation—The sensitivity of the half-wave v-t voltmeter for small voltages is poor because these voltages are applied near the plate current cutoff and in this region the mutual conductance of the tube is very low. An additional factor making the weak-signal sensitivity poor is the inherent insensitivity of any square-law type of VTVM for small input voltages.

In addition to having poor sensitivity for weak signals, the *accuracy* for weak signals depends to a very great extent upon the maintenance of the exact value of bias voltage. Even a slight shift in this voltage will throw off the calibration over the lower portion of the scale. By always using a fixed small value of operating plate current, as is illustrated in Fig. 3-3b, the stability of calibration can be improved considerably.

Strong-Signal Operation—For stronger input signals where operation is on the upper portion of the plate-current characteristic far removed from cutoff, the sensitivity is considerably better than for weak signals. Here the calibration is not so dependent upon the exact maintenance of the correct voltages. In practical v-t voltmeters, the triode plate-current characteristic is such that the square-law relation is maintained only over a limited portion of the range. For larger input signals, the response tends to become linear so that the increase in plate current is proportional to the signal rather than to the *square* of the signal. The reason for this condition can be seen from the manner in which the plate current characteristic in Fig. 3-2b straightens out as the bias voltage is decreased. Since the response for large signals is no longer proportional to the square of the grid voltage, the voltmeter then tends to read the *average* rather than the *rms* value of the positive half-cycles, and its reading is therefore dependent upon the waveform of the signal in the same way as any other average-reading voltmeter.

Input Resistance and Frequency Range—The input resistance of the half-wave VTVM is extremely high because the grid is at all times biased negatively. The exact input resistance depends upon the frequency and the tube type but is, in general, hundreds of megohms at low frequencies and correspondingly lower at higher frequencies. However, the input resistance remains high even at radio frequencies where it is limited by the losses in the input circuit of the tube. These losses can be minimized at the upper radio frequencies by using an acorn type tube.

The frequency range of the half-wave v-t voltmeter extends to approximately 30 megacycles so that a calibration made at a low frequency (such as 60 cycles) can be used at radio frequencies. At about 30 megacycles, the transit time of the electrons in the space between the elements introduces an error which becomes progressively larger as the frequency is increased.

Half-Wave V-T Voltmeter Using 1N5-GT

The circuit shown in Fig. 3-3a illustrates a practical half-wave v-t voltmeter having an approximate square-law characteristic. A type 1N5-GT r-f pentode is used as a triode; this tube has a 1.5-volt, 50-milliampere filament and is designed for direct operation from a 1.5-volt dry cell. It is particularly suitable for VTVM use because of its small size, low input capacitance, and because the grid cap is on top of the envelope so that the tube can readily be adapted for use at the end of a probe.

Although the circuit and curves shown apply specifically to the 1N5-GT tube, similar curves apply to a-c operated v-t voltmeters using other tubes which have similar characteristics. The reason for the use of a pentode (as a triode) rather than a conventional triode is the fact that the triode types do not usually have the grid cap at the top of the envelope. When used as a triode, sharp cut-off pentodes of the 1N5-GT, 77, 6SJ7, and similar types have an amplification factor of the order of 25. Similar performance can be expected with any of these tubes used as triodes, or with a triode having an amplification factor of about 25.

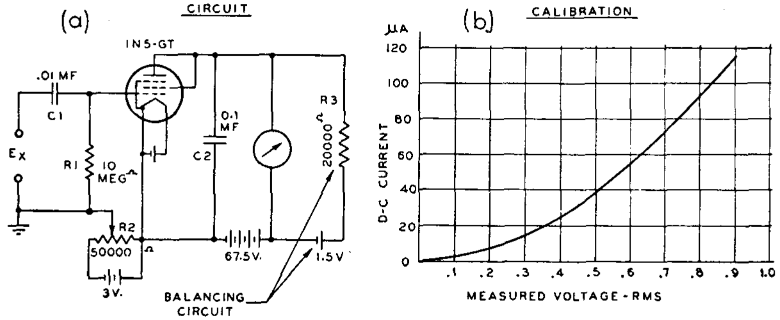


Fig. 3-3. A half-wave v-t voltmeter using a type 1N5-GT connected as a triode. A fixed balancing current is used, the zero adjustment being made by means of *R2*; a 500-ohm rheostat may be placed in series with *R2* to obtain a fine adjustment control. A typical calibration curve is shown at (b).

Circuit Description—The circuit is similar to the basic circuit which has already been described with the exception that a balancing circuit has been added to balance out the initial value of plate current. This balancing circuit consists of the 1.5-volt flashlight cell and the resistor *R3*. A 50,000-ohm potentiometer *R2* across a 3-volt battery is used to provide the grid bias, while a 67.5-volt battery is used for the plate voltage. A 100- or 200-microampere meter is used as the indicator.

The r-f currents which are caused to flow in the plate circuit are returned to the cathode by means of the 0.1-μf bypass capacitor *C2*. This prevents signal currents from flowing through the meter and plate-supply circuits where they would encounter a variable impedance which would introduce a frequency error.

The unknown voltage may be connected directly to the grid or through the blocking capacitor *C1* as shown in Fig. 3-3a. If the blocking capacitor is used, the calibration will be unaffected provided that the reactance of *C1* at the lowest frequency of operation is small in comparison with the resistance of *R1*.

Operating Point—An examination of the plate current-grid voltage characteristic of the 1N5-GT (see Fig. 3-4) when operated at a plate voltage of 67.5 volts shows that the plate current is quite small for a grid bias of about 2 volts. At this grid bias, the operation would be essentially half-wave. Larger values of grid bias could be used; as will be shown later this has the advantage of reducing the sensitivity for weak signals. A good compromise value of grid bias is therefore about 2 volts and the plate current corresponding to this value is about 75 microamperes.

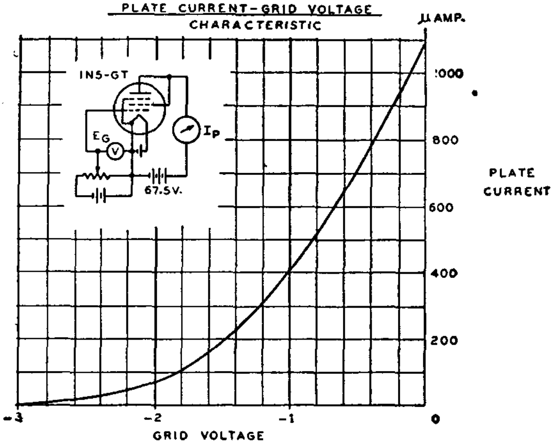


Fig. 3-4. The plate current-grid voltage characteristic of the type 1N5-GT connected as a triode. This tube is used in the half-wave and full-wave v-t voltmeter circuits shown in Figs. 3-3 and 3-6.

To insure that the operating point will always be returned to this initial value of current a fixed balancing resistor is used. This resistance is set at 20,000 ohms so that the balancing current is 75 microamperes. To set the zero when the voltmeter is first turned on, the potentiometer should be adjusted until the meter reads zero. Since the balancing current is 75 microamperes, the plate current will also be 75 microamperes when the meter reads zero.

Calibration and Range—A typical calibration is shown in Fig. 3-3b. The square-law character of this curve for voltages less than 1 volt is apparent. Note, for example, that an input signal of 0.4 volt produces a deflection of about 25 microamperes. Doubling the input signal to 0.8 volt raises the plate current to 94 microamperes or approximately *four* times the deflection for the 0.4-volt signal which was *half* as strong. For larger values of input signal the deflection tends to become linear as the curve shows. Larger input signals than about 1.4 volts rms (or 2 volts peak) should not be applied since the grid will be driven positive and the input resistance lowered.

It is clear from the preceding description that the range of this v-t voltmeter is limited because an input greater than 2 volts peak will cause grid current to flow. When it is necessary to measure larger voltages than this, some modification must be made in the design. One way of obtaining an extension of the range is to use a tube with a lower amplification factor. This will increase the cutoff bias (the cutoff voltage is approximately equal to the plate voltage divided by the amplification factor) and so will increase the maximum signal which can be applied without drawing grid current. Increasing the plate voltage will also increase the range, but this is generally unsatisfactory because it reduces the sensitivity for small input voltages. The most satisfactory solution where higher voltages must be measured is to use one of the other types of v-t voltmeters, such as the rectifier-amplifier or slide-back type.

Numerous modifications can be made in this basic circuit. For example, other tubes such as the 6C5, 6J5, 6P5, 6J7 (as a triode) may be used; full a-c operation can be obtained by using a conventional power supply; etc. Although any of these changes will affect the calibration, they will not alter the general considerations which have been discussed.

Full-Wave Square-Law V-T Voltmeter

If the operating point of the half-wave type v-t voltmeter is moved above cutoff so that an appreciable value of plate current flows, then the operation changes from *half-wave* to *full-wave*. The designation *full wave* is appropriate, as Fig. 3-5 shows, because both halves of the wave are effective in causing the plate current to change. Because the plate-current increase on the positive half-cycle is greater than the decrease on the negative half-cycle, there is a net increase in the plate current when a signal is applied. This increase in current may be taken as a measure of the signal applied to the input, and the voltmeter is calibrated accordingly.

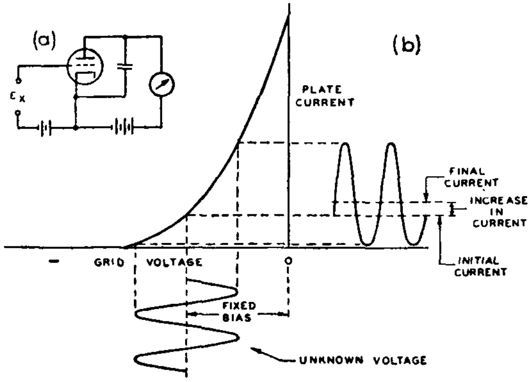


Fig. 3-5. For full-wave operation, the operating point is placed on the curved portion of the characteristic, so that the increase in plate current on the positive half cycle is greater than the decrease on the negative half cycle. The meter indicates the increase in the average plate current.

Elimination of Waveform Error—Where the tube characteristic is such that the plate current is proportional to the *square* of the grid voltage, the full-wave VTVM has the very desirable property that waveform error is eliminated and the reading is proportional to the *rms* or *effective* value of the signal. In this respect the full-wave, square-law v-t voltmeter is superior to the half-wave type which does not take into account the negative half-cycles of the input voltage. In the full-wave type both the negative and the positive half-cycles contribute to the reading; because of the square-law response, the increase in plate current is proportional to the rms value of the input voltage and is independent of the waveform.

Sensitivity—At first consideration it might be thought that the full-wave voltmeter would be less sensitive than the half-wave type because of the decrease in plate current on the negative half-cycles of the input voltage. This decrease does partially neutralize the increase on the positive half-cycles and so tends to reduce the rectification efficiency. In the full-wave circuit, however, operation is on a portion of the plate characteristic where the mutual conductance is greater than for half-wave operation. This greater mutual conductance more than compensates for the decrease in plate current on the negative half-cycles, so that the sensitivity of the full-wave v-t voltmeter is greater than the sensitivity of the half-wave type.

The statements made regarding input resistance and frequency range under the half-wave type of VTVM apply equally well to the full-wave type.

Full-Wave V-T Voltmeter Using 1N5-GT

A full-wave v-t voltmeter circuit having an approximate square-law response is shown in Fig. 3-6. The same tube and general circuit arrangement previously described in connection with the half-wave v-t voltmeter of Fig. 3-3 are used in this circuit. The only significant change is the decrease in the bias voltage so that plate current will flow for both the positive and negative parts of the input voltage.

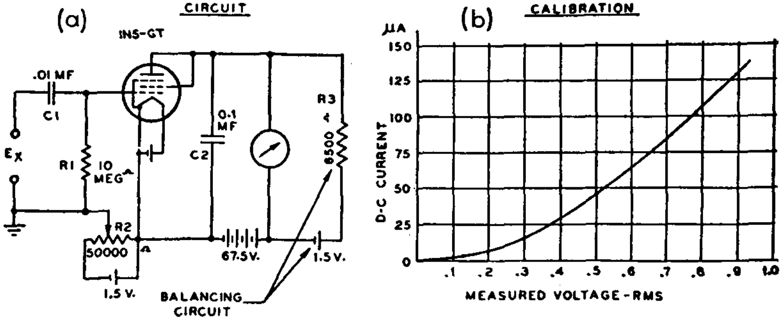


Fig. 3-6. A full-wave v-t voltmeter using the type 1N5-GT connected as a triode. A fixed balancing current is used, the zero adjustment being made by means of *R2;* a 500-ohm rheostat may be placed in series with *R2* where a fine adjustment control is desired. A typical calibration curve is shown at (b).

Referring to the plate-current characteristic of the IN5-GT shown in Fig. 3-4, the operating point is moved up to a bias of 1.4 volts and the corresponding plate current of about 230 microamperes. To obtain the required balancing current, the same 1.5-volt battery may be used. However, the balancing resistor *R3* should be decreased to about 6,500 ohms so that a balancing current of approximately 230 microamperes will flow through the meter. When the grid-bias potentiometer *R2* is adjusted so that the meter reads zero, the plate current will then be exactly equal to the balancing current and operation will be taking place about the correct point on the tube characteristic.

With the circuit constants shown, the range of the voltmeter is limited to about 1 volt rms since larger input voltages will cause grid current to flow. To measure voltages larger than 1 volt it is preferable to use a tube which has a lower amplification factor, if square-law operation is desired. The types 71-A and 6AE5-GT are especially suitable for this application.

Ideal Square-Law V-T Voltmeter

In a perfect square-law v-t voltmeter, the plate current is exactly proportional to the square of the grid voltage. An ideal characteristic of this type is shown in Fig. 3-7a. The square-law character of the plate current curve is readily apparent. To obtain plate-current cutoff, a grid bias of 4 volts is required. If this bias is reduced by 1 volt, the plate current increases to 1 milliampere. If bias is decreased by *twice* this amount (to 2 volts), the plate current is multiplied by *four* and is thus 4 milliamperes. If the grid bias is decreased by *three* times the original 1 volt decrease (to 1 volt), the plate current is multiplied *nine* times and thus becomes 9 milliamperes. Similarly for a *four* time decrease in grid voltage, the plate

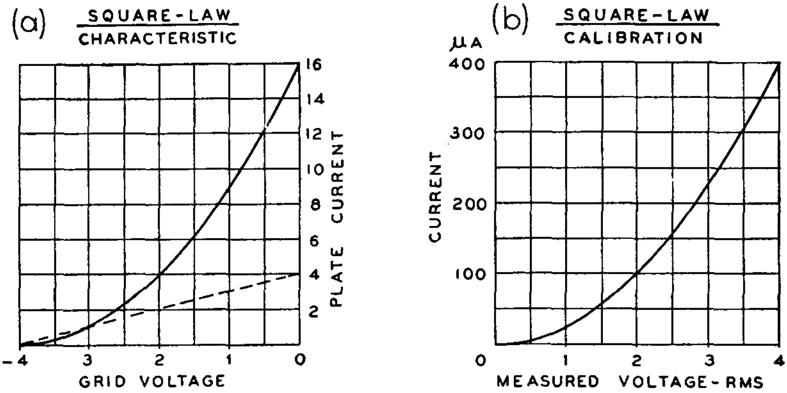


Fig. 3-7. A plate current-grid voltage characteristic can be checked for square-law response by plotting the square-root of the plate current, as shown by the dotted straight line at (a). A v-t voltmeter biased at cutoff, and using this characteristic, will give the calibration shown at (b). See also Fig. 3-8.

current increases *sixteen* fold, so that at zero bias the plate current is 16 milliamperes.

To check whether a given characteristic is square-law, the *square root* of the plate current readings are plotted against the grid voltage. If a straight line is obtained,—as the dotted line in Fig. 3-7a—this indicates that the square root of the plate current is proportional to the grid voltage; this is simply another way of stating that the plate current is proportional to the *square* of the grid voltage. In the case of the ideal square-law plate current curve just described, the square-root curve is a straight line, indicating that perfect square-law operation would be obtained if a tube having a characteristic shown in Fig. 3-7a were used as VTVM. Since the dotted curve is straight over its entire length, square-law operation would be obtained regardless of the position of the operating point. If the grid bias were at cutoff or −4 volts, then *half-wave* square-law operation would be obtained, whereas if the operating point were at −2 volts, then full-wave square-law operation would result.

Square-Law Scale Distribution—The characteristics of a square-law scale are of interest. Fig. 3-8 shows the exact scale calibration for a half-wave v-t voltmeter having the plate current curve shown in Fig. 3-7a; however, the same type of scale calibration applies to all square-law v-t voltmeters regardless of type.

The essential characteristic of a square-law scale is the crowded appearance of the lower portion of the scale. Thus an input voltage equal to *one-half* the full-scale voltage gives a deflection of only *one-fourth* of full scale, while an input voltage of *one-tenth* of full scale gives a deflection equal to only *one-hundredth* of full scale. The practical effect of this square-law distribution is to limit the range of voltages which can be read on any one scale to a value much lower than for a linear scale. For example, a deflection of one division on a 100-division scale requires 1 per cent of the full-scale voltage for a *linear* voltmeter, whereas it requires 10 per cent of the full-scale voltage for a square-law v-t voltmeter. Clearly, then, a square-law VTVM requires a great many more ranges to cover the same range of voltages than does a voltmeter having a linear scale. Despite this disadvantage of the square-law v-t voltmeter, there are some limited and specialized applications where it is used in preference to the *peak* or *average-reading* v-t voltmeter. These applications are limited to those special cases where measurements are made on complex waves and where the rms value must be determined. The measurement of noise voltages is a typical application where a true rms v-t voltmeter is required.

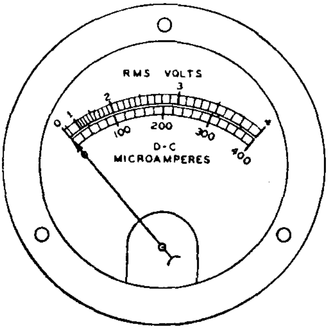


Fig. 3-8. The scale of a perfect square-law v-t voltmeter is crowded over the lower portion so that it is difficult to take readings less than about ¼ of full scale. *Note the much greater ease of reading on* the linear scale which is shown below the square-law scale to enable a comparison.

Determining the Bias for Square-Law Operation

To determine the operating bias for plate rectification v-t voltmeters, the plate current should be plotted against the grid bias, so as to obtain a plate current–grid voltage characteristic similar to Fig. 3-4. In addition to this characteristic, it is desirable to plot the square root of the plate current against the grid voltage in order to determine the region over which the response will be square law. The latter curve need be plotted only if square-law operation is required. In addition to these two curves, it is desirable to plot another curve showing the variation in sensitivity with the operating bias.

The square root of the plate current plotted against the grid voltage for the 1N5-GT VTVM's previously described is shown in Fig. 3-9. This curve is straight only over a portion of its length, indicating that perfect square-law operation can be obtained only by working over that particular section. This is in contrast to the ideal square-law characteristic which is straight over its complete range from cutoff to zero bias (see dotted curve of Fig. 3-7a).

Where square-law operation is of major importance, Fig. 3-9 shows that the range of operation should be restricted to the straight portion between 0 and 1.8 volts. The operating point should be in the middle of this range at about 1 volt.

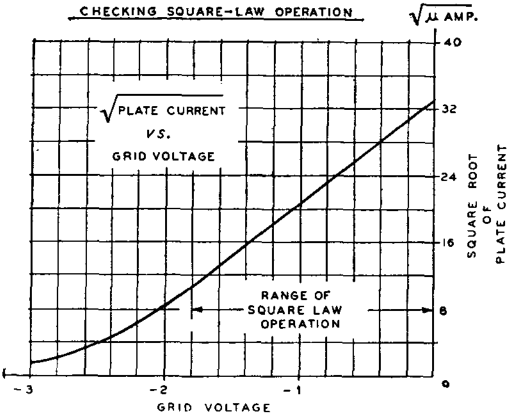
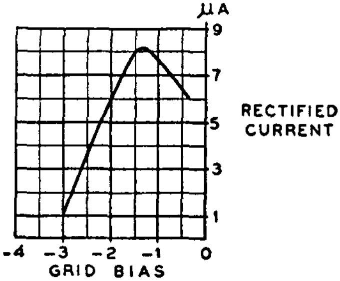


Fig. 3-9. To check for square-law operation, the square root of the plate current is plotted against the grid voltage (see Fig. 3-4). Square-law response will be obtained provided operation is restricted to the straight portion of the square-root curve.

Variation of Sensitivity with Operating Bias—Where square-law operation is not an essential, the operating point may be chosen without regard to whether it is in the middle of the square-law region. In any case, however, the efficiency of rectification, and hence the sensitivity, depend to a marked extent upon the proper location of the operating point. The manner in which the sensitivity is dependent upon the operating point is shown in Fig. 3-10. This curve was made by noting the change in plate current which resulted when a 0.2-volt signal was applied with the operating point successively set at different values. The resulting curve shows that the greatest sensitivity is obtained when the operating point is in the neighborhood of 1.3 volts. At this point a 0.2-volt signal causes a change in plate current of about 8 microamperes. If the operating bias is increased, the sensitivity drops quite rapidly until at a bias of −3 volts (near plate-current cutoff) the sensitivity drops to about one-eighth of the maximum sensitivity. If the bias is made very small the sensitivity also decreases, but not so much as for values of grid bias larger than the optimum value. The decrease in efficiency for small values of bias is the result of the more linear plate current variation in this region. This makes the increase in current on the positive half of the cycle only slightly greater than the decrease on the negative half-cycle so that the net increase is very small.

In choosing the operating point for full-wave square-law v-t voltmeters it is preferable to use a somewhat higher value of grid bias than would be called for by operation in the middle of the square-law region. This is desirable in order to reduce the operating current so that the current which has to be balanced out will not be too large in comparison with the rectified current. This helps to improve the stability of the zero reading and the permanence of the calibration, as well as to increase the input resistance.

Fig. 3-10. The sensitivity of a plate rectification v-t voltmeter varies with the operating bias. The curve shows the increase in current for a 0.2 volt signal for various values of operating voltage, using the characteristic shown in Fig. 3-4.



Peak Plate-Rectification V-T Voltmeter

The half-wave and full-wave v-t voltmeters both use a value of operating bias which is less than cutoff, so that some plate current flows when no signal is applied. If the operating bias is increased beyond cutoff, however, a third type of VTVM operation is obtained. This type of operation is referred to as *peak* operation.

As Fig. 3-11 shows, peak operation corresponds to Class C amplifier operation in that plate current flows only during a part of the positive half-cycle. The further the tube is biased beyond cutoff, the smaller is the interval during which current flows. Since no current flows when there is no applied signal, it is clear that a balancing circuit is not required.

The response of the peak type plate-rectification v-t voltmeter is proportional to neither the peak, the average, nor the rms value of the plate current. However, as a closest approach, the reading is proportional to the peak value of the signal since only the peak part of the cycle is effective in causing an increase in current flow. More exactly, the response is proportional to the *average value of that part of the positive half-cycle during which plate current flows.* Because considerably less than the full positive half-cycle is effective in causing rectification, the peak VTVM has a larger waveform error than any of the other types. In particular, its reading cannot even be called a *peak* reading, because the response depends to an appreciable extent upon the waveform of the voltage in the neighborhood of the positive peak.

A characteristic of the peak type of circuit is that the calibration does not begin with zero voltage at the left of the scale, but begins with a voltage considerably larger than zero. Thus a typical range for a peak plate rectification v-t voltmeter is from say 7 volts (at 0 on the scale) to 11 volts for full-scale reading. This type of calibration results because plate current does not flow until the applied peak signal voltage is sufficient to exceed the operating bias. At the point where current just begins to flow, the voltmeter is a true peak voltmeter, but as the signal voltage is increased beyond this value, the rectified current and hence the reading depends more and more upon the shape of the positive half-cycle of the signal as well as upon its peak value.

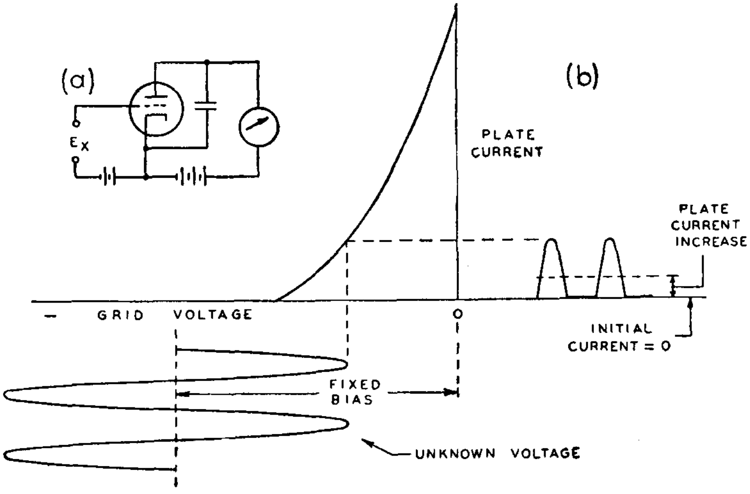


Fig. 3-11. In the peak plate-rectification v-t voltmeter, the operating bias is considerably beyond cutoff so that only the positive peak of the applied voltage is effective in causing the plate current to increase. Note that the range which can be covered on any one scale is less than the cutoff bias.

Range—The range which can be covered on any one scale with a peak v-t voltmeter is limited to a value less than the cutoff voltage. As the operating bias is increased, the ratio between the highest and lowest voltages becomes very limited because the cutoff bias becomes small in comparison with the operating bias. For example, if the cutoff bias on a particular tube is 4 volts at the operating plate voltage, and the operating bias is 15 volts, then an 11-volt peak signal will just cause plate current to flow, so that zero current on the meter scale will correspond to 11 volts peak. The input voltage for this same range cannot exceed 15 volts peak or grid current will flow and loading take place. Thus the range covered on this peak VTVM would be limited to from 11 volts to 15 volts peak, a range of less than 1.5 to 1.

As would be expected, peak voltmeters of this type have an extremely limited application. For the most part their use is limited to multi-range v-t voltmeters where peak operation enables an extension of the range to about 15 volts full-scale. In voltmeters of this type, the successive ranges utilize *full-wave* operation, then *half-wave* operation, and finally *peak* operation on the higher ranges.

Self-Bias or Reflex V-T Voltmeter

The v-t voltmeter circuit shown in Fig. 3-12 is commonly designated as the *self-bias* or *reflex* type. It is generally similar in operation to the plate-rectification circuits previously described with the important exception that the bias voltage is obtained from the voltage drop resulting from the flow of plate current through the cathode resistor *R1*. Because of this self-biasing action the sensitivity is reduced by an amount depending upon the value of the cathode resistor. To compensate for this reduced sensitivity, however, the self-bias v-t voltmeter has the advantage of an approximately linear calibration (except on the low ranges) and greater stability than the fixed-bias type. This increase in stability results because the operating bias automatically tends to compensate for changes in the operating voltages and tube characteristics.

Because of the reduction in sensitivity accompanying the use of self bias, the principal application of the self-bias circuit is in v-t voltmeters which have full-scale ranges above about 2 volts. To obtain full-scale deflection for signals smaller than about 1 volt requires the use of a microammeter having a sensitivity better than 100 microamperes. In view of the comparatively high value of no-signal plate current, the use of meters more sensitive than 100 microamperes is not recommended.

The self-bias rectifier circuit can also be used in conjunction with a d-c amplifier to provide a sensitive VTVM covering a wide range of voltages. This type of circuit is described in Chapter 4.

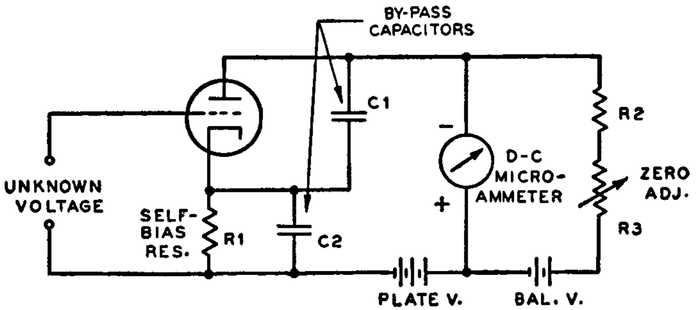


Fig. 3-12. A self-bias or reflex v-t voltmeter in which the bias voltage is supplied by the voltage drop across the cathode resistor *R1*. Although the self-bias circuit results in improved stability, the sensitivity is reduced because of the resulting degeneration.

Operation—The plate current of the self-bias v-t voltmeter depends upon the value of the cathode resistor *R1*. The greater the resistance of *R1*, the greater is the bias produced and hence the smaller is the initial or no-signal plate current. When a signal is applied, the increase in plate current on the positive half of the input cycle is greater than the decrease on the negative half of the cycle. As a result plate rectification takes place, and there is a net increase in the plate current; this increase can be taken as a measure of the signal applied to the input. This operation is similar to the operation of the plate-rectification circuits previously described.

The alternating or high-frequency component of the plate current is returned directly to the cathode by means of the two bypass capacitors *C1* and *C2* in Fig. 3-12. These capacitors prevent an alternating voltage from being built up at either the cathode or the plate. To permit calibration at 60 cycles and the measurement of low-frequency voltages, *C2* should be large enough so that its reactance at 60 cycles is small in comparison with the cathode resistance.

Although the cathode is bypassed, degeneration is introduced by the use of self bias rather than fixed bias. The manner in which the sensitivity is reduced may be seen from the following considerations. When a signal is applied, rectification takes place so that the average or d-c value of the plate current increases. This increase in plate current flows through the bias resistor, and therefore *increases* the bias voltage. Since an increase in bias voltage lowers the plate current, the over-all effect of this action is a *smaller increase* in current than would have taken place if a bias battery or bleeder had been used to supply a *fixed* bias voltage.

As a result of the degenerative action just described, the self-bias type of v-t voltmeter tends to have a linear calibration on the higher voltage ranges. Another result of this action is that a higher range of signal voltages can be handled without overload taking place. This ability to handle larger voltages is due to the automatic increase in bias voltage which takes place as the input voltage is increased.

Input Circuit—The self-bias v-t voltmeter, like other plate-rectification VTVM's, has a very high input resistance. Ordinarily the grid current is sufficiently small so that a blocking capacitor and grid resistor are not required unless a d-c voltage is present along with the a-c voltage to be measured. Where tubes having a high amplification factor are used, however, it is desirable that a blocking capacitor and grid leak be made a permanent part of the v-t voltmeter.

Self-Bias V-T Voltmeter Using a 954 Acorn Tube

The circuit and constants of a self-bias type of VTVM suitable for measurements extending up to about 50 megacycles is shown in Fig. 3-13.[1] This wide frequency range is secured by using an acorn type tube which has exceptionally low losses at high frequencies, and by using the probe type of construction so as to permit a direct connection between the control grid and the point at which the voltage measurement is made. Two ranges are provided by using two different values of self-bias resistance. On the low range up to 2 volts rms can be applied before grid current flows, while on the high range the maximum voltage is about 14 volts rms.

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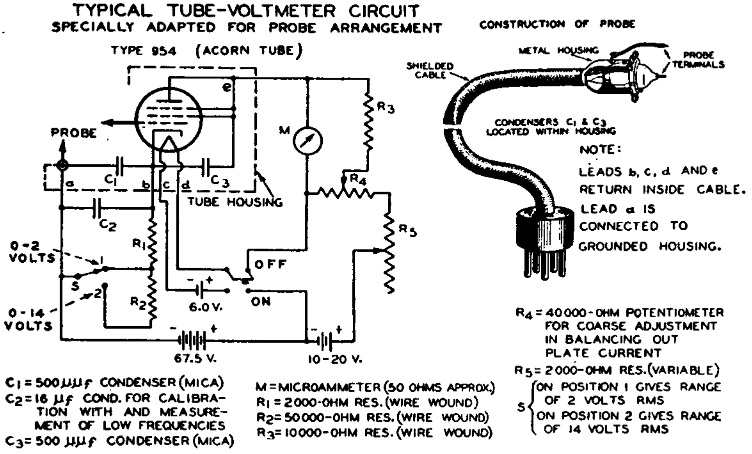
[1] This voltmeter is described in detail in RCA Application Note No. 47, published by RCA Mfg. Co., Inc.

The current arrangement is generally similar to the basic circuit previously discussed in connection with Fig. 3-12. The type 954 r-f pentode is used as a triode with the screen, suppressor, and plate connected together so as to form the triode plate. The input capacitance for this type of connection is approximately 1.4 $\mu\mu$f; this does not include any terminal connected to the grid which would of course increase the input capacitance.



Courtesy RCA Manufacturing Co., Inc.

Fig. 3-13. A reflex v-t voltmeter which is especially designed for use at frequencies up to about 50 megacycles. The instrument may be constructed in three sections: the probe unit containing the 954 acorn tube, the control unit, and the power unit.

A double-pole double-throw switch controls the filament, plate, and balancing voltages. The filament voltage may be supplied by four dry cells or by a 6-volt filament transformer. If the latter is used, the line voltage must be steady or there will be a shift in the zero with changes in line voltage. It is not recommended that plate and balancing voltages be obtained from a line-operated power supply unless a regulated supply is used.

To enable the measurement of low-frequency voltages and calibration at 60 cycles, it is necessary to use a large cathode bypass capacitor. When this capacitor is used (*C2* in Fig. 3-13) the 60 cycle calibration will hold at low audio frequencies and at all frequencies extending up to at least 25 megacycles. A 16-μf electrolytic capacitor is satisfactory, since the capacity value is not critical. A high-voltage electrolytic should be used since its leakage resistance must be high in comparison with the cathode resistance. A small 500-$\mu\mu$f mica capacitor provides adequate bypassing at the higher frequencies where the electrolytic capacitor is not effective.

From a constructional standpoint the v-t voltmeter is divided into three units. The *probe unit* is indicated schematically in Fig. 3-13 by the dotted rectangle containing the tube and the r-f bypass capacitors. The physical appearance of this unit is also shown in the same figure. The *control unit* contains the various resistors, controls, range switch, and the electrolytic capacitor. A *power unit* which is connected to the control unit supplies the heater, plate and balancing voltages. A multi-range microammeter providing full-scale ranges from 100 microamperes full scale to 500 microamperes full scale will permit accurate readings to be made, although a less sensitive meter can be used.

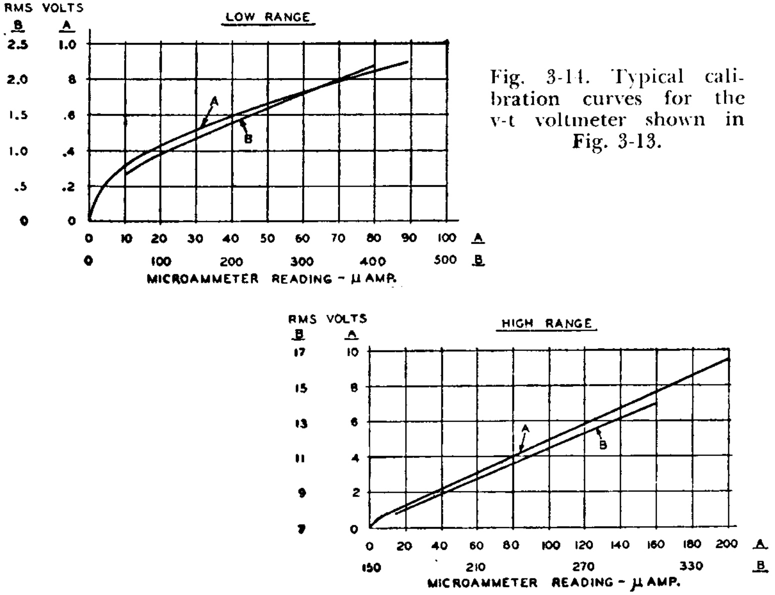


Fig. 3-14. Typical calibration curves for the v-t voltmeter shown in Fig. 3-13.

Variations in tube characteristics will cause the calibration to vary somewhat. However, the calibration curves in Fig. 3-14 hold approximately for any voltmeter which uses the circuit constants shown in the figure. The same performance can also be expected for v-t voltmeters using the same design but employing a conventional receiving tube such as the 1N5-GT or the 6J7 (as a triode). With either of the latter tubes the input capacitance will be larger as will also be the loading effect at high radio frequencies.

When a blocking capacitor is used with this voltmeter, it is necessary to use a grid resistor to complete the grid circuit. A value of several megohms is satisfactory for general use, although higher values are preferable where the circuit impedance is high.

Grid-Rectification V-T Voltmeter

The triode v-t voltmeter shown in Fig. 3-15 is based on *grid rectification* rather than on plate rectification as are the half-wave, full-wave, reflex, and peak v-t voltmeters described in the preceding sections. The *grid-rectification* or *grid-detection* VTVM is similar to the now obsolete grid detector. Its distinguishing features are high sensitivity for weak signals of the order of 0.1 to 1 volt, and a comparatively low input impedance which results because its operation depends upon the flow of grid current.

The grid-rectification circuit is often convenient where the use of a sensitive meter is undesirable and where a high input resistance is not required. It is not recommended, however, that elaborate circuits, including meter shunts and other refinements, be built up around the grid-rectification circuit. Other types of v-t voltmeters, in particular the rectifier-amplifier type described in Chapter 4, are more suitable for use in multi-range VTVM's.

Operation—The operation of the grid-rectification v-t voltmeter can be most easily understood by considering that it functions in much the same way as a diode rectifier followed by a triode amplifier. This equivalence is indicated in Fig. 3-15b which shows that the grid-cathode sections of the triode operate in exactly the same manner as a diode rectifier. Thus when a signal is applied to the grid, the grid draws current on the positive peaks with the result that the input capacitor *C* becomes charged negatively. The way in which the potential at the grid varies with the applied signal voltage is shown in Fig. 3-15c. This curve shows that a small negative voltage is present at the grid even when no signal is applied. This negative voltage is due to the initial speed of the electrons leaving the cathode and is similar to the "contact potential" effect explained previously. As the input signal is increased, the control grid (which corresponds to the diode plate) becomes more and more negative. As a rough approximation, the negative voltage developed at the grid is somewhat less than the peak value of the applied signal.

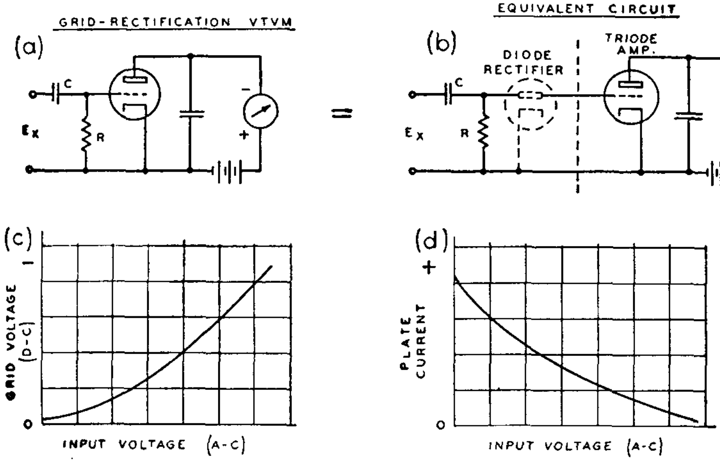


Fig. 3-15. The grid-rectification v-t voltmeter can be considered roughly equivalent to a diode rectifier followed by a triode amplifier. When a signal is applied, the grid is driven negative and the resulting decrease in plate current can be taken as a measure of the unknown a-c voltage.

The negative voltage developed at the grid by means of rectification in the grid-cathode circuit is effective in controlling the plate current, since the grid is not only the "diode plate" but it is also the triode control grid. Because of the controlling action of the grid on the plate current, the plate current *decreases* progressively as the input voltage is increased. This variation in plate current, shown in Fig. 3-15d, is to be expected since the grid becomes more negative for increasing input voltages and hence the plate current is correspondingly reduced.

Sensitivity—The grid-rectification v-t voltmeter is primarily suitable for the measurement of small voltages ranging from about

0.1 volt to several volts. Over this range, and especially for voltages of the order of a few tenths of a volt, the grid rectification VTVM is quite sensitive. For example, a plate-current decrease of about 300 microamperes for a 0.5-volt signal can readily be obtained; under the same conditions a plate-current decrease of about 1,000 microamperes can be obtained for an input signal of 1 volt. Because of this comparatively large plate-current change, a relatively insensitive meter can be used in grid-rectification v-t voltmeters.

High Initial Current—A disadvantage of the grid-rectification v-t voltmeter is the comparatively high value of plate current which flows when no signal is applied. This high plate current is a result of operation at zero bias. Because of this high *zero-signal* plate current, even a very small variation in the filament or plate voltage will cause an appreciable shift in the zero reading. Usually the plate current is of the order of several milliamperes depending upon the amplification factor of the tube and the plate voltage. To reduce erratic changes and wandering of the zero reading, it is desirable to use either battery operation or a regulated a-c power supply. The initial current can be kept to a minimum by using high-mu triodes, such as the 6Q7, 6K5G and 6SC7.

An effective means for minimizing zero drift is to use a two-tube balanced circuit such as is shown in Fig. 3-22. This latter circuit also has the advantage that the comparatively large balancing current required does not throw the meter off scale during the warm-up period.

Low Input Impedance—Although the grid-rectification v-t voltmeter is of the triode type, it has an unusually low input resistance because of the operation at zero bias. Unlike the biased type of triode v-t voltmeter where no grid current is drawn, the grid-rectification type depends upon the flow of grid current and it is this grid current which results in loading of the circuit under test.

The loading of the grid-rectification VTVM is approximately the same as that of a diode rectifier having a load resistor equal to the grid resistor. For small values of input signal, however, the input resistance of the grid-rectification type is even lower than for the comparable diode v-t voltmeter. As the input signal is increased, the input resistance becomes progressively larger because the grid is biased more negatively.

It might seem that the input resistance could be increased by using a large grid resistor. This, however, is not effective for weak signals since the losses are in the tube itself and not in the grid resistor. For example, a typical grid-rectification v-t voltmeter using a 2-megohm grid resistor may show an input resistance as low as 100,000 ohms (at 60 cycles) even though the grid resistor is much larger than this.

It is undesirable to use excessively high values of grid resistance in an attempt to increase the input resistance of the grid-rectification v-t voltmeter. Not only is this ineffective, but the use of a large grid resistor will cause instability, erratic variations in the plate current, and consequent wandering of the zero. Usually there is no advantage in using a grid resistor higher than several megohms.

Grid Resistor and Capacitor—The shunt type of input circuit shown in Fig. 3-15a is preferable to the type of circuit in which the grid resistor is connected in parallel with the grid capacitor. The latter circuit (corresponding to Fig. 2-6) has the disadvantage that the grid capacitor does not function as a d-c blocking capacitor and that the zero adjustment depends upon the resistance of the circuit in which the measurement is made. The value of C should be such that its reactance at the lowest operating frequency is small in comparison with the resistance of R. A capacitance of about 0.01 μf is satisfactory for all frequencies down to a few hundred cycles. A 0.25-μf capacitor will permit operation down to 60 cycles with negligible error, provided the grid resistor is at least 1 megohm.

Comparison with Separate Diode and Triode—The grid-rectification v-t voltmeter is not as flexible as the *rectifier-amplifier* type described in Chapter 4. In the latter circuit the diode rectifier is completely separate from the triode amplifier. This separation has the desirable advantage of making it possible to use self bias in the triode amplifier and to operate the triode under the best conditions without affecting the performance of the diode. In the grid-rectification v-t voltmeter, the triode cannot be biased separately as an amplifier since the bias would affect the operation of the grid-cathode section as a rectifier.

Response—For weak signals the response of the grid-rectification VTVM is approximately square law. This square-law response for weak signals is due to the curvature of the grid current-grid voltage characteristic in the neighborhood of zero bias. For larger values of input signal, however, the response becomes linear and is roughly proportional to the positive peak of the signal. The maximum change in plate current is always limited to a value somewhat less than the initial value of current with no signal. Actually the change in plate current never quite equals the full value of the initial plate current because—no matter how strong a signal is applied—the grid will still be driven slightly positive on the very positive peak of the signal. As a result the plate current can never be driven to cutoff, although it can be made to approach cutoff within about 25 per cent of the zero-signal current. From the viewpoint of accidental overload, it follows that the maximum current through the meter is limited to a value less than the zero-signal plate current.

Grid-Rectification V-T Voltmeter Using a 1G4-G Triode

The circuit of a practical grid-rectification v-t voltmeter is shown in Fig. 3-16. This circuit uses a type 1G4-G triode which is somewhat similar to the type 30 tube, but has a 1.5-volt filament

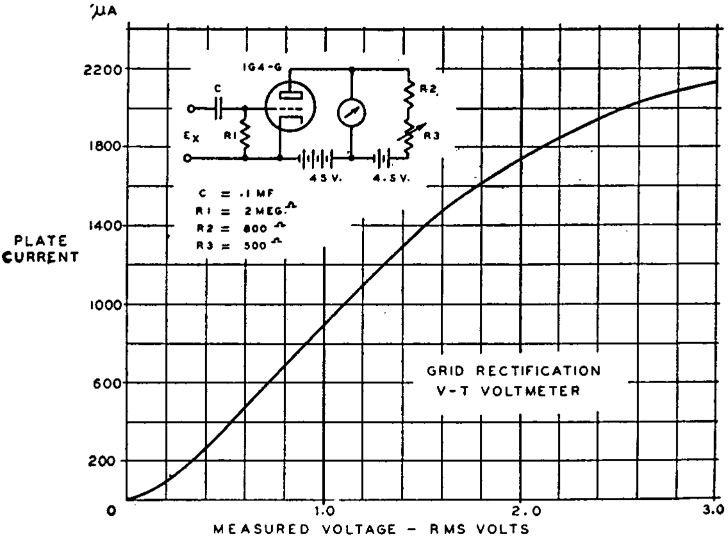


Fig. 3-16. The circuit and calibration of a typical grid-rectification v-t voltmeter. The positive terminal of the meter is connected to the plate so that the meter will swing up scale as the input voltage is increased.

so that it is more convenient to use than the type 30. The circuit is quite similar to the plate-rectification circuits previously shown with the important exception that operation is at zero bias so that no bias battery is required. The polarity of the meter connection is reversed in order that the decreasing plate current will cause the meter to read up scale.

The comparatively low plate voltage of 45 volts is used for two reasons: (1) in order to keep the no-signal plate current as low as possible so as to obtain stable operation and (2) to improve the sensitivity for weak signals. The no-signal plate current for the circuit shown in Fig. 3-16 is 3.9 milliamperes. Since a 4.5-volt balancing battery is used, the balancing resistance should be approximately 1,100 ohms.

Calibration—The calibration is shown in Fig. 3-16. Over the first part of the curve up to about 0.3 volt the response is approximately square law as is indicated by the curved characteristic. For input voltages greater than about 0.3 volt the response is essentially linear and continues to be linear for voltages up to about 1.5 volts. For voltages greater than about 1.5 volts the response gradually falls off and approaches a maximum value at about 3 volts. For example, for an input signal of 10 volts, the reading is 2.7 milliamperes, which is only slightly larger than the reading for 3 volts.

The input resistance of the grid-rectification VTVM varies with the input signal as has been previously mentioned. For this particular v-t voltmeter, the input resistance varies as shown in Fig. 3-17; there, measurements were made at 60 cycles. Note that the input resistance increases from a low value of about 200,000 ohms at a signal input of 0.1 volt to about 1.3 megohms at a signal level of 3 volts. This compares unfavorably with the plate-rectification type of v-t voltmeter where the input resistance is ordinarily of the order of hundreds of megohms for both weak and strong signals.

If a 0-1 milliampere meter is used in this circuit, the calibration curve shows that full-scale deflection will be obtained for approximately 1.1 volts rms. The use of a meter more sensitive than 300 microamperes full scale is not recommended because of zero drift and the possibility of accidental overload. A 300-microampere meter would permit full-scale deflection to be obtained for an input signal slightly less than 0.5 volt.

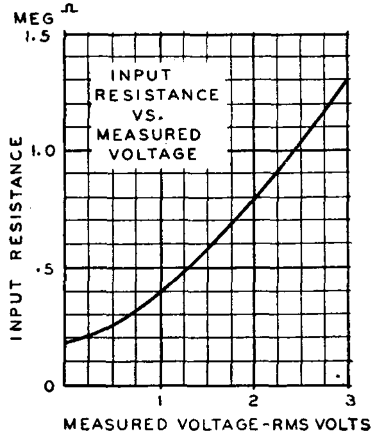


Fig. 3-17. The input resistance of the grid-rectification v-t voltmeter increases as the input voltage is increased. This higher input resistance is a result of the negative bias applied to the grid as a result of rectification of the applied voltage (see Fig. 3-15).

Inverted Triode V-T Voltmeter

The circuit shown in Fig. 3-18, in which the usual plate and grid functions of a triode are interchanged, is called an "inverted" triode circuit.[2] The signal to be measured is applied to the plate while the indicating meter is connected to the grid which is also supplied with a positive bias. In this v-t voltmeter, as in the others discussed in this chapter, the input (plate) circuit exhibits a very high impedance while the output (grid) circuit exhibits a low impedance. The circuit is not very sensitive, but it is useful for high-voltage measurements. Its ability to handle very high voltages is due to the fact that the voltage to be measured is applied to the plate.

The inverted triode circuit is inherently linear and with proper tube choice linear high voltage ranges may be readily obtained. A Western Electric 211D type tube, for example, when used in this circuit will give good linearity over a voltage input range of from 500 to 5,000 volts.[3] With an input of 5,000 volts, using the 211D tube in an inverted triode circuit, the measured input resis-

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[2] F. E. Terman, "The Inverted Vacuum Tube, a Voltage-Reducing Power Amplifier," *Proc. IRE*, vol. 16, pp. 447–461, Apr. 1928.

[3] Max Kupferberg, "Vacuum-Tube Voltmeter for Measuring High Negative Potentials," *Review of Scientific Instruments*, vol. 19, p. 254, Aug. 1948.

tance is 5,000 megohms. There are many other tubes that may be used in this type circuit, however, the transmitting types are most suitable for use at very high voltages.

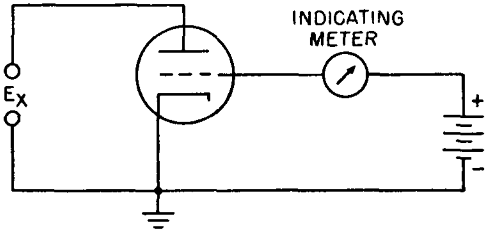

Fig. 3-18. An "inverted" triode circuit used to measure very high voltages. This circuit features a high input impedance, but low sensitivity.

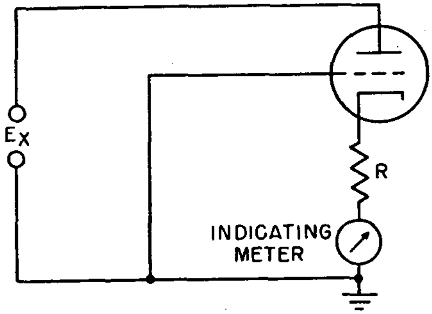

Fig. 3-19. An "inverted" triode circuit with cathode degeneration. The inclusion of the cathode resistor R results in self biasing for the triode (the cathode is at a higher negative potential than the grid) as well as cathode degeneration.

The addition of degeneration to the inverted triode as shown in Fig. 3-19, permits a wider range of voltages to be measured with improved linearity.[4] As resistor R is increased, the sensitivity of the voltmeter is decreased but, its linearity is improved. In general, this resistor will be required to dissipate a considerable amount of power. Using a large value for R, and a Westinghouse 4-125A type tube, this circuit will measure voltages up to 30 kv with good linearity. Under these conditions, the input resistance of the circuit is of the order of 10^7 megohms.[5]

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[4] H. G. Foster, "A Modified Inverted Triode-Valve Voltmeter," *Electronic Engineering*, vol. 19, p. 731, Oct. 1945.

[5] R. J. Schneeberger, "An Inverted Tetrode Voltmeter for High Negative Voltages," *Review of Scientific Instruments*, vol. 19, pp. 40–48, Jan. 1948.

Little is known about the high frequency characteristics of inverted triode voltmeters. They are probably limited in usefulness to frequencies in the low and middle megacycle ranges due to the relatively high input capacities of the tubes used as well as transit time effects. Some extension of the frequency range in which this meter is applicable can be expected from the use of power tubes especially designed for high-frequency operation.

Balancing or Bucking Circuits

A number of different circuits are used to balance out the comparatively large value of initial plate current present in practically all types of v-t voltmeters (excluding inverted triode circuits). In some of these circuits the meter is located in the plate circuit while in others the meter is in the cathode circuit. All of these balancing arrangements, however, resemble each other a great deal. In all of them it is important to have the proper relation between the various components so that the balancing circuit will neither lower the sensitivity nor impair the stability.

A very common balancing circuit, which has already been used in connection with several of the preceding VTVM's, is shown in Fig. 3-20a. The equivalent circuit shown at (b) in this figure makes it clear that the balancing circuit is essentially a bridge circuit. Two of the bridge arms are formed by the tube resistance and *R1*, while the other two arms are formed by the plate battery and the balancing battery. When no signal is applied, zero current will flow through the meter provided the usual bridge balance condition is satisfied:

$$\frac{R1}{\text{Plate Resistance}} = \frac{E1}{E2}.$$

When a signal is applied, the plate resistance of the tube is changed and the bridge balance is upset so that the unbalance current flows through the meter. In plate-rectification v-t voltmeters, the tube resistance *decreases* with the application of a signal so that the negative terminal of the meter should be connected to the plate. In the grid-rectification circuit and in certain d-c amplifiers the plate resistance *increases* so that the positive terminal of the meter should be connected to the plate.

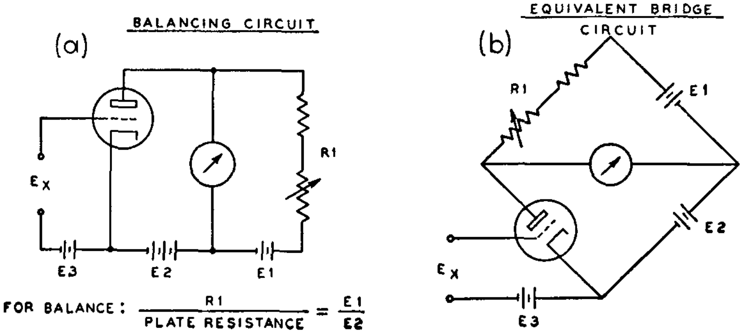

Fig. 3-20 (a), a widely used circuit for balancing out the steady plate current. This circuit is equivalent to the bridge circuit shown at (b).

As the relation for the balance condition shows, a considerable latitude is possible in choosing the values of the balancing voltage *E1* and the balancing resistor *R1*. Thus suppose that a balance is obtained when the balancing voltage *E1* is 10 volts and the balancing resistor *R1* is 10,000 ohms. A balance would also be obtained if *E1* were 1 volt and *R1* were 1,000 ohms. Similarly a balance would be obtained if *E1* were 50 volts and *R1* were 50,000 ohms. It is worth noting that the balance condition does not depend upon the resistance of the meter, although the most desirable value of *R1* and *E1* is related to the meter resistance, as indicated in the following paragraph.

A convenient rule to follow in designing balancing circuits is to select first the balancing resistor *R1* so that it has at least ten times the meter resistance. Thus if the meter resistance is 100 ohms, the balancing resistor should be at least 1,000 ohms and preferably greater. The value of the balancing voltage can then be determined from the relation:

$$E1 = (\textit{Plate Current}) \times R1$$

That is, the balancing voltage should be equal to the voltage drop of the zero-signal plate current across the balancing resistor.

The balancing resistance is made large in comparison with the meter resistance in order to prevent the change in the plate current (when a signal is applied) from going through the balancing resistor instead of through the meter. On the other hand, if the balancing resistance is about the same as the meter resistance, then only a fraction of the change in the plate current will flow through the meter and thus the sensitivity will be reduced. In practice the resistance of the meters used in v-t voltmeters is of the order of several hundred ohms, so that it is usually possible to make *R1* at least ten times the meter resistance without using excessively high values of balancing voltage. Where sensitive meters which have several thousand ohms resistance are used, the balancing voltage may have to be made as high as 50 volts in order to prevent a reduction in the sensitivity.

Balancing Circuit Using Voltage Divider

The balancing circuit shown in Fig. 3-21 operates on the same principle as the preceding circuit with the exception that the several voltages are supplied by means of a voltage divider across a single source of voltage. As the equivalent circuit at (b) shows, the bridge principle still applies, but in this case the second pair of bridge arms are supplied by *R3* and *R4* instead of *E1* and *E2*. A circuit of this type is often used in both a-c and battery-operated VTVM's because of the advantage that all voltages are supplied from a single source. In the case of a-c operated voltmeters, this source can readily be regulated by means of a voltage-regulator tube. The circuit can be modified as shown in Fig. 3-22 for use with battery-operated tubes so that the same voltage source will also supply the filament current.

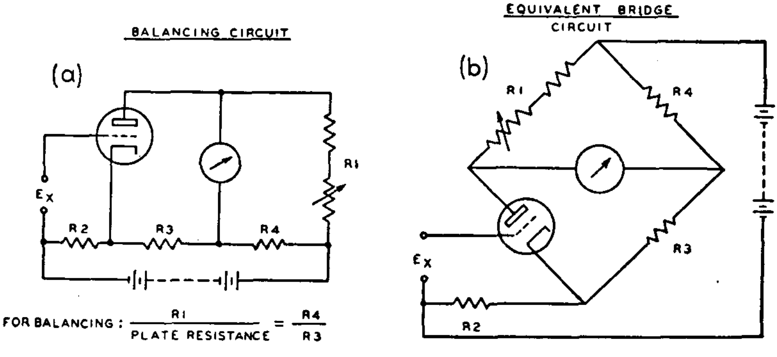

Fig. 3-21 (a), a balancing circuit for use with v-t voltmeters having a voltage divider. The circuit is redrawn at (b) to show the equivalent bridge circuit.

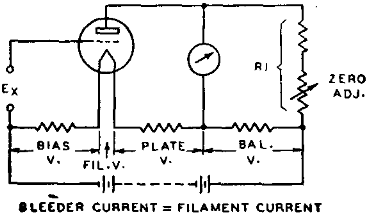

Fig. 3-22. A v-t voltmeter circuit in which the bleeder current supplies the bias, filament, plate, and balancing voltages.

As in the preceding circuit, the constants should be chosen so that the balancing resistor *R1* is at least ten times the meter resistance. To prevent loss in sensitivity because of excessive bleeder resistance, the bleeder resistance should be small enough so that the bleeder current is several times the maximum plate current. For example, if the plate current varies between 2 and 4 milliamperes, then the bleeder current should be from three to five times the 4-milliampere value—or approximately 12 to 20 milliamperes.

Cathode Balancing Circuits

In some instances it is desirable to place the meter in the cathode circuit rather than in the plate circuit as in the preceding balancing circuits. A representative cathode balancing circuit for use with heater type tubes is shown in Fig. 3-23a. The balancing circuit is indicated by the heavy lines. To avoid loss in sensitivity the balancing voltage should be large enough so that the balancing resistance will be at least ten times the meter resistance.

Battery operation is not essential in this circuit. For example the batteries can be replaced by a voltage divider. Where this

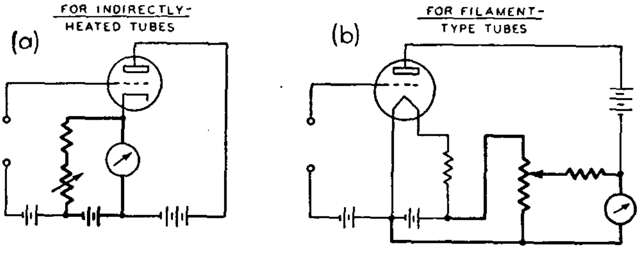

Fig. 3-23. Two balancing circuits which enable placing the meter in the cathode circuit. The circuit at (a) is adapted for indirectly heated tubes, while that at (b) for filament type tubes.

scheme is used the bleeder current should be several times the maximum plate current.

The circuit shown in Fig. 3-23b is designed for use with battery-operated tubes so that the same battery can be used to supply the filament voltage and the balancing voltage. This circuit was formerly widely used but is no longer very popular.

Two-Tube Bridge Circuit

The two-tube bridge circuit shown in Fig. 3-24 is similar in operation to the conventional balancing circuit which has already been described in connection with Fig. 3-21. The important difference between these two circuits is that one of the arms of the bridge is formed by a tube instead of by a resistor. This use of a tube as a resistor makes the circuit symmetrical so that changes in either filament, plate, or bias voltages will not cause the zero to drift. This is an important advantage since the time lag accompanying changes in heater voltage makes it very difficult to compensate in any other way for such changes. The two-tube circuit is especially advantageous where a high-mu tube is used since the change in "contact potential" accompanying changes in heater voltage is largely balanced out.

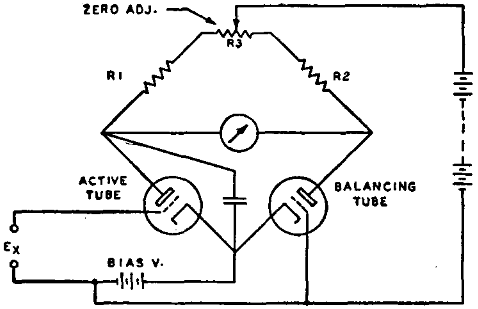

Fig. 3-24. A two-tube v-t voltmeter circuit in which an inactive balancing tube is used to complete the bridge circuit. This type of circuit can be used with any grid-rectification, plate-rectification, or d-c v-t voltmeter.

To secure a symmetrical circuit both the active and the balancing tube should be of the same type and preferably should be matched. The values of *R1* and *R2* should be approximately equal so that no current will flow through the meter when no signal is applied. The values of *R1* and *R2* are not critical, and about the only requirement is that they have a value which is at least several times the meter resistance. The use of high values of *R1* and *R2* will not raise the sensitivity appreciably, but will tend to make the calibration more linear because of the higher plate load resistance. Because the resistance of both *R1* and *R2* limits the off-balance current through the meter, the sensitivity of the bridge type of circuit is about one-half that of the single-ended circuit.

The zero-adjustment control *R3* makes it possible to compensate for variations in the characteristics of the two tubes. This control should have approximately one-seventh the resistance of *R1* so as to make possible a smooth adjustment. If there is insufficient latitude to enable the zero adjustment to be made, the two tubes differ too widely in their characteristics and should be replaced with a matched pair.

In ultra-sensitive v-t voltmeters the circuit is often modified by the inclusion of resistances which compensate for slight variations in the plate resistance and amplification factor of the two tubes. In this way perfect symmetry is attained so that the drift in the zero is made negligible. In all ordinary VTVM's these refinements are not required and merely matching the two tubes for equal plate current is sufficient to obtain good stability.

In the interests of simplicity, bypass capacitors have been omitted from some of the circuits shown in this chapter. It should be understood, however, that adequate bypassing of the plate and cathode circuits is required in order to prevent a variation in sensitivity with frequency and to permit calibration at 60 cycles.

Degenerative Two-Tube Bridge Circuit

Fig. 3-25 shows an improved two-tube bridge circuit in which the two resistance arms are in the cathode circuits where they provide a high degree of degeneration. With well matched tubes, the circuit is insensitive to plate voltage changes making regulation generally unnecessary. The voltage range is increased by increasing *R4* in series with the meter. The zero balance point is thus unaffected by changing the range, and the apparent stability of the circuit increases in direct proportion to the voltage range. The value of *R4* is much smaller than would be required of an input attenuator, and this resistor is generally a wire-wound one, adding to the stability of the circuit and to the permanence of calibration.

There are many variations of the two-tube bridge circuit used today in commercial vacuum-tube voltmeters.[6] In Chapter 13 will be found circuits and descriptions of many of these voltmeters. The inherent stability of present day VTVM's, even in the presence of line voltage fluctuations, is one of the big advantages of this type meter.

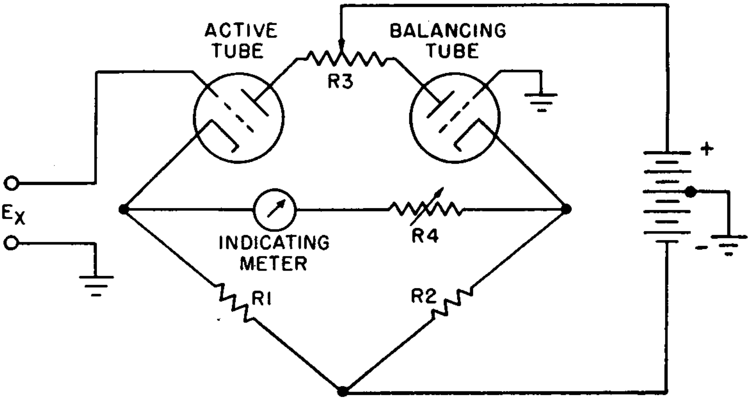

Fig. 3-25. A two-tube v-t voltmeter in which the resistance arms are in the cathode circuit providing degeneration as well as a bridge balance.

One interesting variation of the two-tube degenerative bridge utilizes vacuum tubes in place of the usual cathode resistors.[7] This circuit is shown in Fig. 3-26, in which two arms of the bridge are formed by tubes *V1* and *V2*. *V1* is the active tube receiving the signal to be measured. Tubes *V3* and *V4* form the remaining two arms of the bridge. Degeneration in the latter two arms results from the use of the large cathode resistors *R1* and *R2*. The meter is connected between the cathodes of *V1* and *V2* through the range determining resistor *R3*.

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[6] The following v-t voltmeters are only a few of those employing the two-tube bridge as a d-c amplifier. The RCA VoltOhmyst 195-A, the Reiner model 451, the Barber Laboratories models VM-27 and VM-72, and Measurements Corp. model 62.

[7] This circuit is used in the General Radio type 1800A.

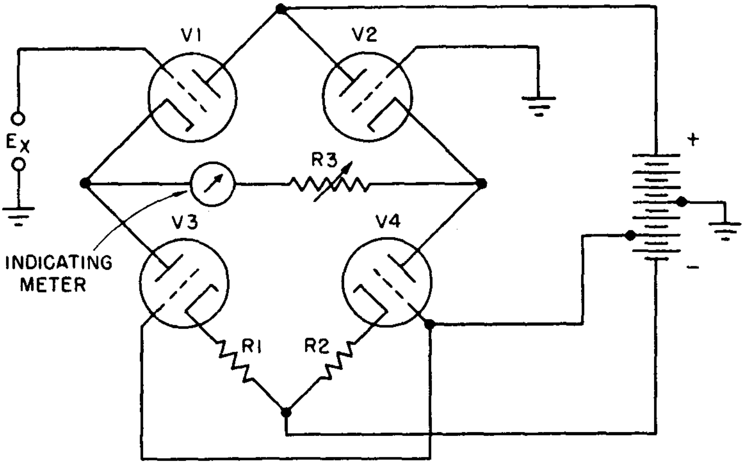

Fig. 3-26. Four-tube bridge in which two tubes act as cathode loads for the other two tubes.

Cathode Follower Bridge Circuit

Fig. 3-27 shows a still further refinement of the two-tube bridge. In this circuit two of these bridges are connected in cascade. The first acts as a cathode follower for the second. The object of the first bridge is to provide a circuit with the highest possible input resistance. The cathode resistors *R1* and *R2*, which may have values of several megohms, reduce the plate current of the input tube to a very low value which in turn, reduces the grid current and raises the input resistance. A further increase in input resistance is obtained by cutting down the plate voltage, especially if it is lowered to a point below the ionization potential of any possible residual gas in the tube.

The first bridge, with its very large cathode resistors, is highly degenerative and has a gain very nearly equal to one. The second bridge is generally similar to those previously described in this chapter. Its grids are directly connected to the cathodes of the first bridge. Examples of the commercial use of this two stage bridge circuit are described in Chapter 13.[8]

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[8] Commercial v-t voltmeters using the two-stage bridge are the Hewlett-Packard model 410A, and the Sylvania Polymeter type 221.

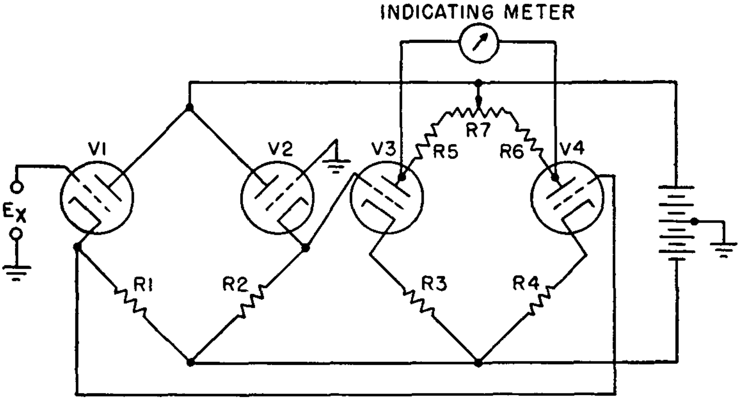

Fig. 3-27. Two two-tube bridge circuits in cascade. The first acts as a cathode follower.

Push-pull Bridge Circuit

Fig. 3-28 shows a two-tube bridge circuit which has degeneration and push-pull action.[9] The two tubes *V1* and *V2*, together with resistors *R1* and *R2*, form a bridge with the meter connected across it. The cathodes are returned through two relatively low value resistors *R4* and *R5*, and a relatively large common resistor *R6*,

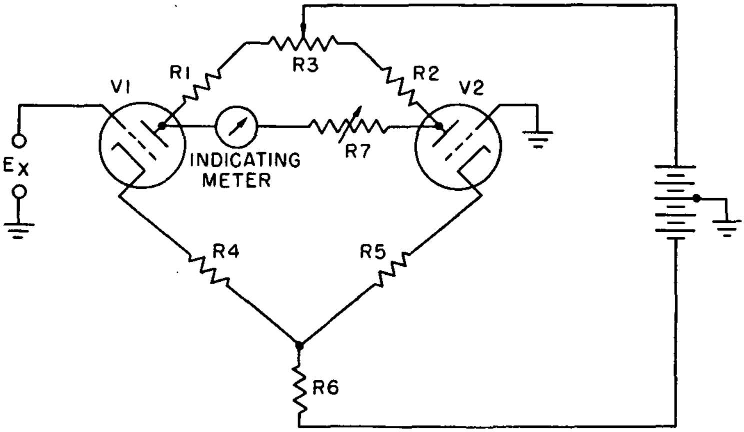

Fig. 3-28. Two-tube push-pull bridge d-c amplifier.

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[9] This circuit is used by RCA in VoltOhmysts types WV-65A, WV-95A, and 195-A. It is also used by Triplett in model 2451.

to a negative voltage point. The voltage to be measured is applied to the grid of *V1* causing its cathode current and its plate voltage to change. The change in cathode current flowing through the common cathode resistor causes the plate voltage of the second tube to change in the opposite direction to the plate voltage change of the first tube. In this way the current passed through the indicating meter is approximately doubled by the push-pull action. On the other hand, due to the bridge balance and to cathode degeneration, the circuit is not sensitive to changes in heater, plate, or bias voltages and other such fluctuations.

REVIEW QUESTIONS

CHAPTER 3

3–1. What advantage has the triode for use in VTVM's over diodes?
3–2. Explain the operation of the half-wave square-law VTVM.
3–3. Why is the sensitivity of the half-wave square-law v-t voltmeter poor for small voltages?
3–4. Why is the sensitivity of the full-wave square-law VTVM superior to that of the half-wave type voltmeter?
3–5. To what value of an a-c voltage is the peak plate-rectification VTVM responsive? Explain this.
3–6. What limits the application of peak plate-rectification VTVM's?
3–7. What important advantage offered by VTVM's is lacking in the grid-rectification type?
3–8. For what type measurements is the inverted triode VTVM applicable? Why?
3–9. Why are bridge type circuits used to balance out initial (no signal) plate currents in v-t voltmeters?
3–10. Describe briefly three types of balancing circuits.

CHAPTER 4

RECTIFIER-AMPLIFIER VACUUM-TUBE VOLTMETERS

Fundamentally all a-c v-t voltmeter measurements depend upon rectification of the a-c voltage so that it can be determined in terms of a d-c current or voltage. As mentioned earlier, the advantage of rectifying the a-c voltage is that it permits the use of d-c instruments which are more sensitive, more accurate, and less expensive than a-c instruments. At the same time, the conversion of the unknown a-c voltage into a d-c voltage has the important advantage of enabling measurements to be made over a very wide range of frequency.

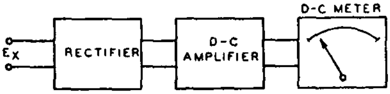

Fig. 4-1. Block diagram of the rectifier-amplifier type of v-t voltmeter.

In the VTVM's described in the preceding chapters, a basic rectifier stage is used with the d-c meter inserted so as to measure the rectified plate current. In none of these circuits has there been any attempt to amplify the d-c output of the rectifier. By adding a d-c amplifier stage as shown in Fig. 4-1, however, the performance can be greatly improved. Provided the circuit is properly designed, the addition of the d-c amplifier has the advantage of providing higher sensitivity, greater stability, a wider range, and, in certain instances, higher input impedance. These advantages can be realized because the separation of the functions of retification and amplification make it possible to obtain the greatest efficiency in each of these two functions.

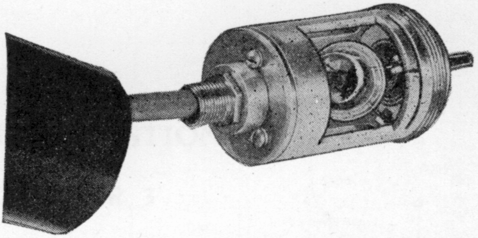

Fig. 4-2. Diode probe partially cut away to show the acorn-type diode tube, and its connections. Such probes rectify the a-c or r-f voltage to be measured and feed the dc to the amplifier in the v-t voltmeter housing.

The rectifier-amplifier type of VTVM is particularly adapted for use with the probe type of construction. As is illustrated in Figs. 3-13 and 4-2, this type of construction has the advantage of permitting extremely short leads to the circuit under test. In practice the rectifier tube is usually mounted in a small shielded assembly at the end of a flexible or "goose-neck" cable. Since the leads from the rectifier to the d-c amplifier and power-supply unit carry only d-c and 60-cycle voltages, this cable may have any desired length. Because the probe is very important in the field of v-t voltmeter design, and since there are numerous varieties now in common use, Chapter 9 is devoted exclusively to the subject.

Diode Rectifier Used with D-C V-T Voltmeter

In some instances a d-c VTVM is available which covers a range of voltages extending from a fraction of a volt up to several hundred volts. A considerable number of instruments of this type (described in Chapter 8) are in use, many of them being multi-range d-c v-t voltmeters and ohmmeters. Such instruments can be adapted for the measurement of a-c voltages by the addition of a rectifier

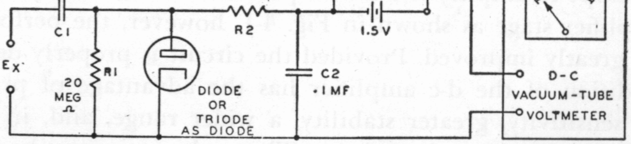

Fig. 4-3. A d-c v-t voltmeter can be adapted to read a-c voltage by the addition of a diode rectifier circuit. For high frequency work, the diode should be mounted in a probe.

unit to convert the a-c voltage into a d-c voltage. Circuits for accomplishing this are shown in Figs. 4-3 and 4-4.

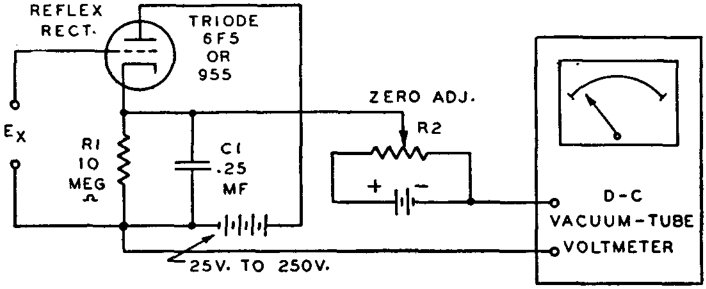

Fig. 4-4. A d-c v-t voltmeter can be adapted to read a-c voltages by the addition of a reflex rectifier which may be mounted in a probe unit for high-frequency measurements.

The circuit in Fig 4-3 employs a shunt type of diode rectifier which is similar to the diode rectifier described in Fig. 2-8. Because the rectifier output is taken off in the form of a voltage rather than a current, it is possible to use a high load resistance. In the diode circuits shown in Chapter 2, on the other hand, high values of diode resistance cannot be used because the effect is to reduce the current output. In the rectifier-amplifier circuit the voltage output is actually *increased* by using high values of load resistance.

The d-c voltage developed at the diode plate is fed to the d-c v-t voltmeter through a filter circuit consisting of *R2* and *C2.* This filter removes the a-c component of the voltage present at the diode plate, so that the voltage at the output of the filter contains only the d-c component. As explained previously, this voltage is slightly less than the peak a-c voltage at the input to the rectifier.

It will be recalled that with no signal applied to the rectifier the "contact potential" at the diode plate is approximately 1 volt (see Fig. 2-13). It is desirable to balance out this negative voltage since otherwise a comparatively large zero-signal deflection will be obtained on the d-c VTVM. A convenient method for balancing the contact potential is to use a flashlight cell shunted with a 20,000-ohm potentiometer as indicated in the figure. A switch should be included to prevent a permanent drain on the cell when the rectifier is not in use. To make the necessary adjustment the d-c v-t voltmeter zero adjustment should first be made in the usual manner with the rectifier disconnected. The filter output should then be connected to the d-c v-t voltmeter, and the control *R3* adjusted so that a zero reading is again obtained. This adjustment should not be made until the rectifier tube has had sufficient time to heat since the adjustment depends upon the emission of the rectifier tube.

Although the diode load resistor *R1* can be made as high as 50 megohms, the filter resistor *R2* should not be larger than about 1 megohm, if there is not to be an excessive loss in sensitivity. From an inspection of Fig. 4-3 it is apparent that *R2* forms a voltage divider in combination with the input resistance of the d-c v-t voltmeter so that only a fraction of the voltage developed at the diode plate reaches the d-c v-t voltmeter. For example, if *R2* is 1 megohm and the input resistance of the d-c VTVM is 10 megohms, then $^{10}/_{11}$ or about 90 per cent of the rectified voltage reaches the d-c v-t voltmeter. For radio-frequency measurements the best value for *R2* is about 1 megohm. This gives an input resistance which is of the order of 1 megohm and at the same time keeps the reduction in sensitivity at a negligible value. If higher values of *R2* are used, the input resistance will be raised only slightly, but the sensitivity will be lowered appreciably.

For voltages below about 10 volts, a direct calibration is required because of the non-linearity of rectification at low voltages. On the higher voltage ranges, however, the a-c peak voltage will be approximately equal to the d-c voltage indicated by the v-t voltmeter, with allowance being made for the reduction in sensitivity due to the d-c drop across the filter resistor *R2*. The most convenient method for reading voltages higher than about 10 volts is to determine the multiplying factor required to give the peak or rms voltage.

Reflex Rectifier Used with D-C V-T Voltmeter

The reflex or self-bias rectifier circuit shown in Fig. 4-4 has several important advantages over the diode circuit just described. The foremost of these advantages is that the input impedance is much higher than for the diode circuit. Because the filter circuit is an integral part of the rectifier, no reduction in sensitivity takes place in the filter circuit. Thus the a-c component of the rectified voltage is completely removed by the cathode bypass capacitor *C1*. When used with an external d-c VTVM as in this circuit, the reflex rectifier has the disadvantage that plate voltage is required. This voltage must be somewhat greater than the highest peak voltage to be measured.

The operation of the reflex rectifier has already been described in connection with the self-bias or reflex plate-rectification v-t voltmeter. The operation of the rectifier shown in Fig. 4-4 is basically the same as that of the circuit referred to above. However, the constants are chosen so that the maximum rectified *voltage* rather than *current* will be produced. Thus the cathode resistor *R1* in the present circuit is 10 megohms as against the much lower values used in the circuits shown in Chapter 3. Since the high value of cathode resistance is bypassed by a large capacitor *C1*, this capacitor charges up to a voltage which is slightly lower than the peak value of the a-c signal impressed on the grid. The fact that there is no amplification in this circuit is no disadvantage since the necessary amplification is provided by the d-c VTVM. The high degree of stability and the high value of input impedance which are achieved as a result of triode operation with low plate current more than compensate for the required plate voltage and the lack of amplification.

As in the diode rectifier circuit, it is necessary to provide an auxiliary battery to balance out the zero-signal cathode voltage. The circuit connections for this are shown in Fig. 4-4. The required battery voltage will vary from a few volts up to about 25 volts depending upon the tube type and the plate voltage.

For average operation a plate voltage of about 200 volts is satisfactory. This will permit operation up to at least 100 volts rms. For deflections less than about 1 volt, improved sensitivity will be obtained by using a plate voltage of the order of 25 volts. Although a still lower plate voltage will improve the sensitivity slightly, its use is undesirable since it will result in grid current and reduced input impedance.

The reflex rectifier circuit shown in Fig. 4-4 is not critical of tube type because of the high value of cathode resistance. Thus triodes having either a high or low amplification factor will function very satisfactorily. In general, however, triodes having a high amplification factor are more suitable where the greatest sensitivity is desired. The lower cut-off voltage of these tubes has the desirable effect of improving the sensitivity for values of signal voltage of the order of several tenths of a volt and at the same time reduces the zero-signal voltage at the cathode. The latter reduction is desirable since it improves the stability of operation.

For average conditions the circuit constants shown in Fig. 4-4 are suitable. The type 6F5 tube is satisfactory for operation at low frequencies, while the type 955 acorn tube is suggested for use at high radio frequencies where the losses and input capacitance must be kept to a minimum. The probe type of construction is recommended regardless of whether an acorn tube is used.

Rectifier-Amplifier V-T Voltmeter Using a Voltage Divider

The rectifier-amplifier circuit shown in Fig. 4-5 has been rather widely used because of its comparative simplicity and ease of design. Essentially the circuit is similar to that shown in Fig. 4-3 with the exception that the separate multi-range d-c v-t voltmeter is replaced by a voltage divider and a fixed-gain d-c amplifier stage which form an integral part of the complete instrument.

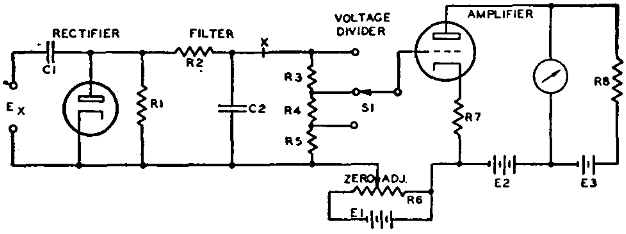

Fig. 4-5. A multi-range rectifier-amplifier v-t voltmeter in which the several ranges are obtained by means of a high-resistance voltage divider in the output of the diode rectifier.

All the elements of this a-c rectifier-amplifier v-t voltmeter have already been described so that only a brief discussion is required here. The diode rectifier is conventional, the capacitor *C1* charging up to slightly less than the peak value of the voltage being measured. This voltage is fed through the filter *R2-C2* into the voltage divider

R3-R4-R5. The voltage which reaches the grid of the d-c amplifier stage is controlled by the multiplier switch *S1*. The d-c amplifier stage works at a fixed value of plate current which is determined by the resistor *R8* and the balancing voltage *E3*.

As mentioned earlier, a negative voltage of approximately 1 volt will be applied to the d-c amplifier because of the "contact potential" of the diode rectifier. Because the voltage divider in the input circuit reduces the contact potential as well as the rectified voltage, it is clear that the operating bias will be different on the several ranges. To compensate for this varying voltage the bias control *R6*, designated as the zero adjustment, must be readjusted on each of the range positions. The major change in this adjustment will occur when the switch is moved from the most sensitive range to the adjacent range.

To eliminate the necessity for readjustment of the zero on each of the ranges, the zero adjustment may be placed in the high side of the grid lead at point *X*. Although this latter arrangement eliminates the shift in the zero, it has the disadvantage that it is not adapted to a-c power supply operation. A flashlight cell can be used to supply the required balancing voltage.

The values of the circuit components depend upon the requirements. In general, *R2* should be small in comparison with the voltage-divider resistance in order to avoid excessive loss in sensitivity. The high-resistance voltage divider presents somewhat of a problem since several of these resistors, including the filter resistor, are of the order of megohms. Thus wire-wound units cannot be used because of the high values of resistance. The usual arrangement is to employ metallized resistors which can be obtained in high values at nominal cost. These resistors can be paired as explained in Chapter 10 in order to obtain a nominal accuracy of about 1 per cent. In practice, however, the voltage-divider accuracy cannot be relied on to an accuracy greater than a few per cent because of temperature variations and changes in resistance with aging.

As compared with the degenerative amplifier circuit described in the following section, this circuit has the disadvantage that the amplifier works at maximum gain regardless of the voltage being measured. The loss in sensitivity due to the drop through the filter resistor and the necessity for compensating for the variable zero shift are further disadvantages of this circuit. In favor of the circuit it should be noted that the use of a voltage divider simplifies the design of the d-c amplifier which does not require any changes as the range switch is varied.

The reflex rectifier shown in Fig. 4-4 can also be used with this type of circuit and enables a voltage divider of comparatively low resistance to be employed. A total resistance as low as 50,000 ohms can be used, although a resistance of the order of 1 megohm is preferable. The advantages of the reflex rectifier are its higher input resistance and the fact that wire-wound resistors can be employed in the voltage divider. The reflex rectifier, on the other hand, requires a plate-voltage supply which is not needed with the diode rectifier. The latter requirement is not usually an important disadvantage since the plate supply of the d-c amplifier can often be used for the rectifier as well.

Rectifier-Degenerative Amplifier V-T Voltmeter

Another basic type of rectifier-amplifier v-t voltmeter is shown in Fig. 4-6. This differs from that of the preceding circuits in that no voltage divider is employed, but instead the various ranges are secured by controlling the sensitivity of the d-c amplifier. This control in sensitivity is secured by means of a variable resistance in the cathode circuit of the d-c amplifier tube. The larger the value of this cathode resistance, the greater is the degeneration introduced and hence the greater is the input voltage required for full-scale deflection. This type of amplifier is described in detail in the chapter on d-c VTVM's.

In the circuit shown in Fig. 4-6, the sensitivity is controlled by means of the range switch *S1*. This two-section switch is so ganged that the bias voltage is changed simultaneously with the change in the cathode resistance. By returning the cathode to the proper point on the voltage divider in this way, the same initial plate current and the same operating point is secured on all ranges. On the higher voltage ranges where values of cathode resistance of the order of several hundred thousand ohms are used, full-scale deflection will be secured for an input of about 100 volts. Under these conditions, the cathode must be returned to a point on the voltage divider which is quite negative with respect to the grid-return point. This large negative voltage is required in order to balance out the comparatively large voltage drop *across the cathode resistor. Where the cathode resistance is very large, the change in plate current is approximately equal to the applied grid voltage divided by the cathode resistance. Thus the deflection becomes independent of the tube voltages and the tube characteristics, so that a high degree of stability is secured.*

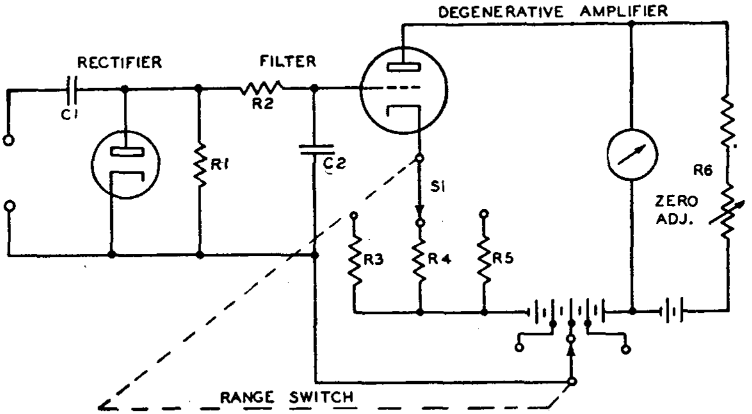

Fig. 4-6. The basic circuit of an a-c v-t voltmeter using a diode rectifier and a degenerative d-c amplifier. The various ranges are secured by means of the switch *S1* which varies the cathode resistance and at the same time controls the bias voltage so as to maintain a constant plate current.

In addition to providing stability and permanence of calibration, the degenerative amplifier circuit has the advantage that a high-resistance voltage divider is not required. Since the cathode resistors *R3*, *R4*, and *R5* which control the sensitivity are all less than a few hundred thousand ohms, wire-wound resistors can be used.

An important feature of the degenerative amplifier circuit results because the amplifier works at a gain which is reduced proportionately as the range of the instrument is increased. This not only improves the stability but also tends to prevent excessive current through the meter if overload takes place. At the same time the degenerative action improves the linearity on the higher ranges where large values of cathode resistance are used.

The degenerative type of amplifier circuit can also be used in combination with the reflex rectifier. As in the previous circuits, the reflex rectifier has the advantage over the diode rectifier of higher input impedance, but the disadvantage that plate voltage must be supplied.

Diode Rectifier and Bridge-Type Amplifiers

In addition to the rectifier amplifier v-t voltmeters described, a very popular circuit in common use comprises a double diode and a balanced d-c amplifier.[1] The advantages and characteristics of various balanced d-c amplifiers of the types used in these voltmeters are shown and described in the latter part of Chapter 8. These d-c amplifiers are well suited to v-t voltmeter use since they are very stable and are linear over a wide range of input voltages. For this circuit, an increase in the d-c grid voltage from 0.1 to 100 volts will result in a linear corresponding increase in the meter current.

The use of the second diode in the double diode solves the problem of contact potential effects. In Fig. 4-7, the diode *D1* is the signal rectifying diode while the second diode, *D2*, is utilized to balance the contact potential of the signal diode. The rectified d-c output from the signal diode is filtered by resistor *R2* and capacitor *C2* and is applied to the grid of the active d-c amplifier tube *V1*. The voltage due to contact potential and initial velocity of electrons from the cathode developed across *R3* by diode *D2* is applied to the grid of the balancing d-c amplifier tube *V2*. With no input signal applied, the system is balanced by adjusting the tap on *R4*. Under these conditions the circuit shows good stability in the presence of plate and heater voltage variations since both the rectifiers and the amplifiers are balanced. For example, an increase in heater voltage tending to increase the initial voltage drop across *R1*, the signal diode load, also increases the drop across *R3*, the balancing diode load.

When an input signal to be measured is applied through *C1* to the signal diode plate, the d-c drop across *R1* is increased which in turn being applied to the grid of the active tube *V1* unbalances the d-c amplifier causing current to flow in the meter circuit. Since the d-c bridge amplifier circuit with cathode degeneration is linear

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[1] Examples are Hewlett-Packard model 410A, Barber Laboratories model VM-72, and General Radio type 1800A, all described in Chapter 13.

over a wide range of voltages, a convenient method of changing ranges is to change the value of *R7* in series with the meter. This method of changing the voltage ranges has two distinct advantages. In the first place, the values of resistors required for *R7* are much lower than the value of resistors which would be required for an input attenuator to the d-c amplifier. This permits the use of wire-wound resistors and hence, provides a maximum of permanence and accuracy of the meter calibration. The second, and even more important advantage is that the effective degeneration is increased as the voltage range is increased. In contrast with an input attenuator, the d-c amplifier always operates at maximum sensitivity and minimum stability. This is so because the values of *R7* used with an input attenuator decrease the effective degeneration in the d-c amplifier. When ranges are changed by changing *R7*, the degeneration is increased as the ranges are increased and hence the stability is increased.

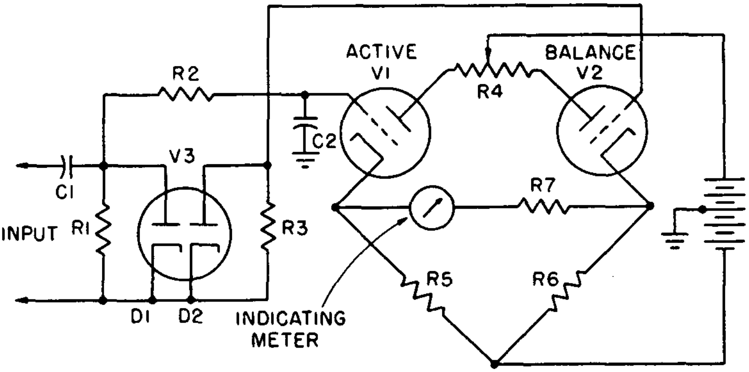

Fig. 4-7. Double-diode rectifier and balanced d-c amplifier circuit with excellent linearity and stability characteristics.

A double diode, *D1* and *D2*, is shown as the signal and balancing tube. The main advantage to be found in the use of the double diode is that the two diodes have received identical treatment in manufacture and are more likely to be well balanced than two separate tubes. However, since some of the latest high-frequency diodes available are only single diodes they are often used in matched pairs in place of a double diode. In this balanced type of circuit it is also important to match the d-c amplifier tubes in order to obtain maximum stability of the v-t voltmeter. If the tubes are properly "aged" to bring them to a stable condition they may be selected to form matched pairs.

Aging consists in operating the tubes for at least 25 hours under normal rated operating conditions. After this the tubes may be matched and they may maintain this match throughout their operating life. Aging has a further advantage in that it usually greatly reduces and stabilizes grid current. Grid current is undesirable in the v-t voltmeter since it causes the zero setting to drift and may cause inaccuracies in the meter reading due to a changing drop in the filter resistor $R2$.

REVIEW QUESTIONS

CHAPTER 4

4–1. An important advantage of rectifying an unknown a-c voltage and measuring the resulting dc is that the frequency range of the meter is extended. Explain this.

4–2. How may d-c v-t voltmeters be adapted to measure ac?

4–3. Explain the operation of the reflex rectifier circuit shown in Fig. 4-4.

4–4. What are the advantages of using a degenerative amplifier in the rectifier-amplifier type VTVM?

4–5. Why is it advantageous to use double diodes in bridge-type amplifiers?

CHAPTER 5

TUNED VACUUM-TUBE VOLTMETERS

Vacuum-tube voltmeters are generally wide-band responsive, that is, they respond equally to voltage components of all frequencies within their frequency range. In this connection we may note that the range of these instruments is constantly being broadened. However, it is at times desirable to have a selective instrument for measuring voltage. A VTVM connected across a wavemeter, or tuned circuit, provides such a selective device. If more selectivity is required, a tuned amplifier may be used ahead of the v-t voltmeter.

Wavemeter With V-T Voltmeter

Probably the simplest tuned v-t voltmeter is the one shown in Fig. 5-1. This circuit is useful in roughly checking the frequency of an oscillator or other signal source and for indicating harmonics and other extraneous signals. However, the circuit is also useful for indicating the relative amplitudes of two or more r-f signals.

The gain or sensitivity characteristic of a well designed coil and capacitor combination such as is used in Fig. 5-1 is shown in Fig. 5-2. With very loose coupling to the circuit under investigation, the over-all sensitivity curve of the tuned circuit VTVM combination will have the same shape. For quantitative results it is necessary to devise some method of calibration. One method is to place a second v-t voltmeter across the circuit in which the signals to be measured originate and to measure the ratio of signal voltage across the circuit to signal voltage across the wavemeter tuned circuit over the range of frequencies under investigation. As long as the coupling is maintained at the same value this calibration may be used.

While tuned voltmeters have important applications, little attempt has been made to produce a general purpose tuned v-t voltmeter. One of the obstacles is the difficulty in obtaining a strictly constant gain in the tuning system over a wide range of frequencies, particularly at high radio frequencies.[1] Where a high degree of accuracy is not required the signal-tracing VTVM fills the requirements.

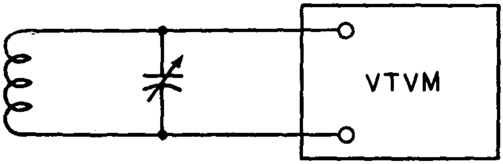

Fig. 5-1. The simplest type of tuned v-t voltmeter, in which the tuned circuit is external to the voltmeter proper.

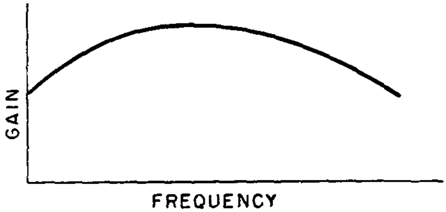

Fig. 5-2. Typical sensitivity curve for the tuned circuit shown in Fig. 5-1.

Signal Tracers

In the preceding chapters we described both *rectifier* and *rectifier-amplifier* types of v-t voltmeters. In these instruments no attempt is made at amplification of the voltage under measurement *before* rectification. Where amplification is used, it is limited to d-c amplification following the rectification of the voltage being measured. There are, however, v-t voltmeters in which the voltage under measurement is amplified *before* it is rectified. Instruments of this type can conveniently be classified as *amplifier-rectifier* v-t voltmeters. Included in this classification are "signal-tracing" instruments which are used to check the progress of the signal through a radio receiver. Such instruments invariably must have a

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[1] A. Peterson, "Vacuum-Tube Voltmeters at Ultra High Frequencies," *General Radio Experimenter,* vol. 19, pp. 1–7, May 1945.

considerable amount of amplification so as to make possible measurement of the relatively weak signal levels in the first stages of the receiver.

The signal-tracing VTVM is essentially a *tuned* v-t voltmeter which is tuned to distinguish between voltages of different frequencies in the same manner as a conventional receiver. The need for selectivity in signal tracing is obvious. For example, in checking the r-f signal level in the input to the mixer stage, it is necessary to have some means of differentiating between the relatively weak r-f signal and the strong oscillator signal. More on this subject will be found in Chapter 12.

Harmonic Analyzer

Another example of a tuned v-t voltmeter is to be found in most types of harmonic analyzers.[2] Fig. 5-3 is a block diagram of one form of selective harmonic analyzer.[3] The input signal to be analyzed is applied to a calibrated input attenuator. The attenuated signal is applied to a mixer where it is combined with a signal from a local tunable oscillator. One of the sidebands thus produced is selected and amplified by the selective amplifier after which it is measured by a v-t voltmeter. The magnitude of the selected component of the input signal is equal to the product of the attenuation factor and the VTVM reading.

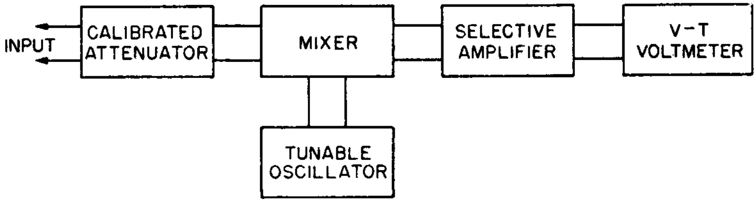

Fig. 5-3. Block diagram of one type of harmonic analyzer. The tuned circuit used here is of the superheterodyne type, the product of the v-t voltmeter reading and the reading on the attenuator gives the voltage of the input signal.

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[2] A. W. Barber, "A Simplified Harmonic Analyzer," *Electronics*, vol. 1, pp. 374–375, Nov. 1930.

[3] L. B. Arguimbau, "The New Wave Analyzer," *General Radio Experimenter*, vol. 13, pp. 1–5, Dec. 1938.

Amplifier-rectifier v-t voltmeters are by no means limited to the tuned type discussed above. On the contrary, there are many v-t voltmeter applications where it is possible to use *untuned* resistance-coupled amplifiers preceding the rectifier. For the most part, however, the untuned amplifier type of v-t voltmeter is limited to comparatively low frequencies below about 100 kilocycles. At higher frequencies it is not feasible to use untuned amplifiers because the gain falls off very sharply as the frequency is increased. Since untuned amplifier-rectifier VTVM's are limited to low frequencies and find their greatest application in audio-frequency v-t voltmeters, we shall describe this type in the next chapter which deals with audio-frequency VTVM's.

Input Circuit and Probe

In many applications involving the use of tuned v-t voltmeters it is desirable to reduce the input capacitance to approximately 1 micromicrofarad. To obtain an input capacitance as small as this, it is clear that the input circuit cannot be connected directly to the grid of the first amplifier tube because the input capacitance of the tube alone is considerably greater than 1 $\mu\mu$f, even where an acorn type of tube is used. To overcome this difficulty special probes have been developed which enable a considerable reduction in the input capacitance. One probe of this type is shown in Fig. 5-4.

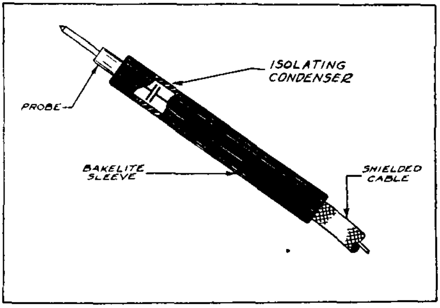

Fig. 5-4. A type of probe which is used with tuned-amplifier v-t voltmeters. The input capacitance is reduced by means of the air gap near the probe tip.

The input capacitance of such a probe can be made less than 1 $\mu\mu$f. An input capacitance appreciable less than this is difficult to obtain because the capacitance of a small probe tip by itself is of the order of 0.5 $\mu\mu$f.

As Fig. 5-4 shows, the low input capacitance is secured by means of a small capacitor which is located close to the probe tip, and is formed by the gap between the probe tip and the inner conductor of the shielded probe cable, which connects to the control grid of the amplifier tube. The complete probe assembly is shielded so that direct pickup to the inner conductor is minimized. A more complete discussion of probes and their uses will be found in Chapter 9.

Multiplier

This type of probe and shielded cable is often used in conjunction with a capacitive type of attenuator in the input circuit to the first amplifier tube. A typical circuit of this type is shown in Fig. 5-5; this is similar to the circuit employed in the RCA-Rider Chanalyst. On the *X1* position of the multiplier switch, a small trimmer may be connected across the input circuit so as to bring the total input capacitance up to some specific design value of the order of 70 $\mu\mu$f. This total capacitance includes the capacitance of the shielded cable, the input capacitance of the tube, and the wiring capacitance. For the case where the probe input capacitance is 1 $\mu\mu$f and the total capacitance between the grid and ground of the first tube is 70 $\mu\mu$f, it follows that the attenuation in the input circuit would be 70. In other words, only $\frac{1}{70}$ of the signal fed to the input of the probe reaches the grid of the first amplifier tube.

On the *X10* position of the multiplier switch, the capacitor *C2* adds enough capacitance to the input so as to bring the total grid-ground capacitance to 700 $\mu\mu$f, or ten times the previous value. As a result the attenuation is raised to 700 or ten times the attenuation for the *X1* position. In the same way the capacitors *C3* and *C4* bring the total capacitance up to 7,000 and 70,000 $\mu\mu$f respectively, so that multiplying factors of 100 and 1,000 are provided by these positions of the multiplier switch.

The attenuation in the input circuit on the *X1* position depends upon the grid-ground capacitance in the input circuit. To keep this attenuation low, the grid-ground capacitance must be kept as small as possible. For this reason it is desirable to use shielded cable of the low-capacitance type for the probe cable; the layout and wiring in the input circuit should be such that the grid-ground capacitance is kept to a minimum. In practice, using ordinary receiving tubes, it is possible to keep the input capacitance down to the order of 70 $\mu\mu$f, so that the input attenuation with a 1-$\mu\mu$f coupling capacitor is approximately 70. This figure includes the capacitance of about 3 feet of low-capacitance shielded cable which makes up the major portion of the total capacitance. In certain applications where the input attenuation on the *X1* position must be kept down to the absolute minimum, the use of an acorn input tube, large diameter, low-capacitance shielded cable, and a special low-capacity plug and jack (or a direct connection of the probe) will enable an appreciable reduction in this figure of 70 $\mu\mu$f.

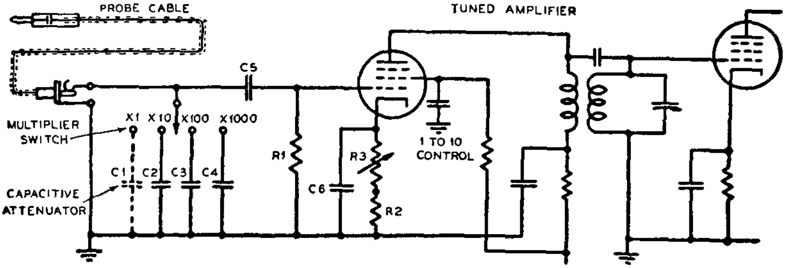

Fig. 5-5. The input circuit of a tuned-amplifier type of v-t voltmeter. The attenuator consists of a multiplier switch which provides attenuation factors in steps of 10, and the cathode control which provides continuous attenuation over a range from 1 to 10.

An important feature of the capacitive type of multiplier is its wide frequency range. Thus the division of the voltage depends on the ratio between the probe-tip capacitance and the total grid-ground capacitance. Since this ratio is independent of frequency, the attenuation is also independent of frequency over a wide frequency range. Above about 2,000 kilocycles, however, the distributed inductance of the probe cable and the lead inductance to the larger capacitors in the multiplier give rise to resonant effects which limit the frequency range to about 2,000 kilocycles. To extend the frequency range above this value, the superheterodyne type of amplifier can be used. With the superheterodyne circuit the most suitable location for the attenuator is in the input circuit of the first i-f stage. The same type of capacitive multiplier may be employed since operation is at a fixed frequency and since the lead connections are short.

Amplifier Design

The design and construction of tuned amplifiers for v-t voltmeter use is more difficult than the design of ordinary receiver amplifiers, although basically the two amplifier types are very similar. The greater difficulty is primarily due to the need for greater stability and permanence of both the gain and frequency calibration. At the same time, the desirability of a uniform frequency response adds to the design problem. The question of uniform frequency response does not arise in tuned amplifiers which work at a fixed frequency or do not require continuous tuning over a wide range. In tuned amplifiers providing continuous coverage, however, the design should be such that the variation in gain with frequency is held to a reasonable value.

In tuned amplifiers for VTVM use, improved performance can be obtained by considering such factors as adequate shielding, individual filtering of the leads to the various tube elements, the use of self bias rather than fixed bias, the use of degeneration, and above all by using very high-quality components which tend to be unaffected by age, temperature, humidity, mechanical shock, etc. When these precautions are taken it is possible to obtain performance characteristics which add greatly to the usefulness of the tuned v-t voltmeter.

Even where extreme precautions are taken in the design of tuned v-t voltmeters, including all the preceding details mentioned as well as a voltage-regulated power supply, it is not feasible to provide the tuned v-t voltmeter with a direct voltage calibration as in the case of the other VTVM's described in this book. The reason is that there will always be residual variations which will affect the accuracy of the voltage calibration. This, however, does not seriously impair the usefulness of the tuned v-t voltmeter since it can always be accurately calibrated by means of a signal generator whenever calibration is required. Regardless of whether an absolute calibration is provided in this manner, the tuned VTVM can always be used for making relative measurements of signals with good accuracy. This latter feature is particularly important in signal tracing where the measurement of the relative signal levels at the grid and plate of a tube determine the performance of the stage.

Use As a Comparison V-T Voltmeter

The tuned v-t voltmeter can readily be used for the measurement of relative signal levels without the need for a meter and without an absolute calibration in microvolts. For example, with the basic tuned v-t voltmeter shown in Fig. 5-5, these measurements can be accomplished by means of the *mutiplier, level control,* and an electron-ray or tuning-eye *indicator tube.* In this application the multiplier indicates changes in signal level in steps of 10 to 1, while the level control may be calibrated continuously over a range of 10 to 1 so as to provide complete coverage. The function of the electron-ray indicator in this setup will be clear from the following description of the manner in which a measurement is made.

To check the gain or change in signal level between two points, for example between the control grids of two successive stages, the multiplier and level controls are adjusted so that the shadow on the electron indicator just closes. The probe is then shifted and the controls readjusted so that the shadow closes. It follows that the ratio of the two signal levels is equal to the ratio of the two attenuator settings. Note that the accuracy of the gain measurement does not depend upon the accuracy of the electron-ray indicator tube, since this serves only to establish a reference point.

Where an absolute calibration is required it can be obtained by connecting a signal generator to the tuned VTVM input. Once the sensitivity of the voltmeter is determined for one setting of the attenuation controls, the signal input for any other setting can be determined by using the indicated multiplying factor. Where the maximum accuracy is required, however, the equivalent signal input for any setting of the attenuation controls can be determined by using a calibrated signal generator. In this way the signal required to produce the same output with the same setting of the attenuation controls can be determined. For ordinary signal tracing, where this degree of accuracy is not required, it is sufficient to rely on the calibration of the multiplier and level controls.

A-F Output Connection

For signal-tracing work, it is desirable to provide the tuned v-t voltmeter with a connection to the rectifier circuit so that the waveform of the demodulated voltage can be observed. The design of the rectifier circuit is thus similar to the design of the detector circuit in a receiver, due attention being given to the capacity of the rectifier bypass capacitor so that the higher audio frequencies are not attenuated. Such an output connection is useful for checking distortion and listening to the signal so as to check the presence of noise, hum, etc.

An oscillograph may be connected across the detector output where a visual examination of the waveform is required. In this application the amplifier in the tuned v-t voltmeter greatly increases the usefulness of the oscillograph by providing radio-frequency amplification to permit its operation. Since the conventional internal oscillograph amplifier functions only up to about 300–1000 kilocycles, the oscillograph can be connected to the r-f circuit through the internal amplifier in special cases. Where the tuned amplifier is used in conjunction with an oscillograph, the input capacitance of the oscillograph is reduced from about 40 $\mu\mu$f to 1 $\mu\mu$f, the latter value being the input capacitance of the probe.

REVIEW QUESTIONS

CHAPTER 5

5–1. For what type of measurements is a tuned VTVM useful?

5–2. Why should amplifiers used before rectifiers in v-t voltmeters be of the tuned variety for measurements above 100 kc?

5–3. Why is the input capacitance a very important consideration in tuned VTVM's?

5–4. How may low input capacitances be obtained?

5–5. How may a tuned v-t voltmeter be calibrated?

CHAPTER 6

AMPLIFIER-RECTIFIER VACUUM-TUBE VOLTMETERS

In Chapter 4 the rectifier-amplifier type v-t voltmeter was described. This is probably the most popular type of VTVM due to its wide frequency response. However, its sensitivity is limited to approximately 1 volt full scale for the most sensitive range. It is often desirable to measure much smaller voltages and this can be accomplished if the signal to be measured is first amplified and then rectified to provide a current for actuating the indicating meter. At radio frequencies, and where a high degree of accuracy is not required, the tuned voltmeter described in Chapter 5 may be used. For very accurate results VTVM's using broad-band amplifiers stabilized with negative degeneration and having essentially flat response from a few cycles to a few hundred kilocycles are available. The use of cathode follower probe tubes has made possible frequency ranges up to a few megacycles.

These voltmeters have been widely used and accepted for audio frequency work and, as their upper frequency limit is extended, will become more useful at radio frequencies. The general purpose amplifier-rectifier type v-t voltmeter provides ranges from about 0.001 to 100 volts full scale. Accessory amplifiers and attenuators are often available to extend this range (often considerably) when necessary.

In special purpose v-t voltmeters for audio-frequency work the frequency range does not exceed 15,000 cycles, and usually a flat response to 10,000 cycles is adequate. This limited frequency range enables the use of a resistance-coupled amplifier by means of which a considerable increase in sensitivity can be obtained. Depending upon the number of resistance-coupled stages used, it is possible to obtain full-scale deflections for input voltages considerably lower than 100 microvolts. A number of typical audio v-t voltmeters employing resistance-coupled amplifiers will be described in this chapter.

The need for greater sensitivity is not the only requirement which has led to special v-t voltmeters designed exclusively for audio-frequency measurements. Low distortion, which is not a factor in other v-t voltmeters, is often an important factor in audio-frequency VTVM's. Frequently provision is made so that the stable amplifier which is the major part of an audio-frequency v-t voltmeter can be used as an amplifier for different applications apart from its use in the v-t voltmeter. Other requirements which are of importance in special a-f v-t voltmeters are the provision for a logarithmic scale so that a wide range of voltages can be read on the same scale without switching ranges. In applications where audio-frequency VTVM's are used as volume indicators for monitoring transmissions and recordings, etc., the speed of response (damping) of the meter is of importance. The above illustrations are sufficient to show that audio-frequency v-t voltmeters present problems which are different from those encountered in general purpose v-t voltmeters.

A Simple Audio-Frequency V-T Voltmeter

The circuit of a useful audio-frequency v-t voltmeter of simple and inexpensive design is shown in Fig. 6-1. This instrument utilizes a high-gain resistance-coupled stage employing a type 6SQ7 tube. One of the diode sections of this tube is used to rectify the output voltage, the rectified voltage being applied through an R-C filter to the control grid of a 6E5 electron-ray tube which is used as the output indicator. An attenuator and level control in the input circuit are calibrated in terms of the audio voltage required to close the shadow of the 6E5 tube. The range covered is from 0.1 volt to 100 volts. The response is essentially uniform over the frequency range from 20 cycles to 10,000 cycles.

The attenuator, which is located in the input circuit, consists of a multiplier controlled by the switch *S1* and the calibrated potentiometer *R4*. By means of the multiplier switch the input voltage can be attenuated in steps of 10 over a range from 1 to 1,000. The potentiometer *R4* permits a continuous coverage over a range of 1 to 10 on any one of the ranges selected by *S1*. In this way continuous coverage over a range from 1 to 10,000 is obtained. The signal voltages corresponding to the two extreme settings of the controls are 0.1 volt and 100 volts. To measure any voltage between these two ranges it is only necessary to note the position of the attenuator for which the shadow of the 6E5 just closes.

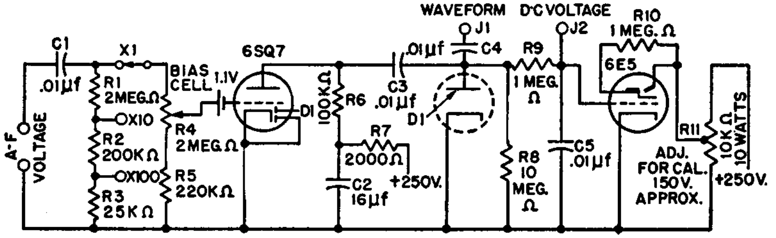

Fig. 6-1. A simple a-f v-t voltmeter using a 6SQ7 amplifier and a 6E5 electron-ray indicator. The attenuator consists of a decade voltage divider and a potentiometer in the input circuit.

Provision is made in the output of the rectifier circuit so that the rectified voltage can be measured by means of an electronic or d-c v-t voltmeter (see Chapter 8). Where this voltage is measured by means of a voltmeter connected to the jack *J2,* the lower limit of 0.1 volt can be extended to about 0.02 volt, since the d-c v-t voltmeter is capable of reading voltages smaller than the voltage required to close the shadow of the 6E5.

The potentiometer *R4* which is calibrated over a range from 1 to 10 should have an "audio" taper. In practice it is not possible to obtain these potentiometers with a resistance tolerance greater than about 15 per cent. For this reason, where the greatest accuracy is desired, the value of *R5* should be adjusted so that it has a resistance equal to $1/9$ the resistance of *R4*. This value will be approximately 220,000 ohms, as indicated in the schematic. When *R5* has the proper value, only $1/10$ of the input voltage will reach the grid when the control is rotated counterclockwise, because *R5* is then $1/10$ of the total resistance.

With the constants shown in the figure, about 0.1 volt rms is required to just close the shadow of the 6E5. There will be some variation from this value, however, as a result of individual differences in tube characteristics and circuit constants. If the greatest accuracy is desired, the target voltage of the 6E5 tube can be either increased or decreased from the specified value of 150 volts. The procedure for making this adjustment is to apply a known a-f voltage of exactly 0.1 volt (see Chapter 9) and to adjust the target voltage until the shadow just closes. The extent of the control which can be obtained by varying the target voltage is evident from the following data for the 6E5 tube. At 100 volts on the target, a negative voltage of 3.3 volts is required to close the shadow, while at a target voltage of 200 volts a negative voltage of 6.5 volts is required to close the shadow. Thus the target voltage should be reduced if the shadow does not close with an applied signal of 0.1 volt; similarly, it should be raised if the shadow overlaps with 0.1 volt applied.

Provision is made in the circuit so that the audio v-t voltmeter can be used as an amplifier. This is done by bringing out a connection from the output circuit by means of the jack *J1*. This connection is useful when it is desired to listen to the signal as in signal tracing, or when it is desired to feed the signal to an oscillograph for waveform examination. To prevent distortion of the positive peaks of the output voltage, a high value of load resistance is used in the diode rectifier circuit. Thus the 10-megohm load resistor *R8* limits the diode current so that the loading effect on the positive peaks (where the diode draws current) is negligible.

It is desirable to provide the 1 to 10 level control *R4* with a direct-reading scale so that the instrument will be direct reading in terms of the voltage required to close the shadow of the 6E5. This calibration can be accomplished by feeding voltages ranging from 1 volt to 10 volts into the input circuit, with the multiplier set at *X10*. By successively setting the control *R4* so as to close the shadow with 2 volts input, then with 3 volts input, etc., the necessary calibration marks can be obtained. Before this calibration is made, *R5* should be adjusted so that a 1 to 10 range is covered as previously explained. If the range is greater than 1 to 10, then *R5* is too small; if the range is less than 1 to 10, then *R5* is too large.

The use of the 6E5 electron-indicator tube contributes considerably to the simplicity, ease of operation, and low cost of this a-f v-t voltmeter. Since the only effect of an overload is to cause the shadow of the 6E5 tube to overlap, it is impossible to damage the instrument. This is an important advantage in a-f work, where the wide range of voltage encountered and stray pick-up cause frequent overloading.

Although no meters are used, the accuracy is adequate for all servicing needs and for many design purposes. This is especially true when the instrument is properly calibrated by adjustment of the target voltage and by use of the proper value of *R5*. Where greater accuracy is required, the instrument can always be calibrated at 60 cycles against the ordinary low-impedance copper-oxide rectifier or iron-vane type of a-c meter, as explained in Chapter 11.

The power supply used for this VTVM should preferably have some provision for adjusting the target voltage of the 6E5 so that the shadow will just close when a 0.1-volt signal is applied to the input. A suitable arrangement is shown in the figure where a 10-watt, 10,000-ohm resistor with a sliding adjustable contact is used to supply the target voltage. A conventional power supply can be used to supply the required 250 volts and the heater voltage for the 6E5 and 6SQ7. A bias cell is used to provide the necessary bias so that one of the diode sections of the 6SQ7 can be used as the rectifier.

It is convenient to use a shielded cable and probe in the input circuit so as to simplify connecting to the circuit under test. Several feet of low-capacity shielded cable fitted with a probe can be used without raising the input capacitance to a point where it is excessive for the usual run of audio-frequency measurements. For special applications, where the lowest possible input capacitance is desired, the triode type of amplifier tube should be replaced with a pentode, since the pentode stage of amplification has a lower input capacitance. This lower input capacitance of the pentode amplifier is due to the action of the screen which prevents reflection of capacitance to the input from the plate circuit. Where a pentode amplifier is used, the operating conditions should be the same as for any resistance-coupled pentode stage. A suitable tube type is the 6J7 or its equivalent.

A High-Sensitivity Audio-Frequency V-T Voltmeter

For some audio-frequency measurements, it is necessary to deal with voltages which are considerably smaller than 0.1 volt. A sensitive audio-frequency VTVM suitable for the measurement of microphone levels and for the measurement of signal voltages in the first stages of high-gain amplifiers is shown in Fig. 6-2. This instrument employs a stable three-stage resistance-coupled amplifier which requires only a 100-microvolt signal to close the 6E5 shadow.

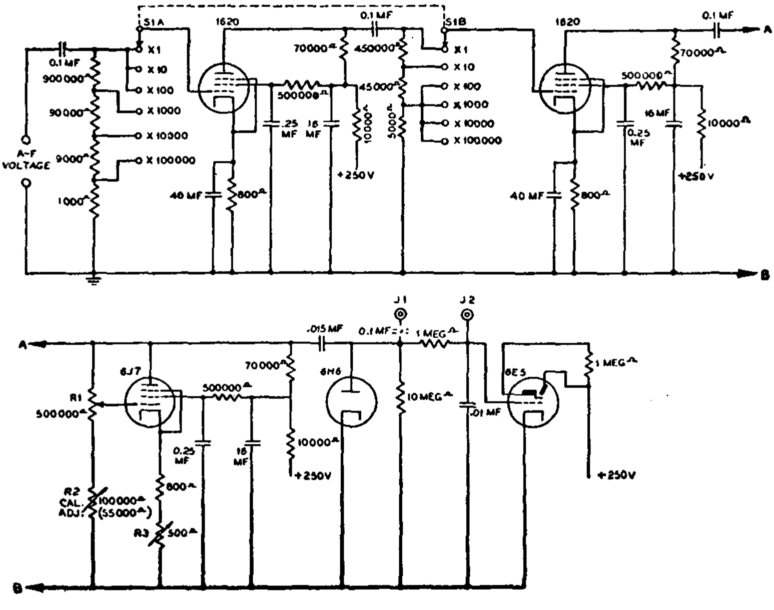

Fig. 6-2. A high sensitivity a-f v-t voltmeter using three stages of resistance-coupled amplification. An input signal of 100 microvolts is sufficient to close the shadow of the 6E5 electron ray indicator.

An attenuator is provided so that stage-gain measurements can be made and so that voltages up to 100 volts can be measured. If desired, this attenuator may also be calibrated in decibels. The use of the 6E5 reference-level indicator in the output circuit has the advantage that overload will not cause any damage. This is particularly important in a high-gain amplifier where even a slight amount of stray pickup or accidental contact will cause a heavy overload. Although a meter indicator is not used, quantitative voltage measurements can readily be made by means of the attenuator switch *S1* which gives voltage ratios of 10, and the input potentiometer which is continuously calibrated to cover the range from 1 to 10. With the potentiometer set at 1, and the multiplier switch at 1, the input signal required to close the 6E5 shadow is 100 microvolts. Any other input voltage can be determined by noting the setting of the two input controls. For example, if the multiplier switch setting is *X100* and the level control setting is 2.6, then the input voltage is 100 × 2.6 × 100 microvolts, or 0.026 volt. In the same way, any other voltage can be measured by merely setting the attenuator controls so as to close the shadow of the 6E5.

The frequency range is essentially flat over the range from 20 cycles to 10,000 cycles. At 20 cycles the output is down less than 15 per cent, while at 10,000 cycles the output is down less than 10 per cent. In terms of decibels, the output is flat within less than 1.2 db over the frequency range from 20 cycles to 10,000 cycles. This frequency range is secured by using relatively small values of load resistance in the several stages so as to prevent a reduction in the high-frequency response. At the same time the low-frequency response is kept up by using large coupling capacitors and grid resistors. Filtering of the plate and screen circuits of each stage, as well as separate self-biasing of each stage, contributes considerably to the over-all stability of the amplifier.

The step attenuation is secured by means of a two-section switch in the input circuit to the first and second stages of the amplifier. Only on the most sensitive range (100 microvolts to close the shadow) is the maximum gain of the amplifier utilized. On the less sensitive ranges, the switch sections in the input circuit of the first and second tubes reduce the signal which reaches the output indicator. In this manner an attenuation of 100,000 to 1 is secured by means of the six-position switch *S1*.

The range of 1 to 10 is covered by means of the 500,000-ohm calibrated potentiometer *R1* in the input circuit to the final amplifier stage. The 100,000-ohm control *R2* in series with *R1* makes it possible to compensate for variations in the resistance of *R1* due to commercial tolerances. The range of 1 to 10 will be covered when *R2* is adjusted to about 55,000 ohms; more accurately its value should be $\frac{1}{9}$ the resistance of *R1*. The potentiometer *R1* may be calibrated by the procedure described previously in connection with the v-t voltmeter shown in Fig. 6-1.

Because of variations in tube characteristics and resistors, the over-all sensitivity of the amplifier will vary somewhat from the 100-microvolt value to close the shadow of the 6E5 indicator tube. To compensate for these initial variations, a variable control *R3* is provided in the cathode circuit of the last a-f stage. To adjust this control the attenuator switches should be set in the position for which a 1-volt signal would normally close the shadow. With the known 1-volt signal applied to the input (multiplier switch in the *X1000* position and *R1* in the *1* position), it will be found that the shadow will either overlap slightly or else will not quite close completely. The proper adjustment of the sensitivity control is secured by rotating *R3* until the shadow just closes. When this adjustment is made, the sensitivity of the amplifier will be exactly 100 microvolts to close the shadow and any value of signal up to 100 volts can be determined by noting the setting of the multiplier switch and potentiometer as previously explained.

Provision is made in the output circuit for connecting phones or an oscillograph by means of the jack *J1*. By means of a second jack *J2,* a d-c v-t voltmeter can be connected so as to measure the d-c voltage developed by the rectifier. Although this meter connection is not required ordinarily, it is useful in special applications. For example, by means of this jack it is possible to measure voltages smaller than 100 microvolts by noting the rectified voltage at the 6E5 grid.

A Video Amplifier V-T Voltmeter

A very useful VTVM can be made by adding a diode rectifier and d-c v-t voltmeter to a broad-band amplifier similar to those which are used in the vertical amplifier channels of oscillographs designed for television applications. This type of amplifier is also similar to the video amplifier of a television receiver. Since such amplifiers can be designed to cover a frequency range from several cycles up to about 3 or 4 megacycles, the addition of a rectifier to such an amplifier makes a sensitive amplifier type of v-t voltmeter which is capable of covering the same frequency range. Because the number of stages required for a given gain increases rapidly as the upper frequency limit is increased, it is not practicable to extend the frequency limit beyond several megacycles for all except very special applications.

To illustrate this type of VTVM, we show in Fig. 6-3 the schematic of the vertical deflection amplifier used in the RCA Type 158 Television Oscillograph. This amplifier is designed to be used for making measurements on television receivers, particularly in the video, deflection, and synchronizing circuits of such receivers. As used in the oscillograph, a deflection sensitivity of about 0.4 volt-per-inch is provided, this value being obtained when a special shielded cable and probe having an input capacitance of only 8 μμf is used. When the input connection is made directly to the amplifier grid, the deflection sensitivity is approximately ten times as great or about 0.04 volt-per-inch. The input capacitance for this connection, however, is about 50 μμf so that the increased gain is offset by the higher input capacitance.

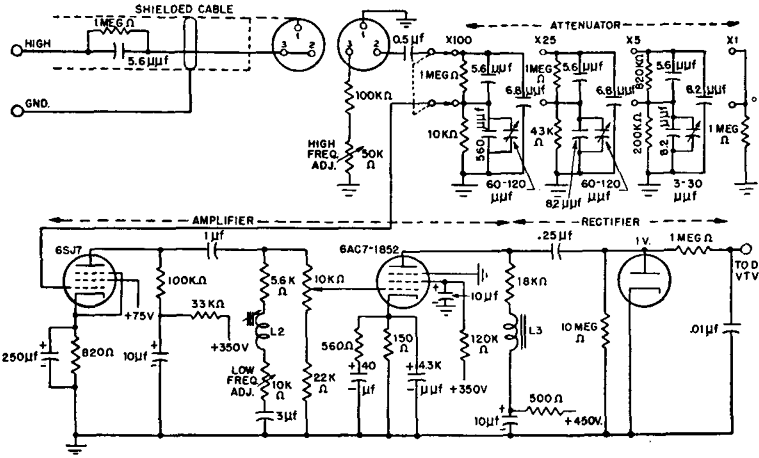

Fig. 6-3. A diode rectifier and d-c v-t voltmeter have been added to the vertical deflection amplifier used in the RCA Type 158 oscillograph, to enable its use as a sensitive a-c v-t voltmeter.

The rectifier circuit which has been added to this amplifier is shown. The addition of this rectifier circuit, in combination with a d-c v-t voltmeter to measure the rectified voltage, extends the usefulness of the amplifier by making it possible to measure smaller voltages than can be measured by observing the height of the wave on the oscillograph screen. Even for larger voltages its indication is more easily read so that the need for measuring the height of the pattern is eliminated.

The amplifier shown in Fig. 6-3 appears rather complex because of the care which has been taken to obtain a uniform frequency response and a minimum amount of phase distortion. This is accomplished by using unusually low values of load impedance and by incorporating high-frequency and low-frequency compensating circuits to keep the gain constant and reduce the phase distortion. The amplifier shown in Fig. 6-3 has a frequency response which is essentially constant over the range from 5 cycles to 500,000 cycles (500 kc). Over this range the phase shift is negligible, although this is of greater concern when the instrument is used as an oscillograph amplifier than when it is used as a v-t voltmeter amplifier. Since the rectifier circuit responds to the peak value, the VTVM is also of the peak type.

The relative complexity of the input circuit is due to the problem of obtaining uniform response and attenuation over the wide frequency range covered. To reduce the input capacitance of the amplifier, a special low-capacitance shielded probe is used. This probe contains an isolating capacitor and resistor which blocks off the capacitance of the cable and of the amplifier input circuit, so that the effective input capacitance is only about 8 $\mu\mu$f. However, this reduction in the input capacitance is not accomplished without a corresponding reduction in the sensitivity. Thus the capacitance of the cable and input circuit is about 50 $\mu\mu$f, so that a loss of about 10 results from the use of the 5.6 $\mu\mu$f isolating capacitor at the end of the shielded cable. To obtain the same voltage division at low frequencies, the 5.6 $\mu\mu$f input capacitor is shunted by a 1-megohm resistor and the grid-ground circuit is likewise shunted by a resistor.

The attenuator consists of a double-pole switch which selects any one of four different attenuation ratios. Each of the attenuation factors is secured by tapping across a compensated voltage divider in which both a resistance and capacitance balance is present. Because both the resistance and capacitance ratio of each of the two elements is the same, uniform attenuation is secured over the entire frequency range. To compensate for variations in the capacitance of the components and for variations in stray capacitance, a trimmer capacitor is incorporated in shunt with the lower section of the voltage divider so that the capacitance ratio between the upper and lower sections of the voltage divider is the same as the resistance ratio between the upper and lower sections of the voltage divider. Four positions of attenuation are shown, the respective attenuation factors being 1, 5, 25, and 100.

The gain of the amplifier itself is approximately 450. Since there is a loss of about 10 in the input circuit because of the isolating capacitor and resistor, it follows that the effective amplification is about 45. The rectifier produces approximately the peak voltage of the signal, so that a 1-volt input signal will produce about 45 × 1.41 or about 63 d-c volts of rectified voltage at the output of the diode rectifier. An input signal of 0.01 volt rms will produce approximately $\frac{1}{100}$ of this d-c voltage or about 0.6 volt. Actually the d-c voltage will be less than this, since the efficiency of the diode rectifier is somewhat lower for values of a-c voltage less than 1 volt.

The increased sensitivity which results from the addition of the rectifier circuit is at once apparent. Whereas an input signal of 0.01 volt will produce a deflection of less than $\frac{1}{32}$ inch, the rectifier arrangement will give a reading of approximately 0.6 volt. The latter value is easily readable on a d-c v-t voltmeter whereas the corresponding deflection on the screen of the cathode-ray tube is about the same as the width of the trace and hence not measureable.

Where a cathode-ray oscillograph having an internal wide-band amplifier is available, the usefulness of the instrument can be extended by the addition of a rectifier tube and filter, as shown in Fig. 6-3. Usually there is ample space inside the oscillograph so that a rectifier tube can be installed near the final amplifier tube. Because of the negligible loading effect of the diode rectifier (a load resistance of 10 megohms is used) the rectifier can be left permanently connected to the output circuit. A jack can be brought out to the front panel of the oscillograph so that a d-c VTVM can be connected to measure the rectified output voltage.

As far as the calibration is concerned, it is sufficient to calibrate the reading of the d-c v-t voltmeter in terms of the input voltage with the attenuator control set in the *X1* position and with the input potentiometer set for maximum gain. Once this calibration is made, the unknown voltage for any one of the other ranges can be determined by using the indicated multiplying factor. Where the greatest accuracy is desired, the instrument should be used as a comparison v-t voltmeter, and the unknown voltage determined by noting the value of 60-cycle voltage required to produce the same output. This procedure is explained in detail in Chapter 11. Also see peak-to-peak television vacuum-tube voltmeter in Chapter 13.

Logarithmic V-T Voltmeters

A number of special applications of v-t voltmeters require a *logarithmic* type of response which is different from the linear or square-law response characteristic of the v-t voltmeters previously described. The logarithmic v-t voltmeter is particularly useful because it enables readings to be taken with the same degree of accuracy at any point on the scale, and because with proper design it is possible to cover an extremely wide range on the same scale without switching.

Logarithmic v-t voltmeters are used for the most part in applications where a wide range of voltages must be covered. A typical example of such an application is in the measurement of the field intensities of radio signals where values from several microvolts to several volts may be encountered. In automatic recording set-ups where it is not possible to change the range as the signal fluctuates, a logarithmic type of response is particularly valuable. Another illustration of the application of logarithmic v-t voltmeters is in volume indicators where the voltage under measurement also varies over a wide range. In monitoring the modulation of a transmitter, for example, the volume indicator must be capable of showing when the audio voltage is so *strong* that it will cause overmodulation, and at the same time it must also be sensitive enough to indicate audio voltages which are so *weak* that the modulation will not override the noise background. In sound measurements of all types the logarithmic v-t voltmeter is especially useful because the instrument has the same type of response as the ear. Just as the response of the ear depends only on the *percentage* change in the sound level, so the response (change in deflection) of the logarithmic v-t voltmeter depends only on the *percentage* change in the input voltage.

Comparison of Linear and Logarithmic Scale

The difference between the ordinary linear and the logarithmic scale is illustrated in Fig. 6-4. At first glance the logarithmic type of scale at (b) may tend to appear inferior to the linear scale at (a) because the logarithmic scale is not uniform. This non-uniformity, however, has the advantage of spreading out the lower portion of the scale so that readings can be taken more accurately than with a linear type of scale. In this respect the logarithmic scale is the opposite of the square-law scale in which the lower portion of the scale is crowded as shown in Fig. 3-8.

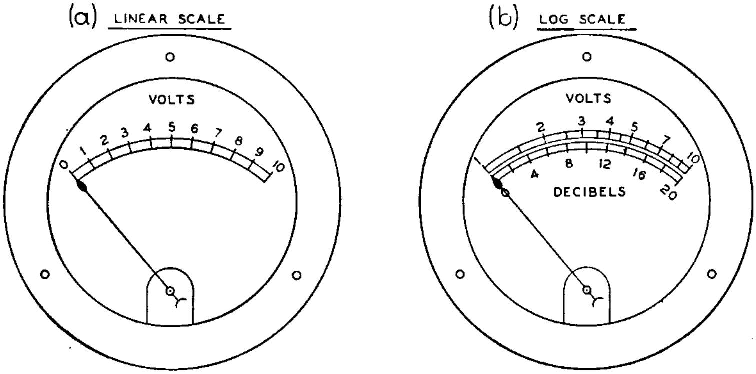

Fig. 6-4. A comparison of the linear and logarithmic scales shows that the logarithmic scale makes possible much greater accuracy of reading over the lower portion of the scale.

The following explanation shows how the logarithmic scale makes possible the same percentage accuracy of reading over the entire scale. Referring to Fig. 6-4b let us suppose first that a 1-volt signal is being measured and that this voltage changes by 100 per cent or by 1 volt; note the deflection which this change gives on the logarithmic scale at (b). Now suppose that a 5-volt signal is being measured and that this voltage changes by 100 per cent or by 5 volts. Note that a change in voltage from 5 volts to 10 volts gives just as much of a change in the deflection as a change in voltage from 1 volt to 2 volts. In each case the change in input voltage is 100 per cent and this 100 per cent variation produces exactly the same change in the deflection.

By way of comparison, it is worth noting that on the linear scale at (a) the change from 1 volt to 2 volts gives only ⅕ of the change in deflection which is obtained for the same 100 per cent change from 5 volts to 10 volts. Thus the accuracy of reading is considerably smaller at low values on a linear scale. On a square-law scale, the accuracy of reading over the lower portion of the scale is even considerably poorer than for the linear scale.

A logarithmic scale such as is shown in Fig. 6-4b has many applications other than in v-t voltmeters. For example, logarithmic potentiometers are often used in Wheatstone bridges to obtain a logarithmic calibration so that the same accuracy of reading can be obtained for the small and large values of any range. Similarly, a logarithmic frequency scale is often used in audio oscillators so that low frequencies can be read with the same degree of accuracy as the higher frequencies. In general a great many phenomena in nature are characterized by a logarithmic response and so it is not surprising that logarithmic meters and scales should find a wide application for measuring these phenomena.

Linear Decibel Scale

If a logarithmic scale is calibrated in terms of decibels, a linear decibel calibration is obtained. Remembering that a decibel represents a fixed percentage change in the level (1 db represents a voltage change of about 12 per cent), a logarithmic scale calibrated in terms of decibels or db will be linear because equal percentage changes occupy the same amount of space throughout the entire length of the scale. This is illustrated in Fig. 6-4b in which a logarithmic scale is shown calibrated in decibels, the decibel calibration appearing underneath the voltage calibration. Note that a change from 1 to 2 volts, a voltage ratio of 2, corresponds to 6 db above the 1-volt reference level. Similarly a change in voltage from 2 volts to 4 volts, from 3 volts to 6 volts, etc.,—all these voltage ratios of 2 to 1 (a 100 per cent change) are represented on the decibel scale by an increase of 6 db.

Wide Range of Logarithmic Scale

In the previous section we indicated the manner in which a logarithmic scale makes possible the same degree of accuracy over the entire scale. In addition to this advantage, the logarithmic scale makes it possible to measure a wider range of voltages on a single scale without switching ranges. To illustrate this point we have shown in Fig. 6-5 a typical logarithmic scale which covers from 0.01 volt to 10 volts on the same range. Throughout this range of 1000 to 1 it is possible to read the scale with the same degree of accuracy. For example, a change in voltage from 0.01 volt to 0.02 volt produces exactly the same change in deflection as a change from 0.1 volt to 0.2 volt, or from 4 volts to 8 volts, etc. The great advantage of the logarithmic scale in providing a wider range can be realized at once by comparing this scale with a linear scale having the same full-scale value. Thus on a linear 10-volt scale a deflection of 0.1 volt would give only $\frac{1}{100}$ of full-scale deflection. With the logarithmic scale in Fig. 6-5, however, the same 0.1-volt signal gives a deflection of $\frac{1}{3}$ of full scale!

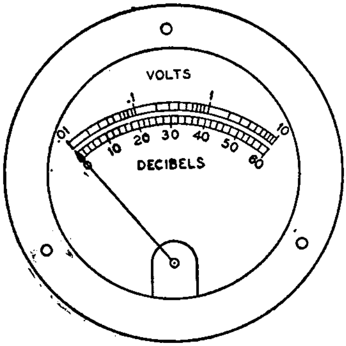

Fig. 6-5. A logarithmic scale covering a range of 1000 to 1. Over this entire range the same accuracy of reading can be obtained at every point.

Both the scales shown in Fig. 6-4b and in Fig. 6-5 are logarithmic scales. The scale in Fig. 6-4b, however, covers a range of 10 to 1, whereas the scale in Fig. 6-5 covers a range of 1000 to 1. It is possible to design logarithmic v-t voltmeters so that any given range can be covered. For special purposes a ratio as wide as 100,000 to 1 can be covered in a single range. Usually, however, logarithmic v-t voltmeters have a useful range of about 10 to 1 (20 db) or about 0 to 1 (26 db). Of course the actual range of the v-t voltmeter can be made much larger than the scale range by using an attenuator or multiplier in the input to the v-t voltmeter. This practice is usually followed.

Types of Logarithmic V-T Voltmeters

Three basically different types of logarithmic v-t voltmeters are described in the following sections of this chapter. The first of these types depends for its logarithmic response upon the use of a special type of d-c milliammeter in which a non-uniform air gap is used. In the second type of logarithmic v-t voltmeter described, the logarithmic response is obtained by using an automatic-gain-control circuit similar to the automatic-volume-control (avc) circuit used in radio receivers. Because of the logarithmic characteristic of the variable-mu tubes used in the controlled amplifier, this circuit makes it possible to obtain a logarithmic response over a wide range of input voltages. The third type of logarithmic VTVM also depends upon the logarithmic characteristic of the variable-mu tube, but here the logarithmic response is secured by a special amplifier-rectifier circuit which will be described in detail.

Logarithmic Milliammeter

The conventional ammeter has a *uniform* air gap between the pole pieces (Fig. 6-6a) so that its response is directly proportional to the current through the moving coil. By using shaped pole pieces so that the air gap varies with the position of the moving coil (Fig. 6-6b), however, it is possible to make the deflection proportional to the logarithm of the current through the moving coil. When such

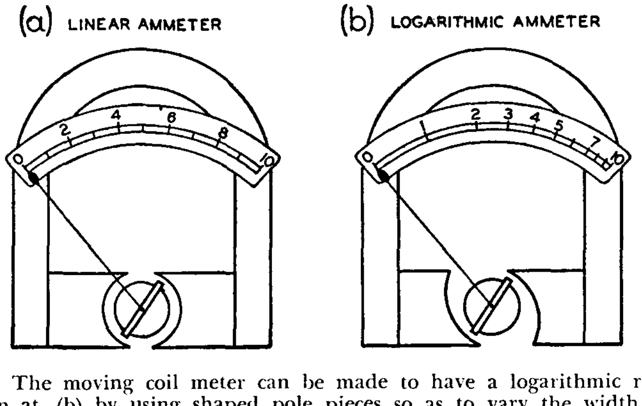

Fig. 6-6. The moving coil meter can be made to have a logarithmic response as shown at (b) by using shaped pole pieces so as to vary the width of the air gap continuously.

a logarithmic milliammeter is used with an ordinary linear v-t voltmeter, it follows that the over-all response of the VTVM becomes logarithmic.

The action of the logarithmic milliammeter can be understood readily from the following description. When the current through the meter is small, the moving coil is in a relatively strong magnetic field because of the close spacing between the pole pieces. For this condition the sensitivity of the meter is relatively high. As the current through the meter increases, the coil rotates so that it is located in a weaker and weaker magnetic field and thus the sensitivity is progressively reduced. By properly shaping the pole pieces so that a logarithmic variation in the magnetic field is obtained, the scale deflection can be made to follow a logarithmic variation similar to that shown in Fig. 6-4b.

With the logarithmic type of meter the first 10 per cent or so of the scale is usually not calibrated since a logarithmic or decibel scale begins with some fixed reference value of current or voltage. In some meters of this type, however, a "suppressed zero" type of construction is used. The term suppressed zero means that with no current through the meter the control springs are positioned so that the pointer presses against the left stop. Before the pointer will reach the first division on the scale, an appreciable amount of current must flow through the moving coil. When a suppressed zero is used, the first division (which is normally zero) thus corresponds to a fixed value of current so that the entire scale can be utilized for the logarithmic calibration.

The logarithmic type of d-c milliammeter using shaped pole pieces requires a higher value of current for full-scale deflection than the conventional meter which has a uniform air gap. This reduced full-scale sensitivity is due to the sacrifice in sensitivity over the upper portion of the scale required in order to obtain a logarithmic response.[1]

Because the scale of a logarithmic milliammeter is linear when a decibel calibration is used, such meters are very often called *decibel* meters. The meters, however, should not be confused with the conventional decibel meter which has a uniform air gap and a *non-linear* decibel scale.

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[1] For further information see F. H. Best, "Decibel Meters," *Bell Laboratories Record,* vol. 15, p. 167, Jan. 1937.

Logarithmic V-T Voltmeter Using a Logarithmic Milliammeter

The logarithmic type of d-c milliammeter described in the preceding section can be used to simplify the construction of a logarithmic v-t voltmeter. As Fig. 6-7 shows, the circuit is generally similar to the audio v-t voltmeters previously described, the essential difference being that the present circuit employs a logarithmic type of milliammeter. This substitution of the logarithmic milliammeter for the usual linear milliammeter makes the over-all output logarithmic, although the other elements in the v-t voltmeter are linear.

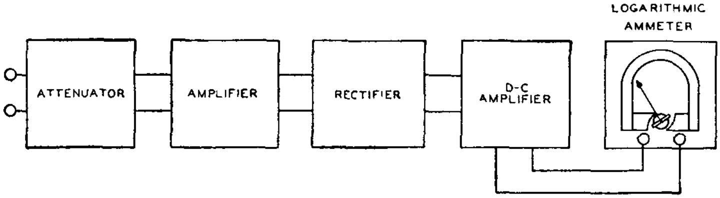

Fig. 6-7. Block diagram showing the structure of a logarithmic v-t voltmeter which employs the logarithmic type of milliameter shown in Fig. 6-6b.

Logarithmic milliammeters with shaped pole pieces are not usually stocked by meter manufacturers. As a general rule their use is limited to instrument manufacturers who can order a large enough quantity of meters of any one type to make it economical to manufacture a special meter. The logarithmic milliammeter is being used in the General Radio Type 759-A Sound Level Meter and in the Ballantine Model 300-A V-T Voltmeter. The former of these instruments uses a circuit basically similar to that shown in Fig. 6-7, while the latter instrument uses a degenerative amplifier in which the meter is located in a combination feedback-rectifier circuit.[2] Both of these instruments use an attenuator in the input circuit to extend the range covered on the logarithmic meter scale.

Controlled-Amplifier Logarithmic V-T Voltmeter

The logarithmic characteristic of variable-mu tubes (78, 6K7, etc.) has been utilized in the design of logarithmic v-t voltmeters.[3]

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[2] S. Ballantine, "Electronic Voltmeter Using Feedback," *Electronics,* vol. 11, p. 33, Sept. 1938.

[3] S. Ballantine, "Variable-Mu Tetrodes in Logarithmic Recording," *Electronics,* vol. 2, p. 472, Jan. 1931.

Fig. 6-8 shows the basic circuit of this type of logarithmic v-t voltmeter in which the gain of the amplifier is controlled by a circuit similar to that used for obtaining automatic volume control in radio receivers. With this circuit, a voltmeter connected so as to measure the rectified control voltage gives a reading which is proportional to the logarithm of the input voltage.

The means by which this circuit produces a logarithmic response can readily be seen by comparing the action to that when no control circuit is used. With no control circuit, the voltmeter reading would be proportional to the input signal. When the control circuit is used, however, the gain of the amplifier is reduced progressively as the input signal is increased. This method of obtaining a reduction in sensitivity for higher input voltages may be compared with the logarithmic milliammeter method where the reduced sensitivity for large currents is obtained by increasing the air gap.

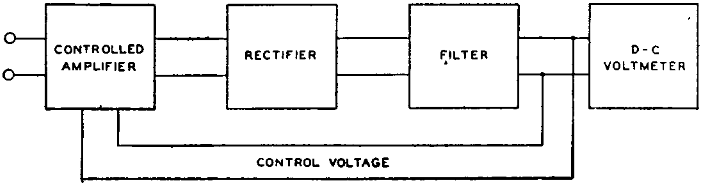
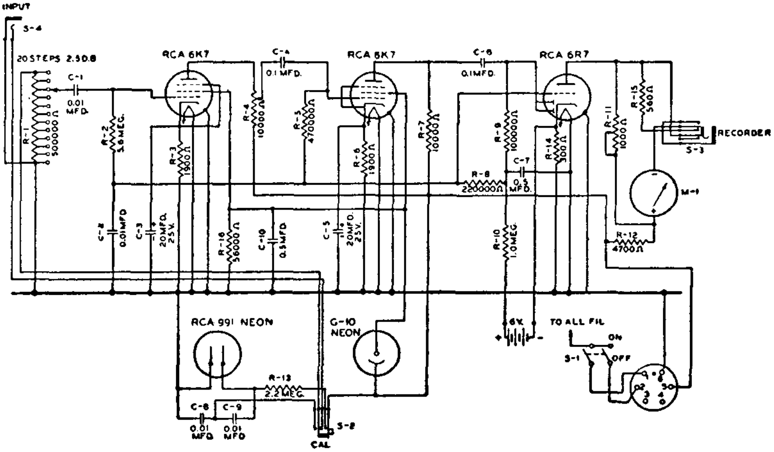


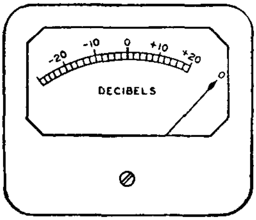
Fig. 6-8. A logarithmic response is obtained by controlling the gain of the variable-mu tubes in the amplifier section. The output is indicated by the d-c voltmeter used to measure the control voltage.

The above explanation merely shows qualitatively that the necessary compression of the scale for the higher values of input voltage is secured by an automatic-gain-control circuit. It does not follow from the above description that the scale distribution will be exactly logarithmic. A mathematical analysis, however, shows that when variable-mu tubes are employed in the amplifier, the rectified voltage will be closely proportional to the logarithm of the input voltage. The range covered depends upon the number of stages which are controlled, and increases very rapidly as the number of stages is increased.

Since the rectified voltage which provides the output indication is a high-impedance circuit, it is general practice to use a linear d-c v-t voltmeter to measure the control voltage and indicate the output. This usually consists of a single triode stage with a d-c milliammeter in the plate circuit. A typical arrangement will be shown in the following commercial circuit which is illustrative of the controlled-amplifier type of logarithmic v-t voltmeter.



Above Fig. 6-9. A controlled-amplifier logarithmic v-t voltmeter using two variable-mu tubes.



Right Fig. 6-10. The appearance of the meter scale used with the circuit shown in Fig. 6-9.

Courtesy RCA Mfg. Co., Inc.

An example of the controlled-amplifier logarithmic v-t voltmeter is shown schematically in Fig. 6-9. This is the circuit of the RCA Type 302-A logarithmic VTVM. This instrument is also designated as a noise meter since it was designed specifically for measuring noise levels. Basically the instrument consists of (1) a calibrated attenuator in the input circuit, (2) two stages of resistance-coupled amplification employing variable-mu tubes, (3) a diode rectifier, and (4) a d-c amplifier. The rectified voltage produced across the diode load resistor *R10* is filtered and applied to control the gain of the two amplifier stages. At the same time this control voltage is applied to the grid of the 6R7 so as to vary its plate current. The logarithmic output indication appears on the scale of a 5-milliampere meter in the plate circuit of the 6R7. Provision is made in the output circuit so that a recorder can be operated for recording signal or noise levels.

Since the plate current of the triode is greatest when no signal is applied to the input, the meter used is of the type in which the pointer is normally at the extreme right of the scale. With no signal applied to the input, the plate current is a maximum since there is no negative control voltage produced by the rectifier. Thus the weakest input voltage is indicated by the pointer swinging toward the extreme *left* of the scale. As the input signal is increased, the rectified voltage increases so that the pointer deflects up the scale toward the right. As shown in Fig. 6-10, the scale is calibrated over a range of 40 decibels, from −20 db to +20 db. The zero reference level is taken as 1 milliwatt into 600 ohms, which corresponds to 0.775 volt across a 600-ohm resistor. Any decibel reading on the scale can, of course, be interpreted in terms of the input voltage by means of a standard decibel–voltage ratio conversion table.

By means of the attenuator in the input circuit a total range of 85 decibels can be covered. Of this range, 40 db is covered by means of the calibrated meter scale, while an additional range of 45 db is covered by means of the input attenuator which is calibrated in steps of 0.5 db. In terms of input voltage, this range of 85 db corresponds to a voltage range extending from 0.044 volt (−25 db) to 775 volts (+60 db). In addition to increasing the range, the attenuator makes it possible to check the calibration accuracy of the meter scale. The procedure for making this check is described in Chapter 8.

Two adjustments are provided which take care of variations in tube characteristics and circuit components. Referring to the schematic in Fig. 6-9, these are the adjustments *R4* and *R11*. The potentiometer *R4* is used to control the gain so that 0.044 volt will read 0 db on the meter scale. The adjustable resistor *R11* in shunt with the meter is used either to expand or contract the scale so that the meter calibration will be accurate. There is some interaction between these adjustments so that if one requires to be changed appreciably, the other one will also have to be reset.

A simple neon-tube oscillator using a 991 tube is incorporated in the instrument so as to provide an input signal for checking the accuracy of the scale calibration against the calibrated input attenuator.

An Amplifier-Rectifier Type Logarithmic V-T Voltmeter

The v-t voltmeter circuit shown in Fig. 6-11a at first glance appears to be an ordinary linear amplifier-rectifier type of VTVM such as was discussed in connection with audio v-t voltmeters. Actually, however, this type of circuit can be designed to have a logarithmic response, provided that a variable-mu pentode tube is used with the proper operating conditions.[4]

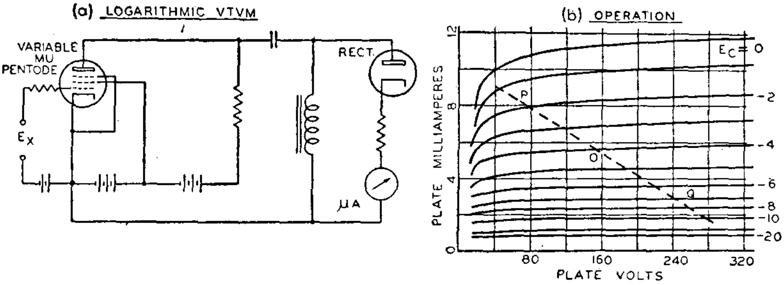


Fig. 6-11. The circuit and operation of a logarithmic type of v-t voltmeter.

The operation of this circuit is as follows. When a signal is applied to the input, the grid of the tube is swung alternately positive and negative. On the positive half of the grid swing, the plate voltage decreases below the normal operating point *O* in Fig. 6-11b toward *P*. On the negative half of the grid swing, however, the plate voltage increases toward *Q* because the more negative bias decreases the plate current which in turn causes the plate voltage to rise. Line *POQ* is essentially a load line which

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[4] F. V. Hunt, "A Vacuum-Tube Voltmeter with Logarithmic Response," *Review of Scientific Instruments*, vol. 4, p. 672, Dec. 1933.

shows how the plate voltage varies as the grid voltage is varied. The slope of this line depends upon the plate load resistance.

The positive grid swing can be ignored completely in the operation of this circuit, since the alternating voltage transferred to the diode as a result of the positive grid swing is negative and thus it will cause no rectified current to flow, and hence will not affect the reading of the microammeter. The negative grid swing, however, causes a positive voltage to be applied to the shunt diode circuit and hence causes the diode to draw current through the microammeter.

The logarithmic response of the rectified current is a result of the compression which takes place because of the logarithmic characteristic of the variable-mu tube. In this connection note that the reduction in plate current (and increase in plate voltage) for each succeeding volt decrease in grid voltage becomes progressively smaller as the grid voltage decreases. For example, the decrease in plate current caused by a 10-volt change in grid voltage from 15 to 25 volts is even less than the change in plate current caused by a change of only 1 volt from 7 volts to 8 volts. The compression effect is even greater than appears in the figure because of the loading effect of the diode. Provided the operating conditions are suitably chosen, the response of a single stage such as is shown in Fig. 6-11a can be made logarithmic over a range from about 3 db to about 15 db, the reference level being 1 volt. This corresponds to a voltage range from approximately 1.4 volts to 6.0 volts. Since no filter circuits are used, the response of this circuit to changes in the input voltage is extremely rapid.

A logarithmic response over a wider range of input voltages can be obtained by using two or more stages similar to Fig. 6-11a; a two-stage circuit is shown in Fig. 6-12. The reason for the wider logarithmic response with two stages can be seen from the following explanation. When two stages are used, the signal is amplified in each stage so that diode *D2*, which rectifies the output of the second stage, will start to draw current first. The response of this diode will be logarithmic up to a certain point, beyond which it tends to saturate so that no further increase in current is obtained. Before saturation of diode *D2* is reached, however, the signal level at the output of the first stage is strong enough so that diode *D1* begins to rectify and carry on where the diode *D2* left off. The result is a considerable extension of the range over which a logarithmic response is obtained. Using type 39 tubes and the constants shown in the figure, a logarithmic response can be obtained over a range from about −30 db to +20 db, using 1 volt as the reference level. In terms of voltage, the response is logarithmic over the range from about 0.03 volt to 10 volts. Similar performance can be expected using variable-mu tubes of the 6K7, 1T4, etc. types.

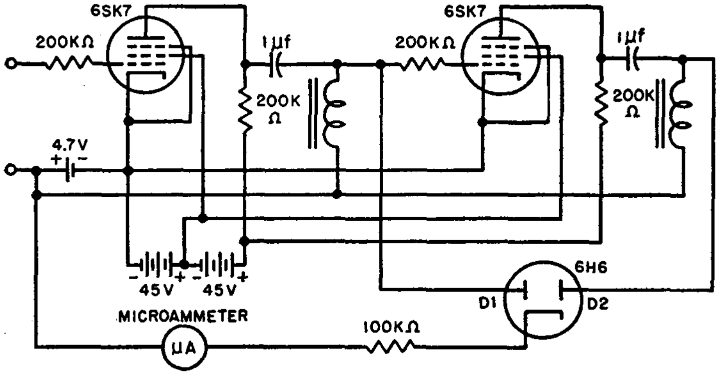

Fig. 6-12. A two stage logarithmic v-t voltmeter using the basic circuit shown in Fig. 6-11.

By using three stages a still wider logarithmic range can be covered. With three tubes, a range of from −60 db (0.001 volt) to +20 db (10 volts) has been obtained by the originator of this circuit. Note that the increase in the number of stages broadens the logarithmic response in the direction of weaker signals, but does not increase the upper limit of the logarithmic range which is limited only by the response of the first stage.

The resistors in series with the several control grids are used to prevent loading of the preceding circuit as the result of grid current. These resistors do not interfere with the operation of the circuit since only the negative grid swing is effective in causing rectification to take place in the plate circuit. Excessive values of resistance should not be used, however, or the high-frequency response of the amplifier will be reduced.

Cathode-Follower Input

The cathode follower is a vacuum-tube circuit in which the output is taken from the cathode rather than from the plate circuit. Fig. 6-13 shows a basic cathode follower. Due to the degenerative effect of an unbypassed cathode its effective impedance is very low. This low effective impedance extends the frequency response since shunting capacities have a reduced effect on the gain at high frequencies. With a large cathode resistor the degeneration may approach 100 per cent making the gain substantially one.

As stated above, one result of applying the cathode-follower circuit is to transform the impedance from a very high value at the grid (input) to a relatively low value at the cathode (output). Since a wide frequency response can be much more readily maintained at a low impedance than at a high impedance, the cathode follower is useful as an input stage for amplifier-rectifier v-t voltmeters.[5]

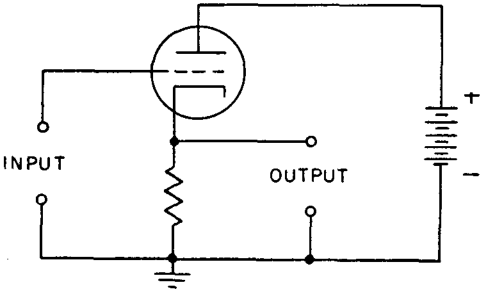

Fig. 6-13. The basic cathode-follower circuit. The output voltage is very nearly the same as the input voltage; however, the impedance across the output is equal to the cathode resistor while the input impedance is very high, being equal to the grid to cathode impedance of the tube.

In order to prevent overload it is generally necessary to use an input attenuator in an amplifier-rectifier v-t voltmeter. However, due to the degenerative feedback in the cathode, the cathode follower will take considerably more voltage at its grid than will a conventional amplifier. Where voltages of not over 10 or 20 volts are to be measured, a low impedance attenuator in the cathode circuit is sufficient. In order to accommodate higher voltages, one or two relatively large steps of attenuation may be provided in the cathode follower grid circuit.

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[5] The cathode follower input is used in the Hewlett-Packard model 400C and the Ballantine model 304 v-t voltmeters whose schematics are reproduced in Chapt. 13.

Cathode-Follower Probe

The cathode follower with the attenuator in the cathode circuit permits the use of an input probe tube in an amplifier-rectifier voltmeter. Since the cathode circuit has a very low effective impedance and can tolerate more shunt capacity, the cathode lead to the attenuator may be connected to the voltmeter proper through a cable. Fig. 6-14 shows a cathode-follower probe connected by means of a low-capacity cable to the voltmeter main amplifier. The attenuator is located in the main amplifier case. It is possible to provide a frequency range up to 5 megacycles or so with this arrangement.

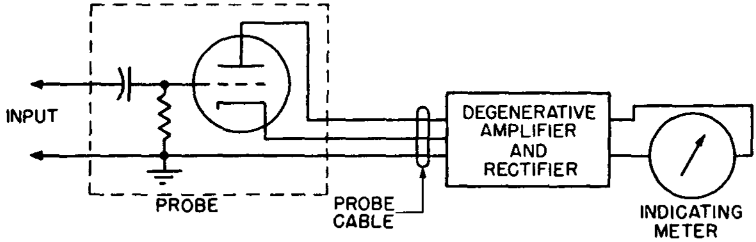

Fig. 6-14. A cathode-follower probe used with an amplifier-rectifier v-t voltmeter. The cathode resistor of the probe tube is the input attenuator for the voltmeter. The input impedance of this circuit is very high.

Peak-to-Peak Voltmeters

Although they are not limited to the amplifier-rectifier type v-t voltmeter, the peak-to-peak voltmeter will be described at this point because it is in this category that they are most popularly applied. The peak-to-peak VTVM is one which rectifies both positive and negative halves of an a-c wave applied to it and indicates the sum of the two d-c components thus produced.

Figure 6-15 shows a double-diode peak-to-peak rectifier. When an a-c voltage is applied to the input diode, *D2* rectifies the negative half of the wave-charging capacitor *C1* to the peak value of this half of the wave with the polarity indicated. It will be noted that the charge placed on *C1* is in such a direction as to make the plate of *D1* positive so that when the positive half of the a-c wave arrives, it causes plate *D1* to pass current, charging capacitor *C2* until the voltage across it is equal to the voltage across *C1* plus the peak of the positive half of the a-c wave. Thus, capacitor *C1* is charged to a voltage equal to the sum of the negative and positive peaks of the a-c voltage, the peak-to-peak value. Since the peak-to-peak value of a sine wave is 2.83 times its rms value, the reading of the peak-to-peak voltmeter will be 2.83 times the rms value. Putting it the other way around, the rms value of an a-c wave measured on a peak-to-peak meter scale may be found by dividing the peak-to-peak value by 2.83.

Since a sine wave is symmetrical, a measurement of either the positive or the negative half gives complete information about the wave. Pulses however, are not usually symmetrical so that the peak-to-peak voltmeter is particularly useful in measuring the total amplitude of such signals. Though the slide-back voltmeter (described in the next chapter), is also useful in measuring positive and negative peaks of unsymmetrical waves, it is evident that the direct-reading amplifier-rectifier VTVM incorporating the peak-to-peak rectifier has some distinct advantages. Commercially, both rectifier-amplifier and amplifier-rectifier peak-to-peak voltmeters are available.

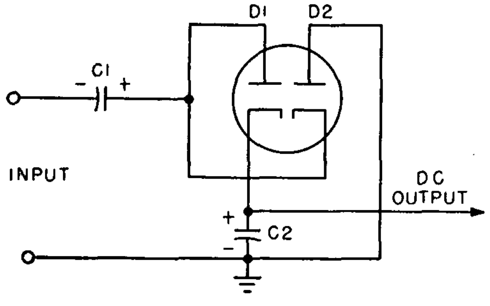

Fig. 6-15. A double diode rectifier of the type used in peak-to-peak v-t voltmeters. The operation of the circuit is described in the text.

Rectifier-Amplifier Peak-to-Peak Voltmeter

If the rectifier of Fig. 6-15 is followed by a d-c amplifier and indicating meter, a rectifier-amplifier v-t voltmeter for measuring peak-to-peak voltages results as shown in Fig. 6-16.[6] Although the

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[6] The RCA Type WV-95A Master VoltOhmyst is available with a peak-to-peak rectifying probe (see schematic in Chapt. 13).

amplifier peak-to-peak voltmeter has a wide range frequency response, it does not extend to as high a frequency as a meter using a half-wave rectifier probe. In the former, two sets of diode elements are connected across the input, increasing the effective input capacity and thereby increasing the load which reduces the maximum frequency response. This type of voltmeter has a voltage range limited at the lower end by the sensitivity of the d-c amplifier and its indicating meter, and at the upper end by the voltage tolerance of the diode rectifier. The upper voltage limit may, of course, be extended by the use of an attenuator connected ahead of the diode rectifier. Relative to the frequency range, the use of a crystal probe as the input rectifying system ahead of the amplifier affords a very great improvement.

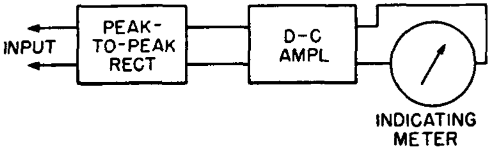

Fig. 6-16. Block diagram of a peak-to-peak rectifier-amplifier type v-t voltmeter. This type meter is commonly used for pulse measurements as described in Chapter 12.

Amplifier-Rectifier Peak-to-Peak Voltmeter

If an a-c amplifier is used ahead of the peak-to-peak rectifier, a voltmeter of the amplifier-rectifier type results as shown in Fig. 6-17.[7] The general arrangement and characteristics of the

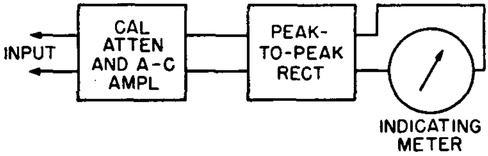

Fig. 6-17. Block diagram of an amplifier-rectifier type peak-to-peak v-t voltmeter. The a-c amplifier used in this circuit must have a wide frequency response for pulse measurements.

amplifier-rectifier peak-to-peak voltmeter are similar to the other amplifier-rectifier voltmeters described in this chapter. However, since many of the pulses commonly met with in practice are essentially square waves of short duration, it is useful to specify the voltmeter response in terms of pulse duration and repetition rate rather than simply in terms of frequency as is common in sine-wave

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[7] The Measurements Corp. model 67 peak voltmeter is an amplifier-rectifier v-t voltmeter. For its schematic see Chapt. 13.

responsive voltmeters. An alternate method of specifying response is in terms of a minimum pulse duration and mark to space ratios.

It should be pointed out that since pulses are not made up of waves of a single frequency but of a whole series of components of different harmonically related frequencies, their faithful amplification requires an extremely good wide-band amplifier. In other words, an amplifier which may have a very good frequency response to sine waves may be rather limited in its capabilities for amplifying pulses.

Pulse Stretching in Peak Voltmeters

The frequency response problem in pulse voltmeters also exists in the diode-rectifier circuits. For example, very short pulses relatively widely spaced may not charge the diode capacitor to its full value and the voltmeter will accordingly read low.

Two devices have been utilized to improve the rectifier response in the amplifier-rectifier v-t voltmeter.[8] The first is the use of an amplifier using feedback to obtain a very low output impedance. This lowers the impedance of the device feeding the diode and allows the capacitor to be changed more rapidly. The second is a pulse stretching device which, in effect, lengthens the duration of the pulse so that it has more time to charge the diode load capacitor. The technique in one such pulse stretching device is to utilize two diode rectifiers separated by an amplifier stage and having successively longer time constants. The first diode has a relatively low time constant so that the pulse will be able to charge its load capacitor substantially to its peak value. This first load capacitor, however, takes a definite time to discharge and its discharge to the amplifier stage is, in effect, a longer pulse than the one received. The amplifier feeds the second diode which has a larger capacitor and a sufficiently long time constant to give a steady indication on the meter. The second diode receiving a lengthened pulse responds much more fully than it would have to the original pulse and hence the meter reading is more accurate. This pulse stretching circuit is used in the Ballantine model 305 peak-to-peak voltmeter.[9]

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[8] F. H. Shepard, Jr. and Edmund Osterland, "Peak-to-Peak Voltmeter," *Electronics*, vol. 21, pp. 101–103, Oct. 1948.

[9] For a complete schematic of the Ballantine model 305 Peak-to-Peak Voltmeter see Chapt. 13.

REVIEW QUESTIONS

CHAPTER 6

6–1. What are the advantages and limitations of amplifier-rectifier vacuum-tube voltmeters?
6–2. Explain the operation of the audio-frequency VTVM circuit shown in Fig. 6-1.
6–3. Why is it impractical to extend the frequency range of amplifier-rectifier VTVM's beyond several megacycles?
6–4. To what type meter may the logarithmic VTVM be converted for sound measurements?
6–5. How does the logarithmic scale make it possible to measure a wider range of voltages on a single scale without switching than is accomplished on the conventional scale?
6–6. Describe the three basic types of logarithmic VTVM's.
6–7. Upon what principle of meter construction does the logarithmic milliammeter depend?
6–8. Explain how the variable-mu pentode, when used in an ordinary amplifier-rectifier type circuit, results in a logarithmic VTVM.
6–9. What characteristic of the cathode-follower circuit makes it useful as an input stage for amplifier-rectifier VTVM's?
6–10. What information about pulses does a peak-to-peak VTVM give that makes it particularly useful for such measurements?
6–11. Why must the a-c amplifier used in a meter designed for pulse measurements be an extremely wide-band one?
6–12. How may the rectifier response of amplifier-rectifier VTVM's be improved for pulse measurements?

CHAPTER 7

SLIDE-BACK VACUUM-TUBE VOLTMETERS

The v-t voltmeters which have been described up to this point have been of the direct-reading type. That is, when an unknown voltage is applied to the input terminals, that voltage is indicated directly on a meter scale. There are, however, voltmeters in which the voltage reading is not obtained directly. An example of such an instrument is the slide-back voltmeter.

Briefly, the voltage to be measured is applied to a circuit including a vacuum-tube detector with adjustable bias. The bias is adjusted until there is no current flow in the circuit—the bias then equals the peak signal voltage. A voltmeter connected across the bias then indicates this peak voltage.

Many variations of this basic circuit will be considered in this chapter. The name "slide-back" derives from the method of adjusting the bias in these instruments.

Slide-Back Diode V-T Voltmeter for Positive Peak Voltages

To measure a voltage with the diode voltmeter shown in Fig. 7-1, the potentiometer R is first adjusted so that the slide-back voltmeter reads zero. Under this condition the tap on the potentiometer will be at point X and a small current reading will be obtained on the microammeter as a result of the high speed with which the electrons leave the cathode. To check this initial reference current, the input terminals of the v-t voltmeter should be connected together so as to provide a d-c path.

The unknown voltage is then applied to the input terminals. Rectification of the positive peaks of this voltage will take place,

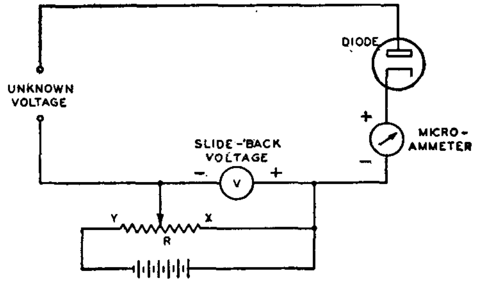


Fig. 7-1. A slide-back diode v-t voltmeter which can be used for the measurement of positive peak voltages. The voltage *V* required to restore the initial plate current is equal to the positive peak voltage.

so that the current through the microammeter will increase appreciably from its previous no-signal value. If, however, the slide-back voltage is increased so as to make the plate more negative, the current will gradually decrease until finally the current is reduced to its initial value. Under this condition, as Fig. 7-2a clearly shows, the positive peak of the unknown voltage is equal to the slide-back voltage indicated by the voltmeter *V* in Fig 7-1. The conditions existing when the slide-back voltage is too small and too large are shown at (b) and (c) of Fig. 7-2. If the slide-back voltage is too small as at (b), then rectification of the positive peaks takes place and the microammeter will indicate a large current flow. On the other hand, if the slide-back voltage is too great as at (c), then the diode plate will be biased so negatively that no plate current will flow during any part of the cycle. The proper setting of the potentiometer is obtained, as shown at (a), when the slide-back voltage is just about equal to the positive peak voltage being measured.

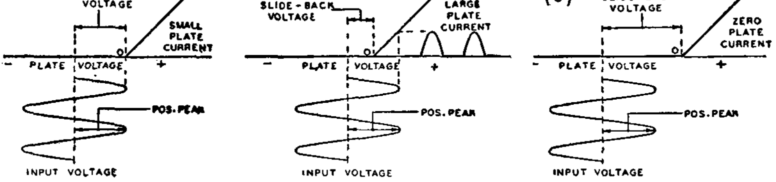


Fig. 7-2. These figures illustrate correct and incorrect adjustments of the slide-back voltage. The slide-back voltage is equal to the peak voltage when the initial small reference value of plate current is restored.

Use of Bias Voltage—Greater accuracy can be obtained if a small negative voltage is placed in series with the slide-back voltage, as shown in Fig. 7-3. This voltage enables the plate current to be reduced to a few microamperes, which is considerably less than the usual zero-signal current of about 300 microamperes.

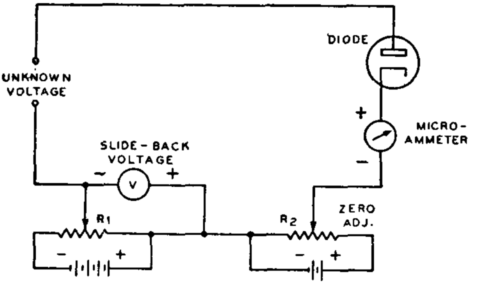


Fig. 7-3. The zero adjustment voltage, controlled by *R2*, makes it possible to reduce the plate current to a small reference value. When the reference current is restored, the slideback voltmeter *V* indicates the positive peak directly.

To use this circuit, *R1* should be set so that the slide-back voltmeter *V* reads zero. With the input terminals shorted, the zero adjustment *R2* should be set so that some definite small value of current is indicated by the microammeter; a suitable value is about 10 microamperes, and this will usually require a biasing voltage of about 0.5 volt negative. As before, the positive peak signal voltage is equal to the slide-back voltage required to reduce the plate current to its initial value—in this case 10 microamperes.

Of course this same method of providing an initial bias can also be used with the circuit shown in Fig. 7-1, since the bias can be provided by adjusting *R* to a suitable point near *X*. However, in this instance the bias voltage will also be read by the slide-back voltmeter, so that the bias voltage must be subtracted from the reading of *V* to obtain the peak voltage.

Accuracy—If the slide-back diode voltmeter is used to measure a-c voltages smaller than about 10 volts, a direct calibration must be made. For small voltages, the slide-back voltage is not accurately equal to the peak value of the signal because the "tip" of the positive peak must be rectified before the small initial value of current is obtained. The effect of this is to introduce an error which makes the slide-back voltage somewhat smaller than the actual positive peak being measured. The amount of this error is of the order of 0.5 volt so that usually it can be neglected only when voltages larger than about 10 volts are being measured.

D-C Path Required—The slide-back diode voltmeter cannot be used unless the source being measured provides a complete d-c path through which the rectified current indicated by the meter can flow. To obtain the greatest accuracy, the d-c resistance when the zero adjustment is made should be of the same order as the resistance looking into the voltage being measured.

Where the source being measured does not provide a complete path for the rectified current, the shunt-type circuit shown in Fig. 7-4 can be employed. This circuit has a self-contained d-c path and in addition incorporates a blocking capacitor so that d-c voltages will not affect the reading.

Positive Peak Is Measured—It is clear from the preceding description that the circuits in Figs. 7-1, 7-3, and 7-4 respond to the positive peak of the applied voltage. The somewhat similar circuits described in the following sections enable the measurement of the negative peak of an a-c wave and the *trough* voltage of a pulsating wave.

Avoiding Injury to Meter—To avoid excessive current through the plate microammeter, it is desirable to apply a large negative slide-back voltage to the plate before the unknown voltage is applied to the input terminals. The slide-back voltage can then be reduced until the initial value of plate current is indicated by the microammeter.

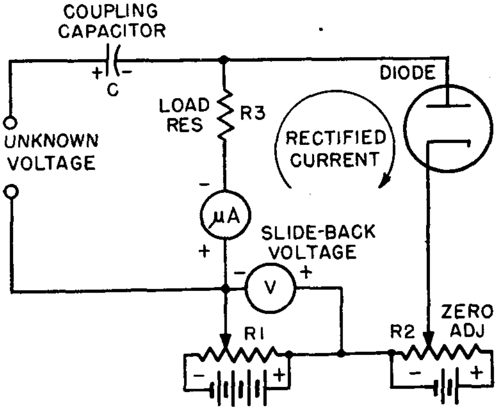


Fig. 7-4. A shunt-type slide-back v-t voltmeter. The rectified current flows through the complete circuit indicated by the curved path on the diagram.

Slide-Back Diode V-T Voltmeter for Negative Peak Voltages

By reversing the connections to the cathode and plate of the diode, the slide-back voltmeter shown in Fig. 7-3 can be converted into an instrument for the measurement of negative peak voltages. The modified circuit is illustrated in Fig. 7-5a. Note particularly that the polarity of the slide-back voltage is still such that it enables the plate to be made negative with respect to the cathode, although apparently the polarity of the slide-back voltage has been reversed.

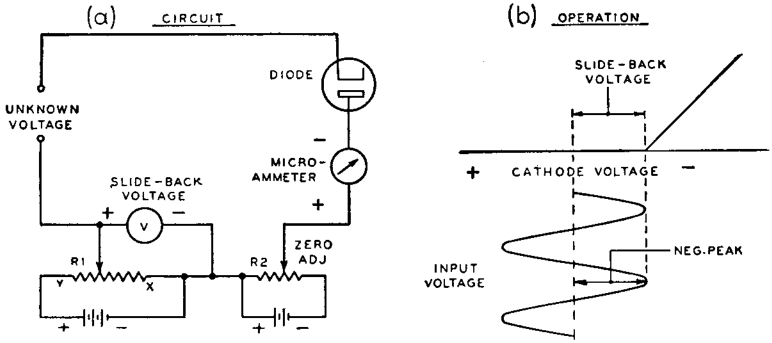


Fig. 7-5. By reversing the cathode and plate, it is possible to measure negative peak voltages. Operation of the circuit is illustrated at (b), which shows the plate current variation in terms of the *cathode* voltage. Note carefully the polarity of the slide-back and zero-adjustment voltages.

To make a voltage measurement of the negative peak, the input terminals are first connected together and the initial bias adjusted so that the plate current is 10 microamperes or some other suitable low value which can be read on the meter. The potentiometer is then set at *Y*, so that the maximum positive slide-back voltage is applied to the cathode. The unknown voltage is applied to the input terminals, and the slide-back voltage reduced until the initial plate current reading of 10 microamperes is again obtained. As Fig. 7-5b shows, under this condition the slide-back voltage will be equal to the negative peak of the applied signal.

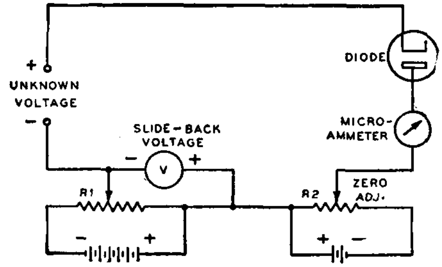
The various considerations explained in connection with slide-back voltmeters for positive peak voltage measurements also apply to this circuit.

In those instances where the voltage being measured is isolated from ground, either the positive peak circuit (Fig. 7-3) or the negative peak circuit (Fig. 7-5) can be used for the measurement of both positive and negative peaks. This can be done simply by reversing the connections to the input terminals of the v-t voltmeter. However, this procedure should not be attempted when one side of the voltage being measured is grounded.

Slide-Back Diode V-T Voltmeter for Trough Voltages

By reversing the polarity of the slide-back voltage, Fig. 7-6, the negative peak voltmeter just described can be used to measure the *trough voltage* in a pulsating wave. As Fig. 7-7a shows, the trough voltage of a pulsating wave is *the lowest value to which the voltage drops during the cycle.* A voltage wave of this type is obtained at the plate of an amplifier tube when an a-c signal is applied to the grid. In a typical instance, the voltage at the plate might fluctuate

Fig. 7-6. A slide-back diode v-t voltmeter arranged so as to measure the trough voltage of a pulsating wave. Note the polarity of the various voltages. The operation of this circuit is shown in Fig. 7-7.



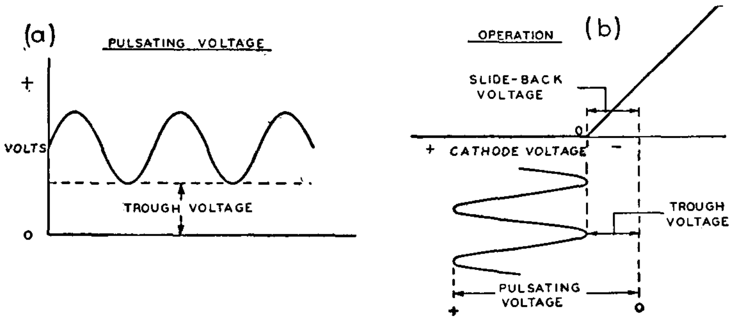


Fig. 7-7. When a pulsating voltage (a) is applied to the voltmeter in Fig. 7-6, the slide-back voltmeter will indicate the trough voltage of the wave, as shown at (b). The diode characteristic is shown in terms of the *cathode* voltage for simplicity.

between say 250 volts and 50 volts; the trough voltage would then be 50 volts.

To measure the trough voltage, the zero adjustment is made so that the plate current reads about 10 microamperes. The unknown voltage is then applied to the input terminals, the connections being made so that the positive side is applied to the cathode terminal. The effect of the unknown voltage is thus to bias the diode so that the plate current is completely cut off. If now the slide-back voltage is increased until the initial value of plate current is obtained, then the slide-back voltage will be equal to the trough value of the pulsating voltage as is clear from a study of Fig. 7-7.

Note that in this circuit the effect of increasing the slide-back voltage is to cause the plate current to *increase.* To avoid overloading the meter, the unknown voltage should be applied before the slide-back voltage is increased. This, of course, is the reverse of the usual procedure with slide-back voltmeters.

Slide-Back Modulation Meter

By combining the peak and trough voltage measuring ability of the slide-back voltmeter the positive and negative peaks of a modulated wave may be measured. Fig. 7-8a shows a circuit[1] in which a slide-back voltmeter is used to measure the amplitude of an unmodulated r-f wave (*A* in Fig. 7-8b), the average value of a modulated wave (*B* in Fig. 7-8b), the trough of a modulated wave (*C* in Fig. 7-8b), and the peak of a modulated wave (*D* in Fig. 7-8b).

The modulated r-f voltage is applied across the first diode, *V1*, which rectifies the wave and produces a pulsating d-c voltage which follows the upper half of the modulated wave shown in Fig. 7-8b. The rf is removed by means of a low-pass filter consisting of capacitors *C1* and *C2* and choke *L*. The remaining pulsating d-c voltage appears across load resistor *R1*. With switch *S1* closed, the contact on *R2* is adjusted until the galvanometer *M2* reads zero current. At this point voltmeter *M1* reads a voltage equal to *B,* the average value of the modulated wave. The unmodulated amplitude of the wave *A*, may be found by turning off the modulation and again adjusting the contact on *R2* until *M2* reads zero and reading the voltage on *M1*.

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[1] W. N. Tuttle, "Modulation Meter and Method," U.S. Patent No. 2,012,291.

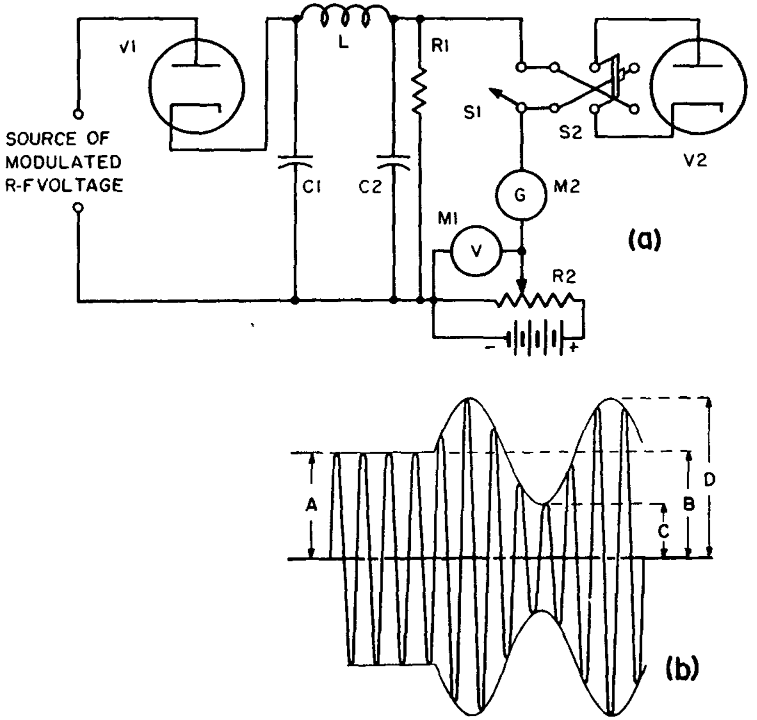

Fig. 7-8. The slide-back VTVM used as a modulation meter. The meter circuit shown in (a) will measure the principal characteristics of the amplitude modulated wave shown in (b).

To find the peak and trough values of the modulated wave, switch *S1* is opened. With switch *S2* thrown to the left, diode *V2* will conduct when the modulation positive peaks exceed the voltage across meter *M1*. If the contact on *R2* is again varied until the current in *M2* just touches zero, meter *M1* will show the value *D* in Fig. 7-8b. Switch *S2* is then thrown to the right under which condition the plate and cathode of *V2* are reversed, and diode *V2* will conduct whenever the applied voltage is less than the voltage across meter *M1*. Again, the contact on *R2* is varied until the current in *M2* just reaches zero; the reading on *M1* will then be equal to *C* in Fig. 7-8b.

When these values are known, several characteristics of the modulated wave may be found. In the first place, the difference between A and B shows the shift in average carrier amplitude due to the modulation. Second, from these data the modulation percentage may be found. The upward modulation percentage is $(D - B)/B \times 100$ and the downward, $(B - C)/B \times 100$. For a pure sine wave and with no carrier shift accompanying modulation, the two modulation percentages should be equal.

Low-Frequency Slide-Back Voltmeter

The slide-back voltmeter is often useful where the more conventional rectifier and amplifier combination voltmeters are not satisfactory. One of these applications is in the measurement of voltages of very low frequency.

Alternating-current voltages at frequencies of the order of one cycle per second are difficult to measure with conventional voltmeters due to the reduced response of amplifiers at these low frequencies. Also, the ballistics of the indicating meter is such that the pointer will generally swing with the signal and not give a steady reading.

Because slide-back voltmeters operate in a zero-current circuit, the problem of meter ballistics is avoided and low-frequency voltage may be measured accurately.

Pulse Measurements with Slide-Back Voltmeters

Another and rather obvious application of the slide-back diode v-t voltmeter is in the measurement of pulses. They are useful particularly in radar and television, where pulses of widely varying duration, separation, and repetition rate are encountered. Voltmeters based on sine-wave calibration often require the application of complicated correction factors in order to obtain the true peak voltage of these pulses. Slide-back voltmeters however may be used to measure both the positive and negative peaks of pulses without special corrections, and circuits may be readily devised to give accurate results for a great variety of pulse forms.

Greater convenience and utility in pulse measurement may be achieved by making the slide-back automatic.[2] Fig. 7-9 shows a slide-back voltmeter which is automatic and direct reading. The

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[2] L. Mautner and C. J. Creveling, "An Automatic-Slideback Peak Voltmeter for Measuring Pulses," *Proc. IRE,* vol. 35, pp. 208–211, Feb. 1947.

pulse signal is applied through the input coupling capacitor *C1* to the plate of the input diode and across shunt resistor *R1*. Pulses which make the plate positive with respect to the cathode are passed by the diode and are applied through capacitor *C2* to the input of the a-c amplifier. Since the accuracy of measurement will depend largely upon the gain of this amplifier, its gain, *G*, should be high and constant over the frequency range of the harmonics composing the pulses to be measured.

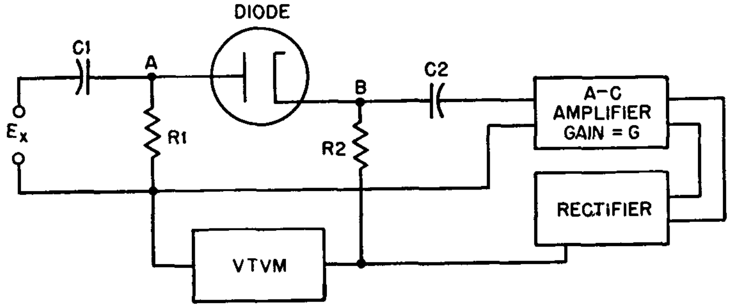

Fig. 7-9. An automatic, direct-reading type slide-back v-t voltmeter used for the measurement of pulses.

The amplified pulses are rectified by the rectifier and the resulting dc is fed back through resistor *R2* to the diode cathode. When this feedback bias (which is positive) becomes equal to the positive peak of the input pulses, the diode will cutoff and no signal will be fed to the amplifier. Evidently, the circuit will stabilize at a condition where the diode is not quite at cutoff, so that a small signal will be passed to the amplifier. Under these conditions, the bias from the rectifier will be equal to the input voltage peaks multiplied by a factor equal to $G/(G + 1)$. Thus, if G is 100, the rectifier feedback bias will be equal to 99 per cent of the peak of the input pulses.

In order to make the circuit direct reading, a v-t voltmeter is connected as shown to read the rectifier-produced bias. The typical voltmeter of this design has a flat response for pulses from 0.5 to 15 microseconds duration at repetition rates between 25 and 10,000 pulses per second.

Negative pulses may be measured in the same way merely by reversing the polarity of the input diode and the rectifier.

The Triode Slide-Back V-T Voltmeter

The basic circuit of the triode slide-back v-t voltmeter is shown in Fig. 7-10. This circuit is similar to that of the diode slide-back v-t voltmeter in Fig. 7-3, with the exception that the diode rectifier is replaced by a triode rectifier. As should be expected, the fundamental operation of the two circuits is the same. The replacement of the diode rectifier with a triode rectifier has the advantage of decreasing the loading of the circuit under test and reducing the error at low voltages.

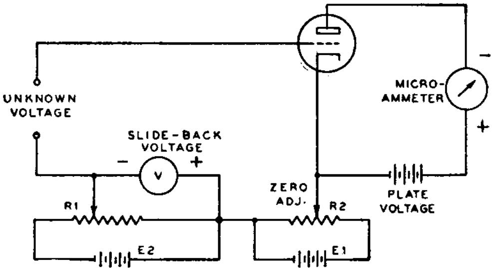

Fig. 7-10. The basic circuit of the triode slide-back v-t voltmeter.

To measure a voltage with the triode slide-back v-t voltmeter, the slide-back voltage is set so that the voltmeter *V* reads zero. With the input terminal shorted, the zero adjustment *R2* is set so that the plate microammeter reads some small reference value of plate current of the order of 10 to 100 microamperes. To prevent overload of the meter, the slide-back voltage should now be adjusted by means of *R1* so that a high negative voltage is applied to the grid. The unknown voltage is then applied to the input terminals and the slide-back voltage adjusted until the plate microammeter reads the initial reference value of plate current previously mentioned. By the same reasoning used in connection with diode-type slide-back v-t voltmeters it is clear that the positive peak value of the unknown voltage is equal to the slide-back voltage as indicated by the reading of the d-c voltmeter *V* which measures the slide-back voltage.

The operation of the slide-back VTVM is illustrated in Fig. 7-11. Here it is shown that the tube is initially biased close to plate current cutoff, the initial bias voltage being provided by *R2* in Fig. 7-10. When the signal is applied, and the slide-back voltage is adjusted, Fig. 7-11 shows that the same reference value of current is obtained *as a result of plate rectification of the positive peaks of the unknown voltage*. Because these positive peaks are effective in causing plate current to flow for only a small fraction of the cycle, it is clear that the peak plate current required is considerably larger than the average or initial reference value of plate current. This condition, illustrated in Fig. 7-11, explains why slide-back voltmeters have an inherent error which tends to make the slide-back voltage less than the peak voltage being measured.

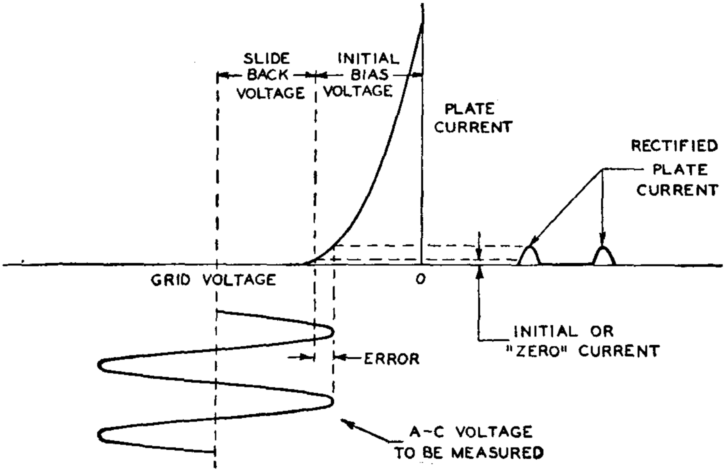

Fig. 7-11. The operation of the slide-back v-t voltmeter. Initially the tube is biased just above plate current cutoff. When the slide-back voltage is adjusted so that it is almost equal to the positive peak of the applied voltage, the initial plate current is restored.

Error in Slide-Back V-T Voltmeters

It is clear from a study of Fig. 7-11 that the slide-back v-t voltmeter will always indicate a slide-back voltage which is less than the positive peak voltage being measured. This condition arises because a part of the positive peak is "lost" in providing the necessary increase in plate current by plate rectification. The amount of this error is surprisingly large, so much so that ordinarily it should not be neglected when the voltage being measured is less than about 10 volts. As would be expected, the error is greatest for small voltages since the part of the positive peak "lost" in providing plate rectification is then an appreciable percentage of the total peak voltage.

In conventional slide-back circuits employing a triode rectifier, an error of approximately 50 per cent can be expected when voltages of the order of 1 volt are measured; this error increases for voltages lower than 1 volt. As a typical example, the slide-back voltage for a balance condition when a 1-volt peak signal is applied may be only 0.5 volt, so that an error of 50 per cent is present. With the same instrument, the error will be of the order of 15 per cent at a 5-volt level, and proportionately less at higher voltages.

The comparatively large error of slide-back v-t voltmeters can be reduced by plotting a correction curve. Such a curve shows the amount which must be added to the slide-back voltage in order to obtain the true peak voltage. As a general rule, however, such curves are themselves subject to error because of the rapid variation in rectification efficiency near cutoff. For this reason a correction curve should always be used with a fixed value of reference current. The procedure for making a correction curve is described in Chapter 11.

Input Resistance of the Slide-Back V-T Voltmeter

The input resistance of the triode slide-back VTVM is considerably higher than that of the diode type since the reference value of plate current is produced without drawing any current from the circuit under test. In general the input resistance tends to be somewhat higher than that of most triode plate rectification v-t voltmeters since the grid is excited only for a small fraction of the cycle. Another factor contributing to the high input resistance of the triode slide-back v-t voltmeter is the fact that operation is usually at a plate-current level of several microamperes so that the losses tend to be smaller. The usual considerations governing the input impedance of VTVM's at high frequencies also apply to the slide-back type. It follows that an acorn tube should be used where the high-frequency losses are to be kept to a minimum.

Slide-Back V-T Voltmeter Measures the Positive Peak

As Fig. 7-11 shows, the slide-back v-t voltmeter is essentially a peak voltmeter which measures the positive peak of the applied voltage. Thus it is subject to waveform errors which are characteristic of all peak v-t voltmeters. Ordinarily it is not possible to measure the negative peak of the applied voltage. In the special case where the voltage being measured is ungrounded, however, the negative peak can be measured by merely reversing the connection of the leads to the v-t voltmeter. In measurements on high-impedance circuits, the "low" lead should never be connected to the grid terminal of the slide-back voltmeter since this will cause an error due to cross ground impedances, as explained in the next chapter.

Measurement of Trough Voltage—The slide-back VTVM cannot be used for the measurement of trough voltages (see Fig. 7-7) except in the special case where the polarity of the pulsating voltage is *negative*. In such cases, the unknown voltage should be applied to the v-t voltmeter with the negative (ungrounded) lead connected to the control grid of the VTVM; note that this is the reverse of the usual polarity of connection. The slide-back voltage polarity should also be the reverse of the usual polarity, with the slide-back voltage connected so as to drive the control grid *positive*. A little reflection will make it clear that when the initial reference current is restored, the trough value of the pulsating voltage is equal to the slide-back voltage.

Unfortunately, the above method for measuring trough voltage has a limited application because usually it is not possible to apply the pulsating voltage with the required polarity. For example, in vacuum-tube plate circuits the trough voltage is always positive with respect to ground so that the above method cannot be used. In such instances a diode type slide-back v-t voltmeter can be used to make the measurement as explained previously. In this connection, the diode circuit is more flexible than the triode circuit in that the cathode and diode plate can be interchanged so as to enable the measurement of peak and trough voltages regardless of polarity.

Preventing Injury to the Meter

Several methods can be used to reduce the danger of overloading the plate microammeter in slide-back v-t voltmeters. These methods, which are illustrated in Fig. 7-12, include (1) the insertion of a resistor R in the grid circuit so as to prevent the grid from being driven positive, (2) the use of a shunt R across the meter during preliminary adjustments, and (3) the use of a high value of resistance R in series with the microammeter.

The use of a high value of resistance in series with the grid, usually about ¼ megohm, provides some protection to the meter but it is not too effective since the grid voltage must drop to zero before the resistor prevents a further increase in the plate current. In addition to providing only a limited amount of protection, the grid resistor method has the limitation that the sensitivity becomes dependent upon the frequency of the signal. This increases the error at high frequencies, especially for small voltages. The grid-resistor method should not be used at frequencies higher than about 100 kilocycles.

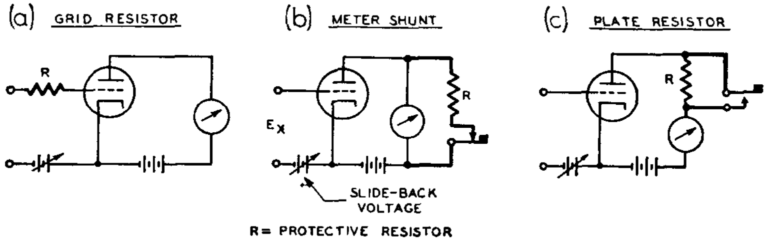

Fig. 7-12. Three methods of reducing the danger of overloading the plate microammeter in slide-back v-t voltmeters. The non-locking push-button switches at (b) and (c) protect the meter at all times except while the final adjustment is being made.

The shunt method shown in Fig. 7-12b is most effective in preventing injury to the plate microammeter when a push-button switch of the non-locking type is used to disconnect the shunt. In this way the meter is unshunted only when the reference value of plate current is being measured and is automatically shunted during all preliminary adjustments. The plate resistor method of reducing the overload current which is shown in Fig. 7-12c is most useful where a sensitive meter is employed and the circuit is designed to be used at a reference plate current of the order of a few microamperes. Under these conditions the plate resistor R can be as high as several megohms.

Where the maximum accuracy is not required, it is not essential that a sensitive microammeter be used to establish the reference value of current. For a great many measurements an 0-1000 microampere meter is entirely satisfactory. The reference value of current should then be about one division on the scale or about 20 microamperes.

Measurement of D-C Voltages with Slide-Back V-T Voltmeter

The slide-back v-t voltmeter can also be used for the measurement of d-c voltages. Almost invariably, however, the measurement can be made more conveniently by other means (see Chapter 8) which provide a *direct* indication of the unknown voltage without the necessity for an auxiliary voltage supply.

Where the slide-back VTVM is to be used for d-c voltage measurements, the instrument should be provided with a polarity switch so that the polarity of the slide-back voltage can be reversed depending upon the polarity of the unknown voltage. If this is positive with respect to ground, the polarity of the slide-back voltage should be such that the grid is made negative. For a voltage which is negative with respect to ground, the polarity of the slide-back voltage should be such that the grid is made positive.

It is worth noting that the plate-rectification error present when a-c voltages are measured does not exist for d-c voltages. When a d-c voltage is measured, it is clear that the slide-back voltage must be exactly equal to the applied d-c voltage in order that the initial reference plate current be restored. For maximum sensitivity, the reference plate current should be considerably higher than for a-c voltage measurements since a large mutual conductance is desired. A convenient reference level is about 250 or 500 microamperes when using a 1000-microampere meter. Usually the accuracy of the slide-back v-t voltmeter for d-c voltage measurements is limited only by the accuracy of the d-c voltmeter used to measure the slide-back voltage. As noted in Chapter 8, special attention must be given to the tube type and the operating conditions in order to obtain the highest possible input resistance.

Input Circuit of Slide-Back V-T Voltmeters

The same considerations which apply to the input circuits of other types of triode v-t voltmeters also apply to the slide-back type. Where the instrument is used solely for the measurement of a-c voltages, it is recommended that a blocking capacitor and grid resistor be used. For the measurement of pulsating and d-c voltages, this blocking capacitor must be removed and the unknown voltage connected directly to the grid. In the latter instance, the resistance in the input circuit must be kept constant to prevent any change in the "contact potential."

Space-Charge Slide-Back V-T Voltmeter

The accuracy of the slide-back VTVM can be increased considerably provided that the conventional triode shown in Fig. 7-10 is replaced with a screen-grid tube in which the screen is used as the control grid, the control grid being connected to the cathode. This type of connection, commonly designated as the *space-charge connection,* has the advantage that the sharpness of the plate-current cutoff is increased several fold. As a result of the steeper slope with which the plate current approaches the zero axis, the space-charging slide-back v-t voltmeter has a higher plate-rectification sensitivity. Thus a relatively small change in grid bias or a-c voltage produces a comparatively large change in plate current, so that the characteristic error of the slide-back v-t voltmeter is greatly reduced.

A typical slide-back VTVM using the space-charge connection is shown in Fig. 7-13. With the exception that the screen functions as the control grid, this circuit is similar to Fig. 7-10. The comparatively high plate voltage of 180 volts is used in this circuit because

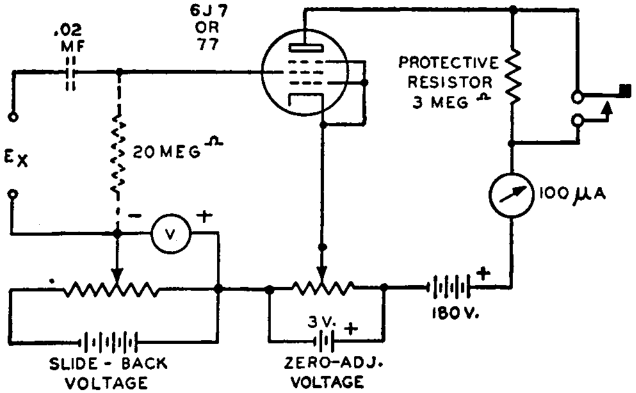

Fig. 7-13. A typical slide-back v-t voltmeter in which the screen grid is used as the control grid. This provides a sharper plate current cutoff so that greater accuracy is obtained in measuring small voltages.

low values of plate voltage tend to result in grid current and a lowered value of input resistance; this is especially true when working near cutoff at plate currents of the order of a few microamperes. Otherwise, the plate voltage has practically no effect on the sensitivity since the slope of the plate current-grid voltage curve near cutoff is practically independent of the plate voltage over a very wide range. A protective resistor of about 3 megohms is shown in the plate circuit.

The error which can be expected with this circuit is about one-third that with circuits using the ordinary triode connection. With the constants shown in Fig. 7-11, the error at a level of 0.5 volt is about 35 per cent; at a 1-volt level, the error is about 25 per cent; at a 5-volt level the error is about 7 per cent; and at a 20-volt level the error decreases to about 2 per cent. Although the error is less than for the triode type slide-back v-t voltmeter, the above figures show that it is advisable to use a correction curve for all voltage measurements lower than about 5 or 10 volts.[3]

Amplifier Type Slide-Back V-T Voltmeter

It is possible to replace the plate microammeter in the slide-back v-t voltmeter with a d-c amplifier. Where this arrangement is used, a high value of resistance is inserted in the plate or cathode circuit and the d-c voltage developed across this resistor is fed to the d-c amplifier.

A circuit of this type is shown in Fig. 7-14, which uses a reflex or self-biased type of rectifier. Approximately 3 volts is developed across the 10-megohm cathode resistor when no signal is applied so that the reference value of plate current is about 0.3 microampere. When a signal is applied plate rectification takes place and the voltage at the cathode becomes more positive. This upsets the balance of the d-c amplifier so that the microammeter connected across the plates of the two amplifier tubes provides a measure of the change in the rectified plate current.

Although more complex than the conventional slide-back circuit, this circuit has the advantage that the microammeter current is limited to about 500 microamperes so that the meter cannot be

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[3] L. C. Birdsall and C. B. Aiken, "Sharp Cutoff in Vacuum Tubes, with Applications to the Slideback Voltmeter," *Electrical Engineering*, vol. 57, p. 171, Apr. 1938.

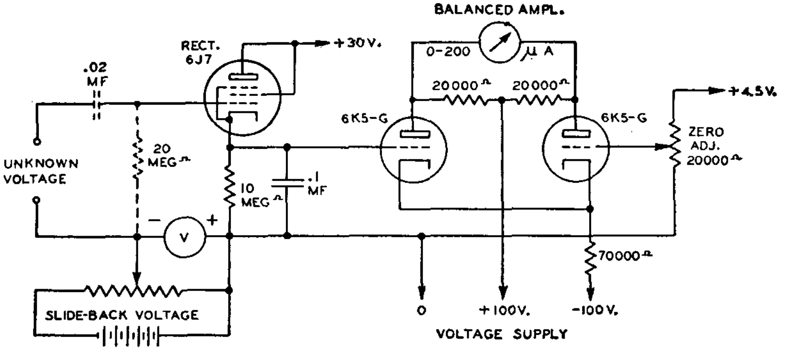

Fig. 7-14. An amplifier type slide-back v-t voltmeter in which the conventional plate microammeter is replaced by the 10-megohm cathode resistor. The reference value of plate current is observed indirectly by measuring the voltage drop across the cathode resistor by means of the balanced d-c v-t voltmeter.

injured. At the same time the input resistance is appreciably higher than for the conventional slide-back circuit as a result of the exceedingly small value of plate current. There is no appreciable difference in sensitivity between this and the conventional plate-rectification circuit of Fig. 7-10.

Because of the high stability of the circuit employed in Fig. 7-14, a direct calibration can be used for voltages less than several volts. That is, the deflection of the microammeter can be calibrated directly in terms of the a-c voltage applied to the input terminals of the rectifier. When this procedure is used, the instrument is no longer a slide-back v-t voltmeter, but becomes essentially a rectifier-amplifier v-t voltmeter (see Chapter 4).

REVIEW QUESTIONS

CHAPTER 7

7–1. Describe briefly the operation of the slide-back v-t voltmeter.

7–2. For what type measurements are slide-back VTVM's most useful?

7–3. Explain how the diode slide-back v-t voltmeter may be used to measure trough voltages.

7–4. What is modulation percentage? Outline a method for obtaining the modulation percentage of a sine-modulated carrier using a slide-back modulation meter.

7–5. Compare the triode slide-back VTVM with triode plate-rectification meters as regards measurement error and input impedance.

7–6. Since a sensitive micoammeter is used in the plate circuit of the slide-back VTVM, and the voltage across it initially may be high, it is necessary to protect it. Give three ways for doing this.

CHAPTER 8

VACUUM-TUBE VOLTMETERS FOR D-C VOLTAGE, CURRENT, AND RESISTANCE MEASUREMENTS

The use of the v-t voltmeter for d-c voltage measurements was touched upon briefly in Chapter 1. There it was shown that the basis of the d-c VTVM is the interpretation of the unknown voltage applied to the input terminals in terms of the resulting plate current which is measured by a d-c milliammeter or microammeter. Fig. 1-3 and the accompanying description may be referred to for a review of the elementary principles underlying the d-c v-t voltmeter. The simple v-t voltmeter shown in Fig. 1-3 is the basis for numerous refinements in design which make possible the measurement of d-c voltages, current, and resistance over an extremely wide range.

The advantage of the d-c VTVM over the conventional d-c voltmeter is primarily due to the much higher input resistance of the v-t voltmeter. In addition to the advantage of higher input resistance, considerably greater sensitivity can be obtained than with the conventional meter. This greater sensitivity results because the inherent sensitivity of the moving-coil meter is combined with the amplification made possible by the vacuum-tube circuit. An important consideration is the protection which the vacuum-tube circuit provides against damage to the indicating meter. In the measurement of very small d-c voltages and currents, it is possible to obtain greater speed of operation with the v-t voltmeter than with a galvanometer of comparable sensitivity. Because the amplification provided by the vacuum-tube circuit enables the use of relatively insensitive meters, the v-t voltmeter is more rugged and less expensive than the nonelectronic meter.

In designing VTVM's for d-c measurements it is undesirable to operate the amplifier tube at the rated conditions which yield the greatest mutual conductance (sensitivity), because such operation is accompanied by a lowering of the input resistance and the flow of a small but nevertheless appreciable value of grid current. In addition, a considerable degree of nonlinearity results when no degeneration is used. This tends to make a direct calibration impossible because of the dependence of the calibration upon the tube characteristic and the operating voltages. Additional factors which must be taken into account are the provision of a balancing circuit which will provide adequate stability of operation. Although the d-c v-t voltmeter is basically simple, it is clear from the above outline that a number of important factors must be considered in order to obtain a satisfactory d-c VTVM.

Input Resistance and Grid Current in D-C V-T Voltmeters

A basic factor in the design of v-t voltmeters is the choice of the tube and the operating conditions so that a high input resistance and low grid current will be obtained. The necessity for low grid current can be seen from the following considerations. If an appreciable value of grid current flows, then the potential at the grid will vary depending upon the resistance which happens to be present in the grid circuit. Thus the plate current will show a corresponding variation so that the voltage reading obtained will depend upon the internal resistance of the voltage source being measured. Such a condition is clearly undesirable. A properly designed d-c VTVM will give a reading which is independent of the resistance in the grid circuit up to values of at least several thousand megohms. Special d-c v-t voltmeters have been designed in which the resistance in the grid circuit may be higher than ten million million megohms!

In describing a d-c v-t voltmeter it is not sufficient to know that the input resistance is 10 megohms, 5,000 megohms, or whatever the particular value may be. This is only a part of the story; in addition, it is necessary to know the *grid current.* For example, a v-t voltmeter may use a voltage divider which has a resistance of say 20 megohms, in which case its *input resistance* would be specified as 20 megohms. This alone, however, is not sufficient since there may be an appreciable grid current. For example, even if the grid current is as small as 0.01 microampere, this grid current will cause a voltage drop of 0.2 volt across the 20-megohm grid resistor. If the input leads of the instrument are shorted, it follows that there will be a shift of 0.2 volt in the reading of the instrument. Such an instrument would show an error of as much as 0.2 volt because of the flow of grid current.

For complete information on the input circuit of a d-c VTVM it is thus necessary to know not only the input resistance, but also the grid current. Of course, the grid current depends upon the voltage which is applied to the grid, but usually it is satisfactory to specify the grid current which flows when no external voltage is applied.

A satisfactory check for grid current can readily be made by shorting the test leads and noting whether there is any shift in the zero reading. This check should be made while the v-t voltmeter is on the most sensitive range. If the v-t voltmeter is of the type which does not use a voltage divider in the input circuit on the lowest range, then the test should be made with about 10 megohms in the input circuit. The change in the positon of the zero will be negligibly small, provided the grid current is sufficiently small.

Compensating for Grid Current

Accurate measurements in very high resistance circuits may often be made even when a noticeable amount of grid current is present in the input tube. Some v-t voltmeters are available without an input attenuator in which case, the d-c voltage to be measured is applied directly to the grid of the input tube.[1] Where measurements are to be made in relatively low impedance circuits, a 1-megohm resistor may be connected across the voltmeter terminals while the zero adjustment is made and during measurements. It is not often that the input tube has so much grid current that it will show up across a 1-megohm resistor, so little error will result.

When measurements are to be made in very high impedance circuits, a somewhat different procedure should be followed. For making the zero adjustment, the input terminals should be con-

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[1] See Barber Laboratories model VM-72, as shown in Chapt. 13.

nected across the circuit under test with no voltage applied, or across a resistor equal to the circuit resistance. *The instrument range switch should always be turned to the most sensitive range while setting the zero.* After the zero setting has been made the circuit may be energized and measurements taken accurately.

Since the grid current is almost constant for a few volts around zero, there is in effect, a small fixed bias added to the input of the v-t voltmeter. The effect of this small current is compensated for by adjusting the zero in the presence of this bias. The adjustment to zero adds a bias to the input which is equal and opposite to that of the grid current. At high input voltages the grid current may change, but its effect will be small in comparison to the voltage being measured and hence, it may be disregarded.

Accuracy of D-C V-T Voltmeters

With proper design the accuracy of a d-c v-t voltmeter can be made to approach the accuracy of the meter movement itself, surprising as this may seem in view of the comparatively large number of variables involved. Where sufficient degeneration is used, the calibration can be made to depend only upon the value of the resistors used, and can be made independent of variations in tube characteristics and line voltage. Production variations in the meter sensitivity and other circuit constants are usually taken care of by an internal calibration adjustment. The greatest single source of error in d-c VTVM's is in the input voltage divider, where one is used. In order to obtain a high input resistance, high values of resistance must be used in the voltage divider. These resistors tend to show a greater variation in resistance with temperature and age than do low values of resistance. By carefully matching resistors in the voltage divider and by using resistors which have about the same temperature coefficient, this error can be reduced to a satisfactorily low value. Where the greatest accuracy is required, the v-t voltmeter can always be checked against an accurate low-resistance voltmeter.

The Slide-Back V-T Voltmeter for D-C Voltage Measurements

The application of the slide-back v-t voltmeter for the measurement of d-c voltages is described in detail in the previous chapter.

Unlike the other d-c v-t voltmeters to be described later in this chapter, the slide-back VTVM has the disadvantage that it is not direct reading, but requires a balancing adjustment in order to obtain a measurement. Other disadvantages of the slide-back v-t voltmeter for d-c voltage measurements are the necessity for an internal voltage supply which must be at least as large as the highest voltage to be measured. With reference to grid current, the slide-back VTVM is subject to the same possible source of error as the direct-reading d-c v-t voltmeter, so that care must be exercised in the choice of the tube types and in the operating conditions under which the slide-back triode functions. In general, low-mu triodes are more satisfactory than high-mu triodes since they have a lower grid current and a smaller "contact potential."

A Simple Center-Zero D-C V-T Voltmeter

The d-c v-t voltmeter shown in Fig. 8-1 is similar in basic design to the fundamental d-c v-t voltmeter shown in Fig. 1-3. In the present circuit, however, the tube is biased in the middle of the grid voltage-plate current characteristic so that the milliammeter reads in the middle of the scale when no voltage is applied to the grid. This point on the scale is designated as zero. If a positive voltage is applied to the input terminals, the plate current of the tube will increase so that the meter will deflect up the scale from the center-zero position. If a negative voltage is applied, the plate current decreases so that the meter deflects down the scale to the left of the zero. A typical scale for this type of center-zero d-c VTVM is shown in Fig. 8-1b. Note that the milliammeter is calibrated directly in terms of the unknown d-c voltage which is applied to the input terminals. The slight compression of the lower portion of the scale is due to the nonlinearity of the tube characteristic near cutoff.

To obtain increased stability and independence of tube characteristics, a self-bias arrangement is used to provide the operating bias. The cathode resistor provides sufficient degeneration so that satisfactory stability and independence of tube characteristics is secured. The calibration adjustment *R7* enables compensation to be made for variations in meter sensitivity, tube characteristics, circuit constants, etc. This adjustment is an internal one, which is made only when tubes are changed or when any of the resistors are replaced. The control *R10* in the voltage divider circuit is used to vary the plate voltage so that the pointer will read zero or mid-scale when no voltage is applied to the input terminals. Thus this control functions as a zero adjustment.

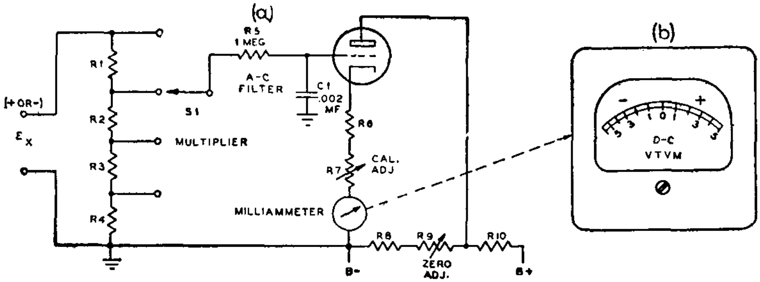


Fig. 8-1. Typical constants for 5, 25, 125, and 500 volt ranges using a 76 tube, an 0-1 ma meter, and a 200-volt plate supply: *R1* = 8 megohms; *R2* = 1.6 megohms; *R3* = 300,000 ohms; *R4* = 100,000 ohms; *R6* and *R8* = 6,000 ohms; *R7* = 2,000 ohms; *R9* = 10,000 ohms; *R10* = 27,000 ohms.

The center-zero arrangement used in this circuit has a number of advantages, particularly where it is desired to make a d-c v-t voltmeter of simple design and low cost. This type circuit eliminates the need for a polarity switch which is otherwise required in order to be able to measure both positive and negative voltages. At the same time, the design is simplified considerably since perfect linearity is not required over the range of both positive and negative voltages, as is the case where the full scale is utilized. In service work, where it is necessary to switch rapidly from the measurement of positive to negative voltages, as for example in measuring first the negative grid voltage, then the positive plate voltage, etc., it is convenient to be able to change from positive to negative voltages without shifting a polarity switch.

Where the conventional left-zero arrangement is used in conjunction with a polarity switch, the disadvantage of having to manipulate the polarity switch is offset by the fact that the calibration is spread out over the full scale. Thus there are advantages in both the center-zero and left-zero circuits; which is preferable depends upon the particular requirements that the instrument is designed to meet. A number of circuits using the conventional left-zero arrangement will be described in this chapter.

An a-c filter is used in the center-zero circuit shown in Fig. 8-1. This filter, consisting of *R5* and *C1* in the grid circuit, is designed to remove any a-c component or signal voltage which may be present at the point where the d-c voltage is being measured. The values shown are sufficient to provide adequate attenuation for practically all applications. Excessively large values of either *R* or *C* should not be used since a large time constant will tend to make the action of the v-t voltmeter sluggish. The grid capacitor *C1* should be a mica capacitor since low d-c leakage is essential if the accuracy of the voltmeter is not to be effected. It is worth noting that complete attenuation of any a-c component which may be present is not required since the linearity of the circuit permits a considerable grid swing to take place before rectification alters the reading of the milliammeter.

Four voltage ranges are provided by means of the voltage divider and selector switch *S1* in the input circuit. To obtain satisfactory accuracy, these resistors should be accurate to 1 per cent. In production, an improvement in the accuracy of the voltage divider can be effected by separating the voltage divider resistors at the time they are checked into two groups which are (1) between 0 and +1 per cent and (2) between 0 and −1 per cent. If all the resistors for any one instrument are selected from any one group of resistors, the accuracy of the voltage divider can be doubled.

Isolating Resistor—"Signal Circuit" Probe

The v-t voltmeter shown in Fig. 8-1 may be used in connection with the type of probe shown in Fig. 8-2. This probe has the advantage that the input capacitance of the voltmeter is reduced to about $1\mu\mu$f. This low input capacitance prevents detuning and loading of r-f circuits and so permits measurements to be made under dynamic operating conditions. For example, using this type of "signal-tracing" probe, it is possible to make measurements directly at the control grid of an oscillator tube so as to check its operation by determining the rectified grid voltage. Similarly, it is possible to measure automatic-volume-control (avc) voltage directly at the control grids of tubes which are receiving avc voltage. In the above examples, the use of an ordinary probe without an isolating resistor would detune and load the r-f circuits so that the measurements could not be made.

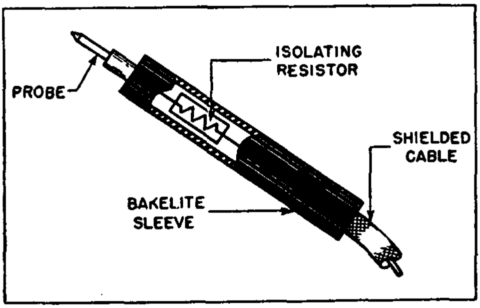


Fig. 8-2. The isolating resistor in the probe enables d-c voltages to be measured at points where r-f voltage is present without detuning the circuit.

The effect of an isolating resistor at the end of the voltmeter lead must of course be considered in the calibration of the VTVM. For example, if the input resistance of the v-t voltmeter is 10 megohms, a 1-megohm isolating resistor, which is the value usually employed, would reduce the deflection by about 10 per cent. This reduction in sensitivity, however, can readily be taken into account in the initial calibration. The instrument will then be accurate when used with the isolating probe which can be considered an integral part of the instrument.

In d-c VTVM's which are not provided with this type of probe, the same objective of preventing detuning of r-f circuits can be obtained by temporarily clipping a 1-megohm resistor to the end of the test lead, and using the other end of the 1-megohm resistor as the input or probe point. Where this arrangement is used, the v-t voltmeter will read less than the true voltage by an amount equal to the voltage drop across the 1-megohm isolating resistor. The error depends upon the input resistance of the v-t voltmeter and will be greater the smaller the value of the input resistance. To obtain the correct voltage, the reading should be multiplied by $(1+R_1/R_2)$ where R_1 = resistance of the isolating resistor and R_2 = input resistance of the v-t voltmeter.

Probes are discussed more completely in the next chapter.

Polarity Considerations in D-C V-T Voltmeters

Some attention has already been given to the question of *polarity* in d-c v-t voltmeters. In the center-zero VTVM just described, the measurement of both positive and negative voltages is taken care of by the center-zero arrangement. This permits the *low* input terminal to be connected to ground at all times, so that positive and negative voltages can be measured without switching leads. Another type of circuit, shown in Fig. 8-6, also permits positive and negative voltages to be measured. In this balanced circuit the *polarity of the milliammeter connection to the vacuum-tube circuit is reversed,* so that the input leads need not be interchanged in order to measure positive and negative voltages.

There are several reasons why the *low* input terminal should be connected to the ground or low side of the voltage being measured. If the leads are reversed, the effect will be to ground the grid circuit and to place the cathode circuit "up in the air." Because of the comparatively high input resistance of the v-t voltmeter, such a connection will cause leakages through the a-c line and between the instrument case and ground to affect the reading of the meter. In addition the resulting stray a-c pickup may overload the input circuit so that rectification will take place and also cause error. An additional reason for always keeping the *low* input terminal of the VTVM connected to the ground or low side of the circuit being measured involves the question of safety. Usually the low terminal is connected to the chassis and cabinet of the instrument. If this *low* terminal is connected to a point which is highly positive or negative with respect to ground, touching the instrument case and the low side of the circuit under test will result in a shock. For all of the above reasons it is recommended that the *low* v-t voltmeter terminal be connected to the low or ground side of the circuit being measured. Positive or negative voltages can then be taken care of by using a center-zero v-t voltmeter circuit or by using a balanced VTVM circuit in combination with an internal polarity switch.

Measuring Voltages Between Points Above Ground

In connection with the problem of keeping the *low* terminal of the d-c v-t voltmeter tied to the low side of the circuit under measurement, it is sometimes necessary to measure the voltage difference between two points which are several hundred volts above or below ground. In such an instance, it is not recommended that the instrument be connected directly across the two points, since this procedure exposes the operator to the danger of shock as explained in the preceding section. A preferable method of making the measurement is to measure the voltage at each of the points with respect to ground. The desired differential voltage can then be determined by taking the difference between the two voltage readings.

Where the voltage difference is quite small, a considerable error will occur in the measurement because the measurement depends upon taking the difference between two large voltages. If high accuracy is required, it can be obtained by ignoring the general rule stated above, and connecting the instrument directly across the two points in question. The instrument can then be set to a low voltage range and the desired voltage readily measured. Extreme care should be taken, however, to see that the operator does not come in contact with any part of the instrument since the instrument case is not at ground potential. Immediately upon completion of the measurement, the low terminal of the v-t voltmeter should be removed from the high-voltage point so as to prevent possible shock.

In some VTVM designs, the low input terminal is not connected directly to the panel or chassis of the instrument, but is connected through a high resistance and capacitor. The General Radio Type 1800-A v-t voltmeter shown in Chapter 13 is an example of this type instrument. This isolating circuit has the advantage that it is possible to ground the instrument case even when the low input terminal is above or below ground potential. Even where this feature is provided, it is usually desirable to limit the voltage difference between the low and ground terminals to approximately 200 volts.

Obtaining a Center-Zero Deflection for Galvanometer Applications

In a number of applications involving the use of the d-c v-t voltmeter, it is desirable to have a center-zero indication. Typical applications of this type are the measurement of the discriminator output in automatic-frequency-control and frequency-modulation receivers, and the use of the d-c v-t voltmeter as a galvanometer in bridge applications. A center-zero d-c v-t voltmeter is directly applicable to these measurements because *plus* and *minus* variations from the balance condition are indicated on the same scale without any polarity switching. With the left-zero VTVM, on the other hand, the meter deflects off scale during the balancing procedure. By the addition of an external biasing circuit, however, it is possible to convert the left-zero v-t voltmeter into a center-zero v-t voltmeter.

A simple method for obtaining a center-zero reading on a left-zero v-t voltmeter is shown in Fig. 8-3. The voltage of the biasing battery in series with the high input lead should be at least half as large as the lowest full-scale range of the VTVM. By adjusting the potentiometer across this battery, while the input leads are shorted, the meter can be made to deflect to the center of the scale. When this adjustment is completed, the center of the scale becomes the new zero of the v-t voltmeter, so that positive and negative voltages will cause deflections on either side of the center, just as in the ordinary center-zero meter. The meter can then be used for balancing adjustments of any type in exactly the same way that a galvanometer or other type of center-zero instrument would be used. The calibration is not affected by the addition of this external biasing adjustment provided that the voltages are reckoned from the center, with each division having the same voltage value as it had before the addition of the biasing circuit.

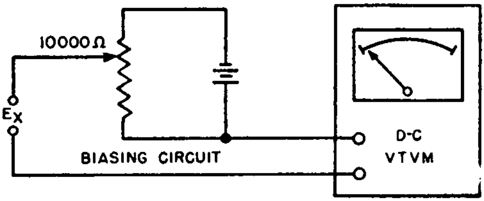


Fig. 8-3. By means of this circuit a conventional left zero v-t voltmeter can be converted into a center-zero meter.

A Single-Tube Degenerative V-T Voltmeter

The need for a voltage divider in the input circuit of d-c v-t voltmeters can be eliminated, at least for voltages up to about 100 or 200 volts, by means of a range switch which controls the amount of degeneration. The basic amplifier circuit used in this type of d-c v-t voltmeter is shown in Fig. 8-4. When a large cathode resistor R is used in such a circuit, an analysis of the circuit shows that a voltage E_x applied to the grid will cause a voltage E_R to be developed at the cathode which is almost equal to the original voltage applied to the grid.

The operation of the circuit will be clear from the following description. When a positive voltage E_x is applied to the grid, the plate current increases so that a voltage drop takes place across the cathode resistor as a result of the increase in plate current. Because the polarity of this voltage drop E_R opposes an increase in plate current, the cathode resistor R exercises a controlling effect on the plate current. In no case can the plate current increase be greater than an amount which will cause the resulting voltage drop across the cathode resistor R to equal the unknown voltage E_x applied to the grid.

It can be shown that the expression for the change in plate current in the basic circuit of Fig. 8-4 is equal to

$$\text{Plate Current Change} = \frac{G_m E_x}{1 + RG_m} = \frac{G_m E_x}{G_m R} = \frac{E_x}{R}$$

when RG_m is large in comparison with 1. This expression shows that when R is sufficiently large, the change in plate current depends only on the value of the cathode resistor and is completely independent of the tube characteristic and operating voltages. In particular the change in plate current is then equal to the applied grid voltage E_x divided by the cathode resistance R.

From the preceding description it is clear that the use of such a degenerative circuit makes it possible to apply much larger voltages than can ordinarily be applied to the grid circuit. This advantage is made possible by the degenerative voltage E_R produced across the cathode resistor; this voltage balances out the large applied grid voltage so that the net grid-cathode voltage change is small and within the normal range of grid voltages which the tube is capable of handling. The only limitation on the voltage which can be applied to the grid is that the plate voltage must always be somewhat higher than the highest voltage which is applied to the grid, in order that the tube may operate as a triode.

When the sensitivity of the amplifier is varied by changing the cathode resistance, it is necessary to change the bias voltage so that the tube will still operate over the linear portion of its characteristic. This is accomplished in Fig. 8-5 by means of a switch

S1B which is ganged with the switch *S1A* selecting the cathode resistor. When the proper value of bias voltage is used for each range, it is possible to maintain the normal value of operating plate current on all ranges. If the simplified circuit shown in Fig. 8-4 were used, proper operation would not be obtained with large cathode resistors because the tube would be functioning near cutoff where the mutual conductance is very small, and the characteristic is nonlinear.

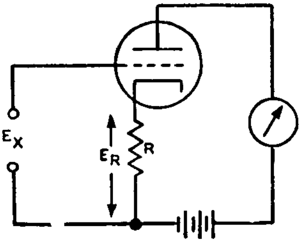


Fig. 8-4. The fundamental circuit of a degenerative d-c amplifier such as is used in many d-c and rectifier-amplifier v-t voltmeters.

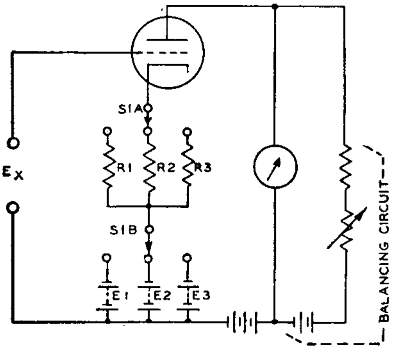


Fig. 8-5. A degenerative d-c amplifier in which the sensitivity is varied by means of *S1A*. The same operating point is maintained by *S1B* which changes the bias voltage to compensate for the change in the cathode resistance.

The following example shows how the bias voltage can be varied to maintain the plate current at the same value on all ranges. Suppose that an operating current of 500 microamperes is decided upon, and that the corresponding grid bias is equal to 3 volts. Now suppose further that the cathode resistor for the highest voltage range is equal to 200,000 ohms. Since 500 microamperes flowing through 200,000 ohms will cause a voltage drop of 100 volts, it follows that the bucking voltage required to obtain the desired bias of 3 volts must be equal to 97 volts, with the polarity indicated in Fig. 8-5. The required cathode voltage *E1* for any of the other voltage ranges can be determined in a similar manner. If the same operating plate current is used on all ranges, no change is required in the circuit for balancing the steady plate current. If a smaller value of operating plate current is used on the higher voltage ranges, however, then another section must be used on the range switch to supply the proper value of meter balancing current.

Balanced Push-Pull D-C V-T Voltmeter

A balanced v-t voltmeter circuit using two tubes is shown in Fig. 8-6. This circuit is unique in that the two cathodes are coupled together through a large value of resistance *R3*. As a result of this common cathode coupling, a large value of *R3* can be used without the accompanying degeneration which would result in a single-ended circuit. Because large values of *R3* can be used on the most sensitive ranges without an appreciable reduction in sensitivity, the circuit makes possible increased stability of operation.

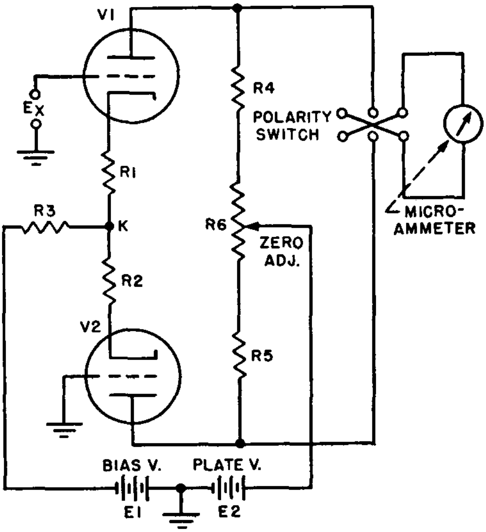


Fig. 8-6. A balanced v-t voltmeter circuit in which stable operation is secured by using a large cathode resistor *R3* common to both tubes. The polarity switch enables the measurement of positive and negative voltages.

The operation of this circuit is as follows: When a positive voltage, for example, is applied to the grid of *V1*, the plate current of *V1* increases. This increased plate current results in a more positive voltage at the junction *K*. This positive voltage at *K* also acts on *V2* since it tends to make the cathode of *V2* more positive, and thus tends to decrease the plate current of *V2*. In this way it is evident that the application of a positive voltage to the control grid of *V1* causes an increase in the plate current of *V1* and a decrease in the plate current of *V2*. Provided *R3* is sufficiently large, it can be shown that the decrease in the plate current of *V2* will be almost equal to the increase in the plate current of *V1*. Because of this push-pull action, the presence of the large value of cathode resistance *R3* causes a negligible amount of degeneration. At the same time the sensitivity of the amplifier can be varied by inserting resistors in each of the individual cathode circuits, as represented by *R1* and *R2*.

The manner in which *R3* contributes to the stability of the circuit can readily be seen. When *R3* is large, the operating plate current is determined largely by the resistance *R3* and the bias voltage *E1*. In designing the circuit, the procedure is to decide upon the value of *R3* and upon the operating plate current. The value of the bias voltage *E1* should then be fixed at a value such that *E1* is equal to the voltage drop of the operating plate current through *R3*. Regardless of fluctuations in line voltage or in tube characteristics, the plate current will then "settle down" to this same value of operating current and highly stable operation will result.

A feature of this balanced circuit is that the sensitivity can be changed by varying the resistance of *R1* and *R2*. When this is done, no auxiliary bias voltage need be changed; the operating plate current will remain essentially constant as the degenerative cathode resistors *R1* and *R2* are varied, provided that *R1* and *R2* are small in comparison with *R3*. Because the circuit is symmetrical, it follows that the same zero adjustment is maintained on all ranges.

This same type of balanced circuit can also be used with the cathode resistors connected directly to ground in the conventional self-biased circuit. Where this arrangement is used, an auxiliary bias voltage must be introduced either in the grid or cathode circuit in order to keep the operating plate current constant as the cathode resistors are changed.

A polarity switch is provided in the plate circuit so as to enable the measurement of both positive and negative voltages without switching the input leads. The reversal of polarity is accomplished by using a conventional reversing switch which interchanges the connections of the meter to the plates of the two tubes. The value of the plate load resistors is not critical; satisfactory operation will be secured so long as these resistors are large in comparison with the meter resistance.

In common with all balanced v-t voltmeter circuits, the circuit in Fig. 8-6 has the advantage that the zero adjustment is stable and that the meter is not overloaded when the instrument is turned on or off. By choosing a value of operating plate current which is not more than several times the full-scale sensitivity of the meter, damage to the instrument can be prevented even though many times the full-scale voltage is applied to the input terminals.

Where unusually high sensitivity is required, it can be obtained by adding a similarly balanced stage of amplification to the circuit shown in Fig. 8-6.

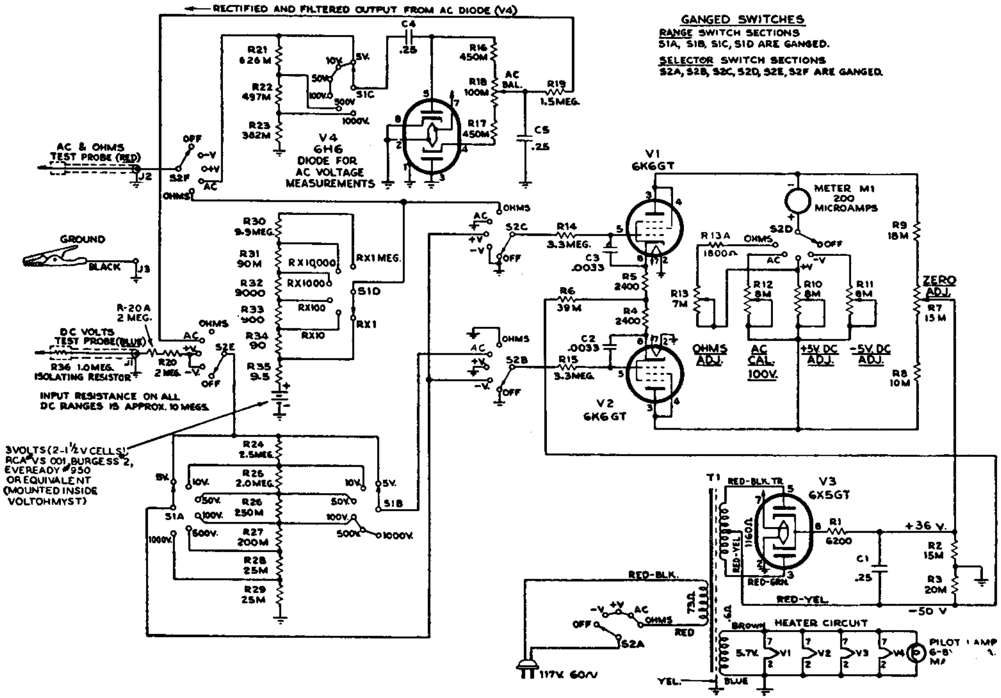
The RCA VoltOhmyst Type 195-A

A commercial instrument using the balanced push-pull circuit is shown in Fig. 8-7. An analysis of the system illustrates that it is essentially similar to the basic circuit of Fig. 8-6. D-c voltage ranges from 5 volts full scale to 1,000 volts full scale are obtained by means of the voltage divider *R24–R29* located in the input circuit. The d-c probe input affords an input resistance equal to about 10 megohms. Thus the input resistance is about 2 megohms per volt for the 5-volt range and 10,000 ohms per volt on the 1,000-volt range.

The a-c voltage ranges (5–1,000) utilize a double-diode 6H6 rectifier circuit. One half of this double diode serves as the signal rectifier while the other half is employed to balance the contact potential. For a-c voltages of from 5 to 100 volts, the d-c output from the diode is attenuated by steps on the d-c attenuator, but for the 500 and 1,000-volt ranges the ac is attenuated before it is applied to the diode so that the latter is never subjected to more than 100 volts.

In addition to the a-c and d-c voltage ranges, the instrument provides for the measurement of resistances over a range extending from 0.2 ohm to 1,000 megohms. This part of the circuit is tied in with the d-c v-t voltmeter and will be explained in the latter part of this chapter in connection with d-c v-t ohmmeters.

Because of the balanced circuit it is possible to use a relatively simple power supply and filter. A full-wave rectifier is employed which delivers 86 volts through a 6,200-ohm filter resistor and



Courtesy RCA

Fig. 8-7. The schematic diagram of the RCA VoltOhmyst type 195-A. This meter uses a balanced, push-pull d-c amplifier similar to the circuit shown in Fig. 8-6.

across a 0.25-μf filter capacitor. The positive voltage applied to the plates of the tubes is about 24 volts, while the negative voltage applied to the cathode return circuit through a 39,000-ohm common cathode resistor is about 50 volts. The plate current of each tube is approximately 600 microamperes. The relatively low values of plate voltage and plate current are utilized in order to reduce the grid current to a very low value (of the order of 0.0001 microampere). To prevent a-c voltages from reaching the grid, *R14* with *C3* and *R15* with *C2* are used as filters in the grid circuits of *V1* and *V2* respectively.

The zero balance control is *R7* in the plate circuit. This is adjusted to make the meter read zero with no input voltage for plus and minus d-c voltage measurements on all ranges. For d-c voltage measurements when the high or ungrounded side of the circuit is positive, the voltage to be measured is applied to the grid of *V1* while for voltages which are negative with respect to ground, the voltage is applied to the grid of *V2*. This is a simple and effective method of reversing the polarity of the meter. Since there are many applications in which it is convenient to have zero at the center of the meter so that it will deflect upward for voltages which are positive with respect to ground and downward for negative ones, the zero adjustment *R7* has sufficient range to permit this setting although the meter scale does not show a center zero.

The normal zero adjustment for voltage measurements is also used for ohmeter resistance measurements. When the function switch is thrown to "ohms" the meter will read approximately full scale with the resistance test leads open. *R13* which is a voltmeter sensitivity control, allows setting the meter accurately to full scale. This latter adjustment compensates for changes in the terminal voltage of the "ohms" battery.

Balancing the contact potentials of the 2 diodes used for a-c measurements is done by means of *R18*. This adjustment compensates for drift in the diode characteristics. Changes due to aging of the tubes are corrected by *R12, R10,* and *R11,* which adjust the a-c, d-c plus, and d-c minus sensitivities respectively. The tube heaters are operated at subnormal voltage (5.7 volts) in order to reduce the grid current. This low heater voltage is permissible because only 600 microamperes is drawing from cathodes which are capable of supplying 100 times as much.

Resistance Measurements with the V-T Voltmeter—V-T Ohmmeters

The d-c v-t voltmeter can readily be adapted to the measurement of d-c resistance over an extremely wide range. A number of different circuits can be used for measuring resistance, but basically all of these methods involve a comparison between the voltage drop across the *unknown resistor* and the voltage drop across a *standard resistor*. Since the two voltage drops are in the same ratio as the two resistances, it follows that the unknown resistance can be determined in terms of the two voltage drops and the known resistance. This basic method has been refined, as will be shown in the following sections, so that a d-c VTVM can be made direct reading in terms of resistance as well as in terms of voltage.

Direct-Reading Vacuum-Tube Ohmmeter

A representative direct-reading vacuum-tube ohmmeter is shown in Fig. 8-8. This ohmmeter circuit may be used with almost any

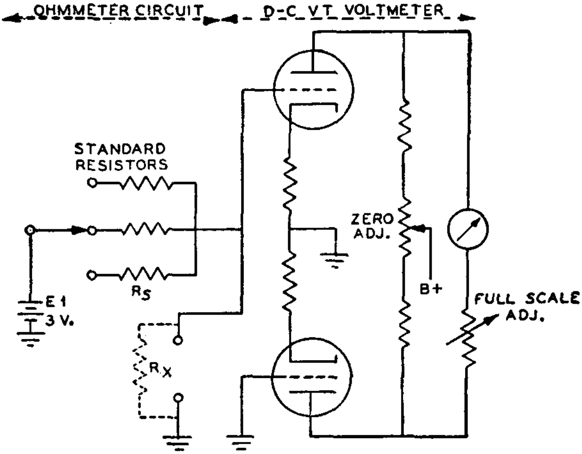


Fig. 8-8. A direct reading v-t ohmmeter circuit. The unknown resistance is determined by measuring the voltage developed across it. A typical scale is shown in Fig. 8-9.

type of d-c v-t voltmeter, although the particular circuit shown is of the balanced type.

An external battery (1.5 or 3 volts) is used to supply the circuit which consists of a standard resistor R_S in series with the unknown resistor R_X. Initially, before R_X is connected to the input terminals, the sensitivity of the v-t voltmeter is adjusted so that the meter reads full scale. This adjustment may be accomplished by a variable resistor in series with the meter, as illustrated in the figure. Note that with R_X disconnected, the full value of the battery voltage is applied to the v-t voltmeter. Now when R_X is connected across the input terminals, a voltage divider is formed so that only a fraction of the battery voltage reaches the VTVM. As a result of this voltage division, the reading of the v-t voltmeter is reduced from the full-scale value by an amount which depends upon the resistance connected between the input terminals. Thus it follows that the scale can be calibrated in terms of the resistance required to give any particular scale deflection.

A typical direct-reading ohmmeter scale is shown in Fig. 8-9. The extreme left of this scale—the zero voltage point—also corresponds to a zero value of R_X since the voltage across R_X is zero when R_X is equal to zero. Similarly, the middle of the voltage scale corresponds to the value of the standard resistor R_S which, for the scale shown, is equal to 10 ohms. The full-scale deflection corresponds to an open circuit or infinite resistance for R_X. Intermediate values of resistance on the voltage scale may be computed by means of the following equation:

$$R_X = R_S\left(\frac{E_X}{E - E_X}\right)$$

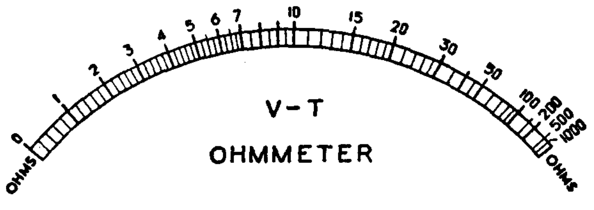


Fig. 8-9. Typical scale of a vacuum-tube ohmmeter using the basic circuit shown in Fig. 8-8. This scale is used in the instrument shown in Fig. 8-7 to cover the range from 0.1 ohm to 1,000 megohms.

where E = full-scale voltage and E_X = voltage with R_X connected.

The same scale shown in Fig. 8-9 can be used in conjunction with multiplying factors to provide a number of resistance ranges. For example, if standard resistors of 10 ohms, 100 ohms, 1,000 ohms, etc., are selected by means of a switch, the corresponding mid-scale values for each of these ranges will be equal to 10 ohms, 100 ohms, 1,000 ohms, etc. Thus the same scale can be used in conjunction with various multiplying factors of *R × 1, R × 10, R × 100,* etc. A typical circuit of this type is illustrated in Fig. 8-7 which shows the schematic of a commercial combination v-t voltmeter and ohmmeter. In this circuit six standard resistors ranging from 10 ohms to 10 megohms are used, so that mid-scale values from 10 ohms to 10 megohms are provided. Since resistances can be read below and above the mid-scale values, the total range covered is from 0.1 ohm to 1,000 megohms.

A feature of this type of ohmeter circuit is the fact that the adjustments remain constant on all the resistance ranges. Thus the zero adjustment need be made only when the instrument is first turned on, and is completely independent of any part of the ohmmeter circuit. The adjustment for full-scale deflection likewise remains the same for all the resistance ranges since it depends only on the battery voltage.

Unlike the shunt ohmmeter in which the battery will run down rapidly if the instrument is left on, the v-t ohmmeter has the advantage that no current is drawn from the battery except during the actual measurement when the unknown resistor is connected across the input terminals. Otherwise the current drain on the battery is limited to the grid current of the tube which is entirely negligible since it is a very small fraction of a microampere.

The subject of grid current leads to an important point in connection with the v-t ohmmeter. Unless the grid current is less than 0.01 microampere there will be an error on the high-resistance range where the grid circuit is completed through the comparatively high resistance of the standard R_S. Although it may still be possible to adjust the meter to read full scale, there will be an appreciable error if the grid current is large because the scale calibration will follow a different distribution. In the commercial VTVM shown in Fig. 8-7, the circuit design is such that the grid current is reduced to a value which is less than 0.0001 microampere on all ranges. As a result of this extremely small grid current, the voltage drop across the standard due to the flow of grid current is negligibly small on even the highest range. (A rapid method by means of which the presence of grid current can be detected is described on page 203.)

Where low-resistance ranges need not be covered, the voltage *E1* in Fig. 8-8 may be supplied from the voltage divider of a power supply. The resistance of the bleeder which supplies the voltage should be small in comparison with the smallest resistance to be measured. As a result of this limitation, it follows that a battery is preferable where resistances smaller than about 1,000 ohms are to be measured.

V-T Ohmmeter with External Voltage Supply

Any good v-t voltmeter can readily be adapted so that extremely high values of resistance can be measured by means of an external voltage supply. Although the circuit shown in Fig. 8-10 is not as convenient as the direct-reading ohmmeter circuit previously described, the present circuit has the advantage that much higher values of resistance extending up to approximately 100,000 megohms can be measured.

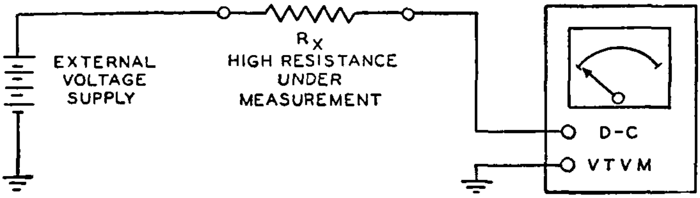


Fig. 8-10. A circuit for measuring high values of resistance by placing the unknown in series with an external voltage supply and a d-c v-t voltmeter.

As shown in Fig. 8-10, the unknown resistance is connected between the high side of an external voltage supply and the input to the v-t voltmeter. The external voltage supply may have any value extending from about 20 volts to 500 volts; the higher values of voltage permit higher values of resistance to be measured. When the connections are made as shown in the figure, the reading of the v-t voltmeter depends on the unknown resistance, the input resistance of the VTVM and the external voltage. The unknown resistance can thus be computed by means of the following formula:

$$R_X = R\left(\frac{E1 - E2}{E2}\right)$$

where $E1$ = External voltage
$E2$ = Reading of v-t voltmeter
R = Input resistance of v-t voltmeter.

Where the unknown resistance is large, the voltage developed across the v-t voltmeter is small in comparison with the external voltage so that the formula can be simplified by rewriting it as

$$R_X = R\left(\frac{E1}{E2}\right).$$

A typical example will indicate the manner in which this relation is used. Suppose that the external voltage $E1$ is equal to 500 volts, that the input resistance R of the VTVM is 10 megohms, and that with a particular value of unknown resistance R_X connected in the circuit, the v-t voltmeter reading is equal to 0.5 volt. Substituting in the above formula, the unknown resistance is equal to

$$R_X = 10 \text{ megohms} \times \frac{500}{0.5} = 10{,}000 \text{ megohms}.$$

This method is particularly valuable in measuring the leakage resistance of paper and mica condensers. To avoid injury to the meter, the v-t voltmeter should be set on the highest voltage range while the capacitor is charging. If this precaution is not followed, the pointer will deflect off scale, since the initial "throw" will correspond approximately to the external voltage. Once the capacitor has been charged, the voltmeter reading will steady down to a small value of leakage voltage the value of which will depend upon the leakage resistance of the capacitor.

When the leakage resistance of large capacitors having a capacitance of several microfarads or more is measured by this method, a considerable period is taken for the capacitor to charge to its final voltage. For example, where the capacitance is 10 μf and the input resistance of the v-t voltmeter is 10 megohms, several minutes will elapse before the leakage voltage reaches its final value. This waiting time can be greatly reduced if the capacitor is initially charged by connecting it directly to the external voltage supply.

Use of Guard Terminal—In the measurement of high values of resistance it is frequently necessary to use a *guard* terminal in order to prevent surface leakage from impairing the accuracy. An illustration of the manner in which such a guard terminal is connected when the VTVM is used for measuring high resistances is shown in Fig. 8-11. In this application, the problem is to measure the leakage resistance of a cable. To prevent leakage from the inner conductor over the surface of the cable to the outer sheath, it is customary to strip the shield for at least 18 inches and to wind a conductor over this section, as is shown in the figure.[2]

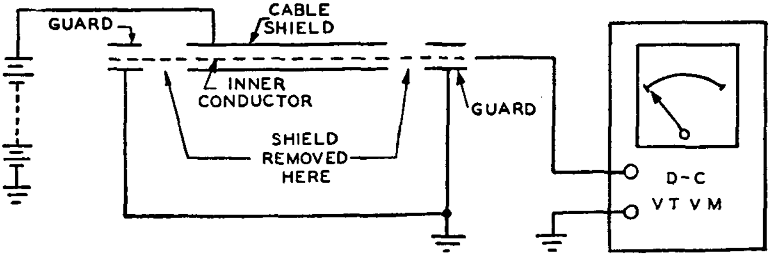


Fig. 8-11. The use of a guard terminal to prevent surface leakage when high values of resistance are measured with the v-t voltmeter.

This constitutes the *guard* which should be connected to the common circuit ground. Because of the large voltage difference between the guard and the shield of the cable (the low side of the resistance being checked), and because of the negligible difference in voltage between the inner conductor and the guard, it follows that whatever surface leakage takes place will flow directly to ground and will not affect the accuracy of the measurement. Although the specific application discussed above deals with the measurement of cable leakage, a similar guard ring may also be employed in other measurements where surface leakage must be prevented. It should be noted that no special guard terminal need be brought out from the v-t voltmeter (as in the case of the Megger for example)

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[2] A complete description of the necessary precautions to reduce surface leakage will be found in F.A. Laws, *Electrical Measurements*, 2nd ed., McGraw-Hill Book Co., New York, N.Y., 1938, p. 197.

since the guard connection is made directly to the low or ground terminal of the VTVM.

Slide-Back V-T Ohmmeter for High Resistances

A circuit which is adapted to the measurment of resistances as high as a hundred thousand million million (10^{17}) ohms is shown in Fig. 8-12.[3] This circuit bears a close resemblance to the circuit described in the preceding section but differs from it in two essential respects. First, the v-t voltmeter employs a special General Electric FP-54 electrometer tube which is designed to have a very low grid current and very high input resistance. Secondly, the v-t voltmeter is not calibrated, but instead a slide-back method is used to determine the voltage developed across the VTVM input. In this way the accuracy is made to depend only on the accuracy of the low-resistance voltmeters used to measure the voltages *E1* and *E2*. This circuit can of course be used with a conventional d-c v-t voltmeter instead of with the electrometer tube circuit in which case the range is limited only by the grid current and input resistance of the particular vacuum tube employed.

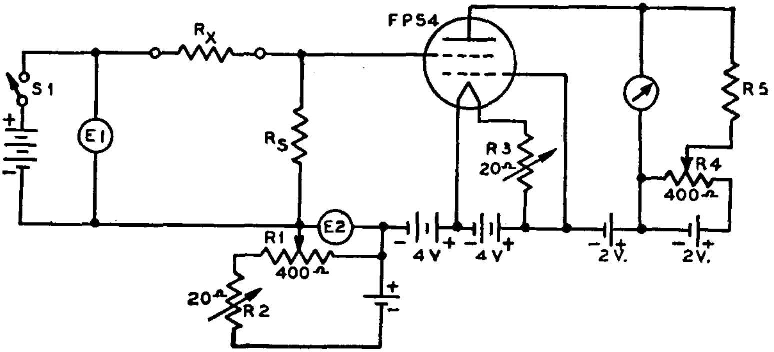

Fig. 8-12. A v-t voltmeter circuit for the measurement of extremely large values of resistance up to 10^{17} ohms. A type FP-54 electrometer tube is used to obtain a high input resistance and low grid current.

The unknown resistance R_X is placed in series with a standard resistance R_S and a source of voltage *E1* which may vary up to several hundred volts. The voltage developed across R_S is applied

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[3] G. M. Rose, "A Method for Measuring Very High Values of Resistance," *Review of Scientific Instruments,* vol. 2, pp. 810–813, Dec. 1931.

to the input of the v-t voltmeter and since this voltage depends upon R_X, it follows that R_X can be determined in terms of the voltage developed at the input to the VTVM.

The procedure for making a measurement is to open the switch *S1*, adjust the slide-back potentiometer *R1* to zero, and to note the galvanometer or microammeter reading. The switch should then be closed so that the voltage *E1* is applied to the two resistors, and the potentiometer *R1* adjusted so that the same galvanometer reading is obtained. When this adjustment is made, the unknown resistance R_X can be determined in terms of *E1, E2,* and R_S by means of the following relation:

$$R_X = R_S\left(\frac{E1}{E2} - 1\right).$$

The accuracy of this method depends only upon the accuracy of R_S and the low-resistance voltmeters used to measure *E1* and *E2.* To cover a wide range, it is recommended that three standard resistors having values of 10^9, 10^{12}, and 10^{15} ohms be used.[4] Any of the high-resistance standards may be calibrated in terms of a known standard resistor of lower value. The next higher value of standard resistor may then be calibrated in terms of the lower standard just calibrated, and so on up to the highest value of standard resistor.

The circuit shown in Fig. 8-12 can be used with very slight modifications for the measurement of very small direct currents.

Sensitive Current Measurements with the D-C V-T Voltmeter

The v-t voltmeter can be readily adapted to the measurement of d-c currents over a very wide range. In this application, standard values of resistance are placed in the input circuit of the v-t voltmeter and the unknown value of current interpreted in terms of the voltage drop caused by the current flow through the known input resistor. For example, in the simple circuit shown in Fig. 8-13, suppose that the v-t voltmeter has a full-scale sensitivity of 1 volt, and that three values of standard resistance can be selected by means of the input switch *S1.* When the 10-megohm resistor is shunted across the input, the meter will read full scale for a current

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[4] Suitable resistors, which are supplied with a calibration giving the exact value, can be obtained from the S.S. White Dental Mfg. Co., Industrial Division. Deposited carbon resistors from several manufacturers are also available to accuracies of 1 per cent or better.

of only 0.1 microampere. Similarly, on the other two ranges shown, full-scale deflection will be obtained for currents of 1 microampere and 10 microamperes. By using lower values of input resistance, larger values of current can be measured.

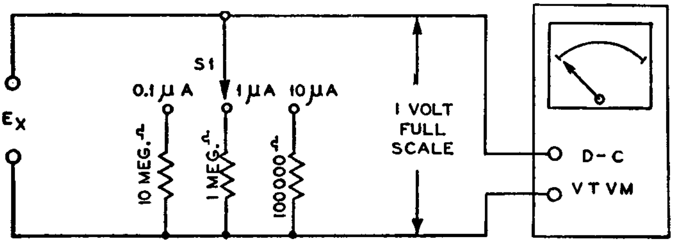

Fig. 8-13. The v-t voltmeter can be used as a sensitive microammeter by placing standard values of resistance in the input circuit and interpreting the voltage developed across these resistors in terms of the unknown current.

Using the basic circuit just described, v-t microammeters have been designed which have numerous advantages over the relatively delicate suspension type galvanometers used for measuring small currents. These advantages include greater sensitivity, ruggedness, lower cost, portability, and greater speed of measurement. The accuracy which can be secured is as good or better than can be obtained by other methods.

With the v-t voltmeter type of microammeter there is always a voltage drop across the input which depends upon the sensitivity of the v-t voltmeter. Ordinarily the drop of approximately 1 volt or less required for full-scale deflection is not objectionable in circuits which carry small currents. In special applications which require a lower voltage drop it is possible to use v-t voltmeters which give a full-scale deflection for approximately 0.1 volt or less.

Degenerative V-T Microammeter and Voltmeters

The basic circuit of an amplifier which has been used in multirange d-c VTVM's and microammeters is shown in Fig. 8-14.[5] This circuit employs a high-gain direct-coupled amplifier the output of which is fed back to the input so that degeneration is produced. As a result of the 100 per cent feedback employed, the circuit is extremely stable and a high degree of accuracy is secured.

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[5] A. W. Vance, "An Improved Vacuum-Tube Microammeter," *Review of Scientific Instruments,* vol. 7, pp. 489–493, Dec. 1936.

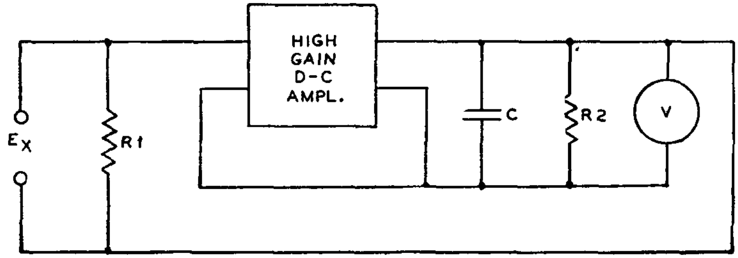

Fig. 8-14. The basic circuit of a degenerative direct-coupled amplifier which is used in v-t voltmeters and microammeters. 100% feedback is secured by coupling the voltage developed across the output back to the input.

An analysis of this circuit shows that the voltage developed across the load resistor of the final amplifier tube will be equal within very close limits to the voltage which is applied to the input terminals. For example, if the gain of the amplifier is 1,000, then the voltage indicated by the voltmeter *V* will be less than the input voltage by only 1 part in 1,000 or by less than 0.1 per cent. Furthermore, because the gain is so much greater than 1, it follows that the output voltage will remain essentially equal to the input voltage over a wide range of variations in the circuit constants and tube characteristics. This may readily be seen, for if the amplification should change from say 1,000 to 500, a change of 2 to 1, the only effect would be to cause an error in the voltmeter reading of about 0.1 per cent.

Since amplifiers of this type using inverse feedback show a tendency toward high-frequency oscillation, some means must be taken to suppress this oscillation. One method employed is to shunt the output load resistor with a large capacitor as is indicated by *C* in Fig. 8-14.

A Multi-Range Microammeter Using Inverse Feedback

A practical circuit using a direct-coupled amplifier of the type discussed in the preceding section is shown in Fig. 8-15. A three-stage battery-operated amplifier having an over-all voltage gain of 5,000 is employed. As in the basic circuit of Fig. 8-14, the voltage developed across the 10,000-ohm output resistor is fed back to the cathode of the input tube so that 100 per cent negative feedback is secured. With no voltage applied to the input terminals, the amplifier locks in at a stable operating point such that the drop across the 10,000-ohm load resistor is equal to about 1.4 volts. A 1.5-volt cell and potentiometer are used to balance out this voltage so that the voltmeter reads zero.

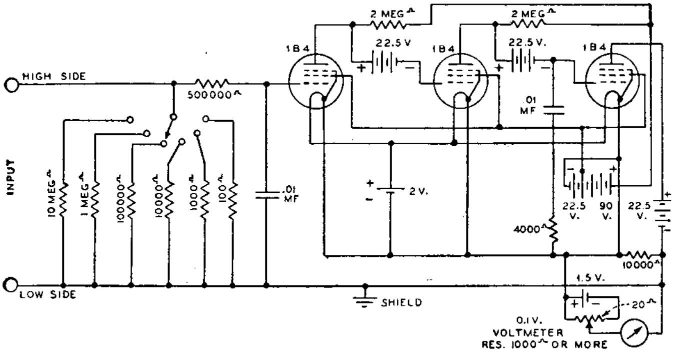

Fig. 8-15. A multi-range v-t microammeter employing a three-stage direct-coupled amplifier. See Fig. 8-14 for the basic circuit.

The input circuit is arranged to provide full-scale current ranges extending from 0.01 microampere to 1,000 microamperes. The several ranges are obtained by inserting different values of resistance in the input circuit. These values range from 10 megohms to 1,000 megohms. Lower values of resistance could be used to increase the current range, but this is not practical since such measurements can be made more simply by using a conventional milliammeter.

The multi-range microammeter circuit shown in Fig. 8-15 can also be arranged so either voltage or resistance can be measured simply by changing the input circuit.[6] A voltage-divider arrangement must be used for voltage measurements since the sensitivity cannot be varied over a wide range by changing the sensitivity of the voltmeter used to measure the feedback voltage.

The basic circuit shown in Fig. 8-14 can also be adapted to a-c operation. In one commercial instrument which was designed primarily for recording small d-c voltages, a three-stage a-c operated amplifier is used to obtain full-scale deflection on a 5-milliampere

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[6] J. M. Brumbaugh and A. W. Vance, "A Feedback D-C Meter," *Electronics,* vol. 11, pp. 16–17, Sept. 1938.

meter for an input voltage of only 0.1 volt. Although designed primarily for operating a recorder, this amplifier may also be used as a VTVM by the provision of a voltage divider in the input circuit.[7]

Ultra-Sensitive Current Measurements

The measurement of currents smaller than about 0.001 microampere requires the use of special electrometer vacuum tubes which are designed to have an extremely low grid current and high input resistance. The General Electric FP-54 Pliotron is suitable for such measurements. This tube uses a special type of construction by means of which it has been possible to reduce the grid current to about 10^{-15} ampere and to raise the input resistance to approximately 10^{16} ohms. A circuit similar to that shown in Fig. 8-12 may be used for the measurements of extremely small current down to as low as 10^{-14} ampere. Many other circuits have been devised which employ special means to obtain the necessary degree of stability.

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[7] J. K. Clapp, "A-C Operated D-C Amplifier for Industrial Use," *General Radio Experimenter,* vol. 13, pp. 1–4, Feb. 1939.

REVIEW QUESTIONS

CHAPTER 8

8–1. Give five advantages offered by d-c v-t voltmeters over conventional d-c voltmeters.
8–2. How does the grid current of the triode in d-c VTVM's affect the input resistance?
8–3. How would you check a d-c VTVM to find the grid current?
8–4. Explain a method for making measurements in a high impedance circuit with a d-c v-t voltmeter having no input attenuator and an appreciable grid current.
8–5. What are the advantages of having a center-zero arrangement in a d-c VTVM?
8–6. Why should the "low" input terminal of a d-c VTVM be connected to ground for measurements?
8–7. Describe a *safe* method for measuring voltages between two high-voltage points in a circuit.
8–8. Outline a method for converting a *left-zero* d-c VTVM to a *center-zero* d-c v-t voltmeter.
8–9. Explain the basis of operation of v-t ohmmeters.
8–10. What is a guard ring? For what type measurements is its use . necessary?
8–11. How may a d-c VTVM be used for sensitive current measurements?

CHAPTER 9

PROBES FOR DC AND RF

A probe is a device or circuit added to the input of an electronic voltmeter to facilitate the measurement of radio, intermediate, or video frequencies, and high voltages. There are various types of probes, each designed for a specific purpose. In general, probes are designed either to increase the input resistance or to decrease the input capacitance of the voltmeter. In particular, d-c isolating probes minimize the effect of d-c measuring equipment leads in circuits carrying a-c or r-f signals which are not to be disturbed.

Although two types of probes have been discussed previously, in Chapters 5 and 8, we will now go into probes and their uses completely.

D-C Probes

Fig. 9-1 is the circuit of a simple probe consisting of a resistor in series with the cable input lead of the voltmeter. The resistance most commonly used for this purpose is 1 megohm. If the d-c input resistance of the voltmeter is 10 megohms, $^{10}/_{11}$'s of the voltage applied to the probe tip will appear across the voltmeter terminals and the voltmeter must be calibrated to read correctly under these conditions. A direct connection to the voltmeter so calibrated will yield a reading that is 10 per cent high.

The use of this resistor permits the probing of circuits without loading or detuning them. This is particularly important for the measurement of d-c bias in the grid circuit of an oscillator where it is undesirable to load the oscillator. A resistance of from 1 to 5 megohms is high enough to prevent loading resistively most circuits; the effective shunt capacitance of the resistor, usually of the order of 1 $\mu\mu$f, does not greatly detune or otherwise affect most circuits. The resistor also increases safety in making measurements since it will effectively limit the current in case of bodily contact with lead or voltmeter terminals.

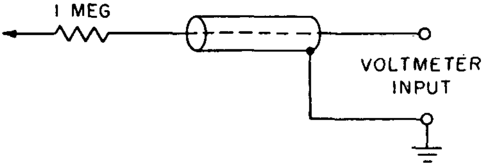
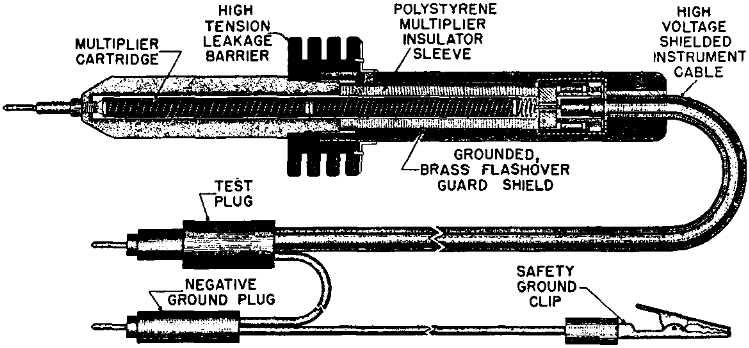


Fig. 9-1. Schematic diagram of a simple d-c probe. This is used to prevent the v-t voltmeter leads from loading the measured circuit.

The voltage range of a voltmeter may be extended to very high voltages by increasing the value of the probe resistance. A probe resistance of 991 megohms, for example, will multiply the range of a voltmeter having an input resistance of 10 megohms by a factor of 100, so that a 100-volt full range scale will read up to 10,000 volts. (A 991-megohm resistor is used because most meters are calibrated for use with a probe resistor of 1 megohm and this value must be added to the multiplier used.) The length of the probe must be increased so that it will accommodate a long 991-megohm resistor. The longer the resistor and probe, the less chance is there that the probe will break down or arc over with 10,000 volts across it. A barrier is usually provided on these probes to prevent the user from handling the tip and making contact with the high voltage being measured (see Fig. 9-2).

Resistors several inches in length having spiral films of carbon or metal are usually used in high-voltage probes. Resistors having values of 30,000 megohms and capable of handling a drop of 30,000 volts or more are available. It should be remembered that carbon and film-type resistors have a negative voltage coefficient. Due to this characteristic an increasing error may be observed as the voltage being measured is increased. For a high degree of accuracy, the resistor used in the probe should be selected so that the decrease in resistance due to increased voltage does not introduce an appreciable error. While the voltage coefficient is usually of prime importance, an error may also appear due to the variation of resistance with temperature. If the current through the probe



Courtesy Precision Apparatus Co., Inc.

Fig. 9-2. Cross-sectional view of a multiplier-type d-c probe, showing the long ribbon-wound resistor, the guard shield, and the barrier. Note that the resistor extends to almost the full length of the probe.

is sufficiently high, the resistor will be heated causing a change in resistance and hence, an error in meter reading. Temperature coefficient effects may be readily noted as the voltmeter reading changes gradually from an initial reading to a new reading as the resistor warms up.

The safety feature of the high-resistance probe for high voltage d-c measurements has been mentioned. These probes drop the voltage to a safe point at the vacuum-tube voltmeter terminals and limit the current from the high voltage source to a safe value. For instance, a 1,000-megohm probe resistor will limit the current from a 30,000-volt source to 30 microamperes. An additional precaution used in some probes is the inclusion of a grounded shield in the handle and extending up inside the barrier. In case of an arc-over, the spark will jump to the grounded shield rather than to the user's hand.

Typical examples of high-voltage d-c probes are RCA's models WG-289 and WG-284, Precision Apparatus models TV-1 and TV-2, and Barber Laboratories model HV-1. The RCA probes have resistors of 1,090 and 991 megohms, respectively; the Precision Apparatus probe resistors are 533 and 480 megohms, and the Barber Laboratories probe resistor is 30,000 megohms. The WG-289 is rated at 50,000 volts maximum, the rest at 30,000 volts maximum, and they draw from about 60 microamperes down to 1 microampere at the maximum rated voltage.

NOTE: *When working with high-voltage probes be certain to use all the precautions necessary for making safe measurements of high voltages.*

A good set of safety precautions to follow when making high-voltage d-c measurements are the following:

1. Locate all high-voltage points of the equipment under test before making measurements.
2. Work with one hand in your pocket.
3. Make sure that no part of your body touches ground at any time.
4. Keep hand close about probe and away from high voltage points; corona discharges may occur through the air and are just as dangerous as contact discharges.
5. Any point in a piece of defective equipment may contain high voltages, use probe when in doubt.
6. Discharge filter capacitors with safety insulated or grounded device before making measurements.

A-C Probes

Probes used as multipliers for a-c measurements have already been discussed under "Multipliers" in Chapter 5. Additional types of a-c probes will be discussed here.

Since in a-c measurements, the leads of the measuring equipment are a source of bypass capacitance, leading to attenuation of the input, it is advisable to shorten the leads as much as possible. To this end, the detector stage of the vacuum-tube voltmeter may be incorporated into a probe unit and applied directly to the circuit to be measured.

Fig. 9-3 is the circuit diagram of a typical diode-rectifier probe used for a-c and r-f measurements. The diodes most often used in a-c probes are the 6AL5 and 6H6. The input impedance is derived from the combination of shunt and series resistors and the shunt and series capacitors shown in the signal diode circuit. The second half of the diode is used to balance the contact voltage of the signal-rectifying half.

Suitable input terminals, one of which is usually grounded, are provided on the probe; jacks, clip leads, or short wires soldered to the circuit under test are used for connecting purposes.

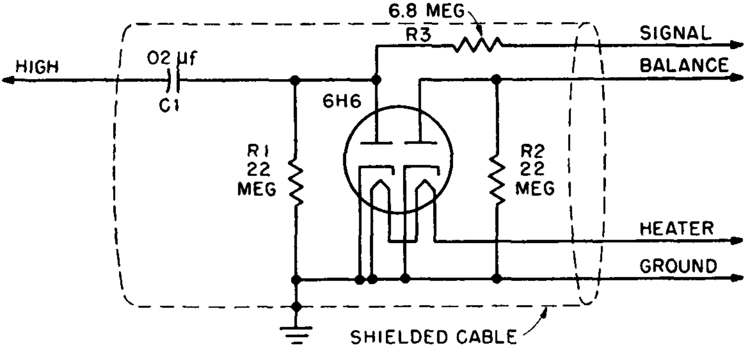


Fig. 9-3. Duo-diode rectifier probe used for a-c and r-f measurements with a v-t voltmeter. The first section of the diode rectifies the measured voltage; the second section balances the contact potential of the first.

The circuit under test is less disturbed by the probe type of voltmeter connection than by conventional leads, and operates more nearly under normal conditions. The probe permits measurement on "hot" or high-gain circuits which may have a tendency towards instability when long leads are connected to it. For power or audio frequency use, the a-c probe may also mount an isolating resistor similar to the kind used in d-c devices. Many voltmeters covering audio and radio frequencies have probes with coupling capacitors adjustable to the frequency being measured. Where such adjustable input capacitors are not included, the large input coupling capacitor required for audio-frequency measurements may be removed to improve the characteristics of the probe at radio frequencies.

Many of the comments to follow on the subject of radio-frequency probes also apply to audio-frequency probes.

R-F Probes

Since a probe permits the use of very short connecting leads, its widest application is with high-frequency voltmeters. The development and improvement of such probes has been going on for over twenty years. Since early vacuum-tube voltmeters were single tube affairs in which rectification and d-c amplification or meter coupling were accomplished in a single tube, and since early tubes were large and awkward, early probes were more or less cumbersome affairs. The gradual development in the art has evolved smaller and smaller probes mounted on more and more flexible cables. This development occurred simultaneously with the emphasis upon the miniaturization of radio components. An example of the size of the typical probe diode used in today's product is shown in Fig. 9-4, a photograph of the 1247-type tube. Notice on the illustration that the lead to the signal rectifying section of the duo-diode enters through the top of the tube; this permits this end of the tube to be inserted close to the tip of the probe so as to exclude the need of a lead wire.

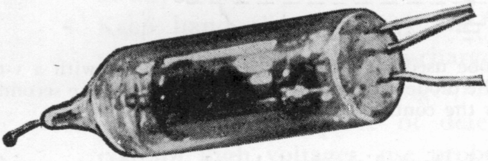
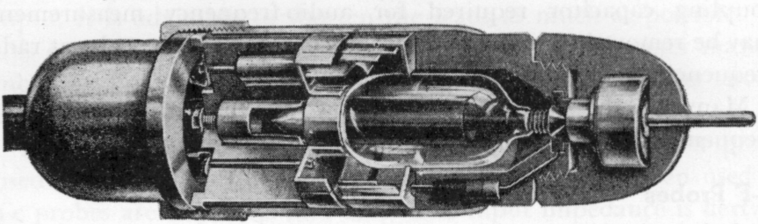


Fig. 9-4. The 1247 duo-diode sub-miniature, a common tube used in r-f probes.

Courtesy Sylvania Electric Products, Inc.

Figure 9-5 is a photograph of a well designed probe capable of measurements of r-f voltages up to about 1,000 Mc. The tube used in this probe was especially designed with the total construction of the probe in mind so as to reduce stray capacitances, inductances, and other error introducing factors. At frequencies above a few hundred kilocycles, long connecting leads introduce such errors and increase the circuit loading, so that the type construction shown in Fig. 9-5 is not only interesting from a design standpoint but also, is necessary for maximum accuracy at high frequencies.



Courtesy Hewlett-Packard Co.

Fig. 9-5. Cross-sectional view of an r-f and high-frequency probe used for measurements up to 1,000 Mc. Note the omission of connecting leads between the elements of the probe proper. Such a probe should not be used for high voltage measurements.

The disassembled probe shown in Fig. 9-6a is the RCA model WG-275. Audio-frequency voltages up to 100 volts rms can be measured with this unit. Its upper frequency limit is above 250 Mc.

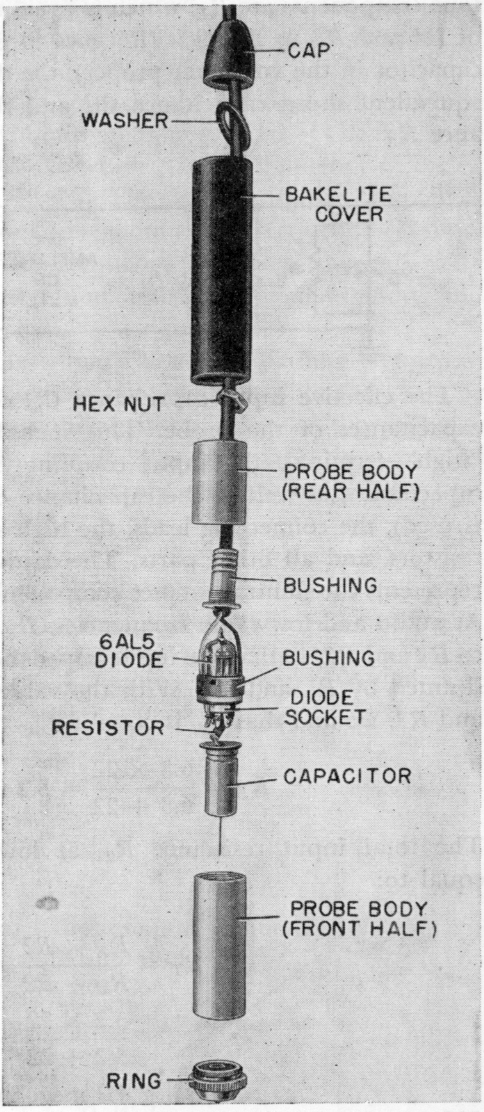


Fig. 9-6a. Disassembled duo-diode probe used for measurements from audio frequencies up to about 250 Mc. Note how each element of the probe is arranged so as to conserve space and give a slim unit. Care must be exercised when such a probe is disassembled for repair since excessive pulling or twisting may rupture some of the connecting leads or even break the tube. Repair instructions for the probe are given in the maintenance procedures for the RCA type WV-75A v-t voltmeter in Chapter 14.

Courtesy RCA

The probe schematic shown in Fig. 9-3 is typical of most r-f probes used today. An equivalent circuit showing the four major components of the input impedance is shown in Fig. 9-6b. These four components are R_E, which is equal to the parallel combination of $R1$ and $R3$ in Fig. 9-3 ($R3$ goes to ground through a coupling capacitor in the voltmeter proper), the diode shunt resistor $R2$, the equivalent shunt capacitance C_S, and the equivalent shunt resistance R_S.

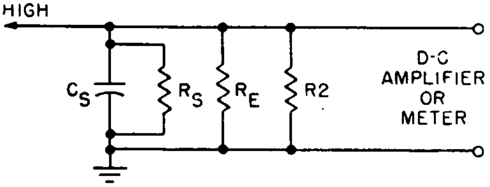


Fig. 9-6b. Equivalent circuit for duo-diode rectifier probes of the type shown in Fig. 9-3.

The effective input capacitance C_S, consists of all the shunting capacitances of the probe. This includes the capacitance of the "high" terminal, the input coupling capacitor, the diode plate capacitance, as well as the capacitance of the diode socket (if one is used), the connecting leads, the high side of the shunt and filter resistors, and all other parts. The equivalent shunt resistance R_S, represents the shunt resistance component of the capacitor dielectric. At audio and low radio frequencies, R_S, is usually large compared to R_E and $R2$, so that the input impedance essentially consists of C_S, shunted by R_E and $R2$. With the values given in Fig. 9-3 for $R1$ and $R3$, we find that R_E is equal to:

$$R_E = \frac{6.8 \times 22}{6.8 + 22} = 5.2 \text{ megohms.}$$

The total input resistance R_T, at low frequencies is therefore, equal to:

$$\begin{aligned} R_T &= \frac{R_E \times R2}{R_E + R2} \\ &= \frac{5.2 \times 22}{5.2 + 22} \\ &= 4.2 \text{ megohms.} \end{aligned}$$

The capacitive shunt resistance decreases linearly in value as the frequency increases. In the typical probe, this resistance becomes equal in value to the combination of R_E and $R2$ at about 1 megacycle. At higher frequencies, R_S rapidly becomes the predominant factor, so that at frequencies above 1 megacycle the input impedance of the probe is almost entirely that of C_g shunted by the R_g.

A probe having an input capacitance of 5μμf will have a capacitive reactance of 3,185 ohms at 10 megacycles. (The reactance of a capacitor is equal to $1/2\pi fC$, where f is the frequency in cycles, and C is the capacitance in farads.) The shunt resistance component of this capacitor will be about 1 megohm at this frequency (Q times the reactance value). As the frequency increases, the capacitive reactance decreases and the shunt resistance assumes more and more importance.

When making voltage measurements across a tuned circuit, an estimate of the error caused by the voltmeter probe may be obtained by computing the equivalent resistance of the probe to the tuned impedance of the circuit. The impedance of a parallel tuned circuit at resonance Z_r, is purely resistive and is equal to:

$$Z_r = Q_r^2 R$$

where Q_r is the Q value of the circuit at resonance
R is the equivalent series resistance of the circuit.

Since by definition, the Q of a series circuit is the ratio of its reactance to its resistance, we have:

$$Q_r = \frac{W_r L}{R}$$

or

$$R = \frac{W_r L}{Q_r}$$

where W_r is equal to 2π times the resonant frequency.

Substituting this into the equation above:

$$Z_r = \frac{Q_r^2 W_r L}{Q_r}$$

or

$$Z_r = Q_r W_r L.$$

Let us, for example, compute the resonant impedance of a tuned circuit having an inductance of 5 microhenrys, a Q of 200, and a resonant frequency of 10 megacycles. Using the equation above,

$$Z_r = 200 \times 2\pi \times 10^7 \times 5 \times 10^{-6}$$

or

$$Z_r = 62{,}800 \text{ ohms.}$$

Using the impedance just obtained and comparing it to that of the probe analyzed above, we find that the tuned-circuit impedance will be reduced by approximately 5 per cent when the probe is connected across it. The gain and selectivity of the circuit will be similarly affected.

Coil and capacitor circuits of conventional design have maximum Q values of from 200 to 300, so that a good 5-$\mu\mu$f input-capacitance probe is usable up to 100 megacycles or so. At still higher frequencies, circuits having very high Q values are encountered. A resonant line is an example of a circuit capable of building up a very high impedance at frequencies above 100 megacycles. Some newly developed high-frequency diodes are available and accomplish significant reductions in the input capacitance. Some of these with their characteristics are listed in Table 9-1.

TABLE 9-1

HIGH FREQUENCY DIODES USED IN R-F PROBES

Tube Name	*Heater Voltage (volts)*	*Heater Current (amps)*	*Input Cap ($\mu\mu f$)*	*Resonant Frequency (Mc)*	*Tube Type*
6AL5	6.3	0.3	3.2	700	Miniature
1247	0.7	0.065	0.6		Sub-Miniature
5647	6.3	0.150	2.2	900	Sub-Miniature
9004	6.3	0.15	1.6	850	Acorn
9005	3.6	0.165	1.0	1500	Acorn
9006	6.3	0.15	1.6	700	Miniature
2-01C	5.0	0.34	0.7	2800	Eimac

There are two additional considerations in the application of diodes to high-frequency measurements. In the above analysis, the effective series inductance of the probe input circuit has been neglected. Also, no mention was made of transit-time effects. Both of these limit the frequency range of a diode rectifier.

Neglecting resistance effects, a probe looks like a capacitance to the circuit across which it is connected at all frequencies up to about several hundred megacycles. Above that it looks like an inductance. This is due to the fact that, in addition to the above discussed shunt capacitance, there is always series inductance in the internal circuits of the probe. This inductance, composed of the inductance of the series leads, the series inductance of the input coupling capacitor, and the inductance of the leads inside the tube, usually varies from 0.01 to 0.1 microhenry.

As the frequency at which measurements are made is increased, the probe resonance (the frequency at which the capacitive reactance equals the inductive reactance) is approached, reached, and passed. The effect of resonance starts to show up as an increase in the reading of the voltmeter above approximately one-half the resonant frequency. The error gradually increases until, at resonance, the reading on the meter is 200 to 300 per cent higher than the actual voltage. After resonance, the error decreases rapidly. It should be emphasized that the resonant frequency of the whole probe is considerably below the resonant frequency of the tube alone. For instance, a tube may have a resonant frequency of 1,000 megacycles, yet the probe it is used in, even when of the best design, will resonate at 500 megacycles or less.

The above condition is shown graphically in Fig. 9-7. Here a type 5647 uhf diode, capable of operation to 1,000 Mc, was used in a typical probe unit. It is seen from the graph that the resonant frequency of the probe unit is a little more than half the resonant frequency of the tube itself (the *APPLIED VOLTAGE/INDICATED VOLTAGE* minimum occurs off the graph at 600 Mc). An equation for finding the factor by which the voltage across the diode is stepped up in the neighborhood of its resonant frequency is the following:

$$m = \frac{1}{1 - \left(\frac{f}{f_r}\right)^2}$$

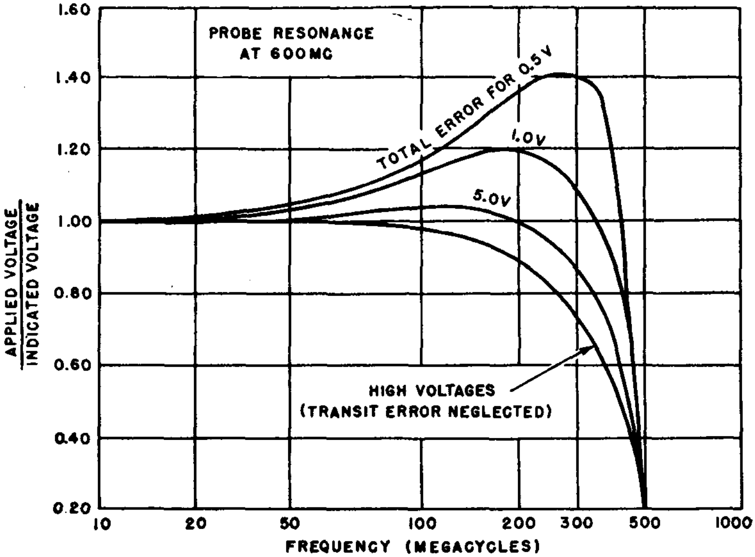
where m is the error factor

f_r is the resonant frequency of the probe circuit

f is the frequency of the applied voltage to be measured. Multiplying the applied voltage by this factor will give the indicated voltage.

Other causes for error in the meter reading near resonance are the increased loading effect accompanying resonance, and the transit-time effect of the diode. The transit time is the period it takes for an electron to move from the cathode to the plate of the tube. At high frequencies, the movement of electrons between the tube elements is not simultaneous with the change in grid voltage. Because of this, the relation between the plate current and the applied signal voltage is subject to error; the higher the frequency, the larger the error.

Large connecting clips and long leads may increase regeneration in circuits under test due to their inherent inductances and capacitances. At 10 megacycles, leads of No. 18 wire, or larger, and two or three inches long do not seriously disturb most circuits. At 50 to 100 megacycles, the shortest possible leads should be used as well as the smallest clips or, better still, the leads should be soldered directly to the circuit. Above 100 megacycles, even more stringent precautions should be taken, such as extensive shielding of all components. Some probes have removable tips, etc., to improve their operation at very high frequencies.



Courtesy Sylvania Electric Products, Inc.

Fig. 9-7. Graph of voltmeter reading error versus frequency of measured voltage for various voltage values measured on a v-t voltmeter using a diode-rectifier probe with a 5647 tube.

Crystal Probes

Germanium crystals are coming into considerable use for high-frequency probes. They have advantages of simplicity, freedom from contact potential, extended high-frequency response, no transit-time restrictions, low input capacitance, and small physical size. However, they have several serious disadvantages in that they are relatively unstable, show large variations in current due to temperature changes, are limited in voltage acceptance, and show wide variations in loss factor. The technique of manufacture as well as the general characteristics of germanium crystal diodes is being constantly improved. The best types available today are many times better than those which were available a few years ago.

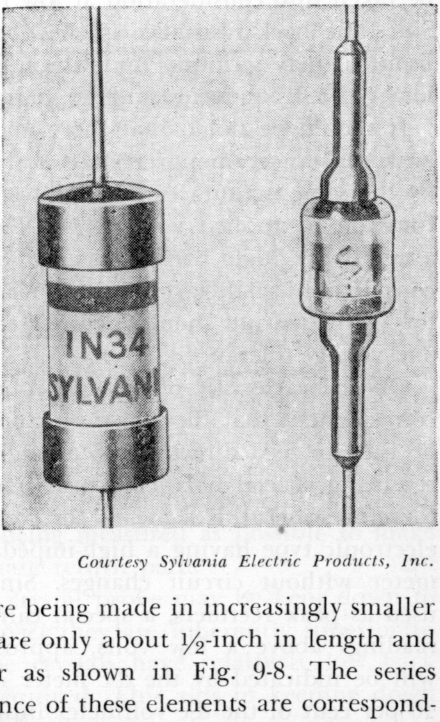


Fig. 9-8. Two germanium crystal diodes of the type used in crystal probes for r-f measurements. On the left is shown the ceramic type where the crystal is enclosed in a ceramic cartridge with metal caps. The one on the right consists of a crystal contained in a hermetically sealed glass container.

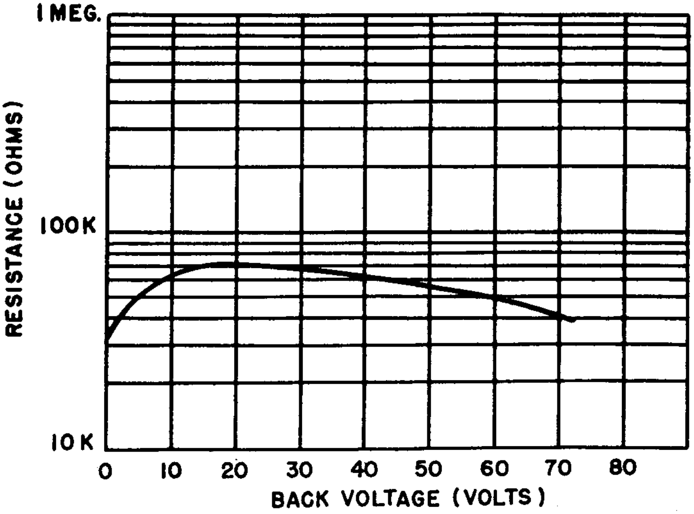
Courtesy Sylvania Electric Products, Inc.

Germanium crystal diodes are being made in increasingly smaller sizes. Some of the latest types are only about ½-inch in length and less than ¼-inch in diameter as shown in Fig. 9-8. The series inductance and shunt capacitance of these elements are correspondingly small, and the frequency response is uniform to hundreds and even thousands of megacycles. Many commercially available crystal probes do not approach the inherent frequency response of the crystal due to inadequate general probe design. This is unfortunate, since most of the real advantages of crystal probes are found only at the very high frequencies (50 megacycles and higher). For frequencies less than 50 megacycles, the crystal probe is at best equal to the vacuum-tube probe, and as the frequency is decreased, it becomes definitely inferior in several respects.

At low frequencies, the back resistance (the resistance at negative voltages), becomes an important characteristic. In diodes it is high enough so that it can be neglected in comparison with the usual shunt resistance and other shunts in the circuit. That is to say, it is negligible compared to resistances of the order of 5 megohms. However, almost all germanium crystals have back resistances ranging from a few thousand ohms to a few megohms, and these must be taken into consideration at low radio and at audio frequencies. Since the back resistance is effectively in parallel with the probe input, it may seriously limit the input impedance of the probe at low radio frequencies and at audio frequencies.

It should be noted that there may be considerable variation in back resistance among crystals of the same type, even those made by the same manufacturer. The back resistance is also generally a function of applied voltage (see Fig. 9-9). A crystal which shows a relatively high back resistance on small signals may show a considerably smaller resistance on large signals. Therefore, crystals for voltmeter use should be selected carefully for back resistance and voltage tolerance.

One characteristic of crystal probes which make their use more convenient is that they have no contact potential. Thus, they may be used to feed directly into a single-ended d-c voltmeter without requiring special balancing provisions in the amplifier. They are, therefore, useful as a means for converting a d-c voltmeter of the electronic type having a high-impedance input into an a-c and r-f meter without circuit changes. Since crystal diodes are usually used as peak rectifiers, a special calibration may be necessary. For readings above a few volts, approximately correct rms voltages will be indicated by the d-c meter if a dropping resistor equal to 40 per cent of the d-c voltmeter input resistance is placed in series with the crystal probe. This resistor also functions effectively as a filter resistor to reduce the effects of ac or rf on the d-c voltmeter circuits.



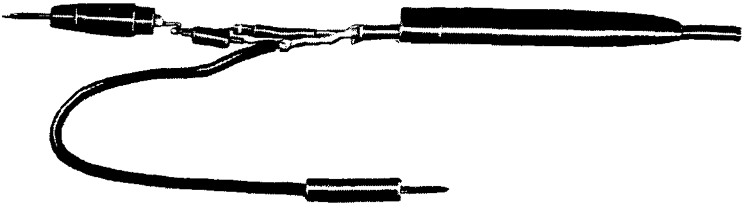
Courtesy General Electric Corp.

Fig. 9-9. The variation of back resistance with back voltage for germanium crystals of the type used in crystal probes.

Figure 9-10 is an illustration of a typical crystal probe and its circuit. The probe shown here has an input capacitance of 3.5 $\mu\mu$f. and an input resistance of approximately 0.25 megohms at 500 kc, and 25,000 ohms at 100 Mc, so that it will give accurate readings up to about 200 Mc. The probe is designed to withstand loads of 400 volts dc. A short ground lead and prod is shown in the illustration in Fig. 9-10a; in most cases the ground lead ends in an alligator clip. It is important to note that when measuring high-frequency voltages the ground lead should always be connected to a point as close to the point being measured as possible to make certain that there is an adequate return path.

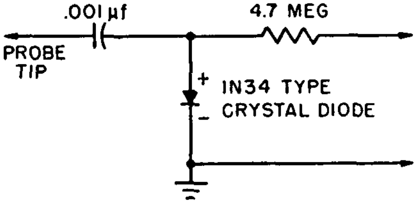
The input capacitance of a crystal probe may be kept down to 1 or 2 $\mu\mu$f, so that in this respect they are inherently superior to vacuum-tube probes. Since the crystals have relatively low back resistances, no shunt load is required. This aids in keeping down the shunt capacitance and prevents detuning when measuring tuned circuits.

When considering the input impedance of the crystal probe in comparison to that of a conventional diode probe, we find that the story is different. The input resistance of crystal diodes at low radio frequencies is generally lower than that of conventional diodes. Fig. 9-11 is a graph of the variation of the input resistance of a typical crystal probe with frequency. Comparing this graph with that in Fig. 11-2, it is seen that at high frequencies the input resistance of crystal-diode probes while declining sharply, is still higher than that of conventional diode-probes.



(a)

Courtesy United Technical Laboratories



(b)

Fig. 9-10. In (a) is shown a breakdown photograph of a typical crystal diode probe used for r-f measurements. The input coupling capacitor is located in the head of the probe and is only partly seen. (b) is the circuit of the probe shown in (a).

A serious disadvantage of crystals is that they have a relatively large temperature coefficient of rectification efficiency, by this we mean that the ratio of forward current to back current decreases as the temperature increases. This is equivalent to stating that the reverse current increases with temperature as is shown in Fig. 9-12, where the ratio of reverse (or back) current at the existing temperature to the reverse current at 25° Centigrade is plotted as a function of temperature. Although this characteristic affects the crystal's operation when the load resistance is low, it also shows up in high-impedance peak response circuits such as is found in a crystal-diode probe. Because the efficiency of rectification changes with the temperature of the crystal, the calibration of voltmeters using crystal probes is unreliable where relatively large changes of temperature are experienced.

In addition to the characteristics of crystals noted above, two others should be mentioned. Crystal rectifiers have a tendency to drift under an applied voltage. Accompanying this drift there is usually a considerable change in back resistance. Also, crystals are limited in the voltage that can be safely applied to them. Some older types are permanently injured by the application of 20 to 30 volts of signal; some newer types will take 100 volts or more and will recover after momentary overload. Welded contacts appear to be advantageous in helping a crystal to recover after overload.

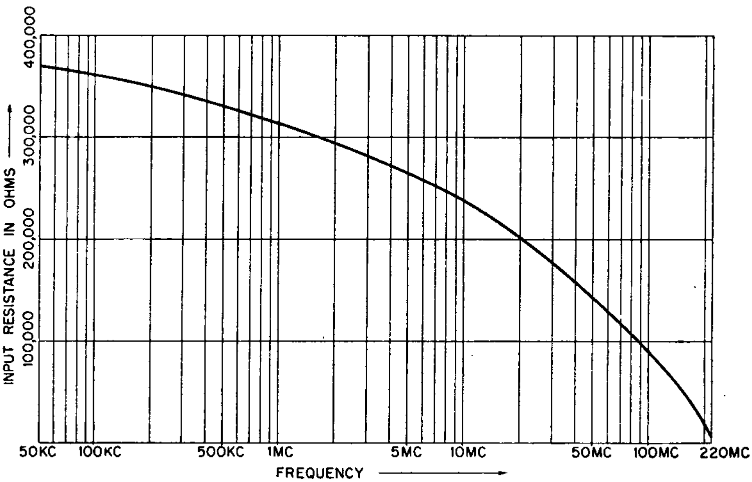


Fig. 9-11. The variation of input resistance with frequency of measured voltage for one type of crystal probe.

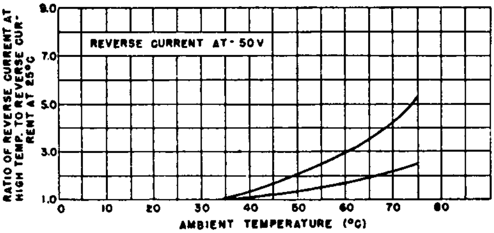
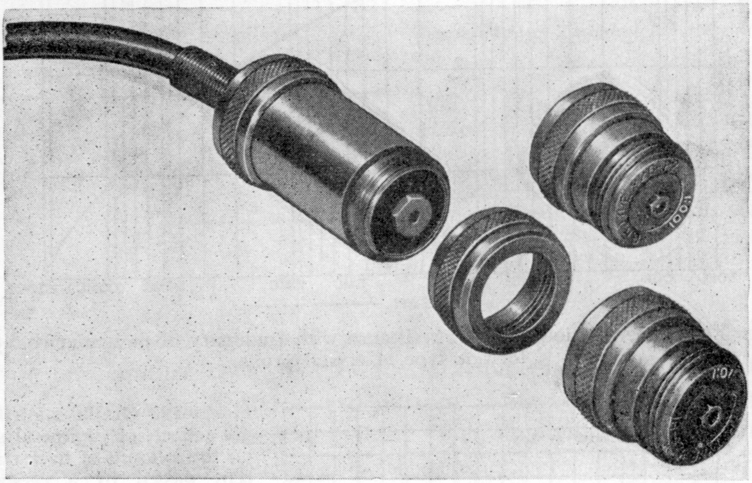


Fig. 9-12. Graph showing the effect of temperature on the amount of back current passed by a crystal-diode rectifier. Two curves are plotted, the upper one is for a IN63 type germanium crystal diode, the lower one is for a IN48 type crystal diode.

Courtesy General Electric Corp.

Multipliers for Probes

The voltage range of a voltmeter may be extended by means of a multiplier attachment adapted to fit over the end of the probe or added in some other suitable manner. When used for r-f measurements, the multiplier consists of a small capacitor which acts as a divider in conjunction with the input capacitance of the probe proper. Thus, if the input capacitance of the probe is 5 $\mu\mu$f, the addition of a 0.55-$\mu\mu$f series multiplier will bring the input capacitance of the probe down to 0.5 $\mu\mu$f, a reduction of 10 to 1. This increases the reactance 10 times, thus extending the range. The multiplier and probe must be shielded, otherwise, stray capacitance across the small multiplier will change its attenuation factor. The General Radio Company makes two multipliers for their crystal probe, one having a 10 to 1 and the other a 100 to 1 attenuation ratio (see Fig. 9-13). The input capacitance of their model 1802-A crystal probe alone is 5 $\mu\mu$f; with the 100 to 1 multiplier it is reduced to 1.6 $\mu\mu$f.



Courtesy General Radio Co.

Fig. 9-13. A crystal probe with a-c voltage multiplier attachments. Each multiplier is affixed to the probe by the knurled ring shown. The voltage multiplication factor of each unit is shown on the face of the unit as a ratio.

The simple series-capacitance type of multiplier is accurate at very high frequencies, but below one megacycle, the shunt resistance of the probe input impedance causes an error which increases as the frequency is decreased. A multiplier which has both capacitance and resistance elements can be made accurate over the full frequency range of the probe. A resistance divider connected in parallel with the capacitance divider proves to be an effective combination for wide ranges. The resistance divider is the important element for the low frequencies (down to about 20 cycles), while the capacitance divider takes over at a few megacycles. The Barber Laboratories probe model ACM-27 is such a combination of resistance and capacitance having an attenuation ratio of 10 to 1 at all frequencies from 20 cycles to several hundred megacycles (see Fig. 9-14).

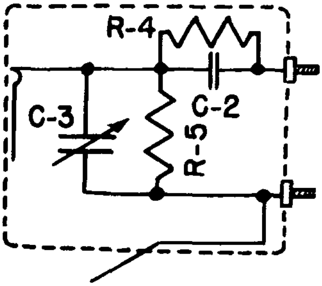


Fig. 9-14. A voltage multiplier unit containing both a series capacitance and a voltage divider connected in parallel with it. The capacitor is effective at high frequencies while the resistor is effective at low frequencies.

Courtesy Barber Laboratories

High Voltage R-F Probes

Probes used for measuring high r-f voltages are usually combinations of capacitance multipliers and peak response diode rectifiers. The high-voltage input capacitor immediately reduces the input voltage by a factor of 100 or thereabouts, and the resulting "safe voltage" is applied to the diode rectifier. One high voltage r-f probe has an input capacitance of about 2 $\mu\mu$f and an effective series capacitance to the diode rectifier of 0.4 $\mu\mu$f.[1]

In the design of these probes, care must be taken that the path of the input side to ground is long and through low-loss dielectric to avoid dielectric heating at high frequencies.

Cathode Follower Probes

Where it is desired to increase the sensitivity of a vacuum-tube voltmeter, an amplifier tube rather than a diode may be used in the probe. The input is capacitance coupled to the grid of the amplifier tube and the output is taken off a resistance in the cathode circuit. In some cases, the output may be fed to additional amplifying

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[1] Barber Laboratories model 37.

stages before entering the rectifier and then the indicating meter. This type circuit was covered in Chapter 6. The cathode follower (discussed in Chapter 3) provides a low-impedance output circuit capable of covering a wide frequency range. A coaxial cable should be used from the output of the probe to the voltmeter amplifiers to decrease the effect of stray r-f or a-c radiations. The cathode follower also permits placing a high signal voltage on the input grid thereby enabling the voltmeter to cover a wide voltage range without requiring the use of input multipliers.

The Ballantine voltmeter model 304 uses a probe containing a 9002 tube connected as a cathode follower as outlined above, see Fig. 9-15. The over-all instrument has a frequency range of 30 cycles to 5.5 megacycles, and full-scale voltage ranges of 0.01, 0.1 and 1 volt. Capacitor-type input multipliers are available for increasing the maximum voltage range by factors of 10 and 100.

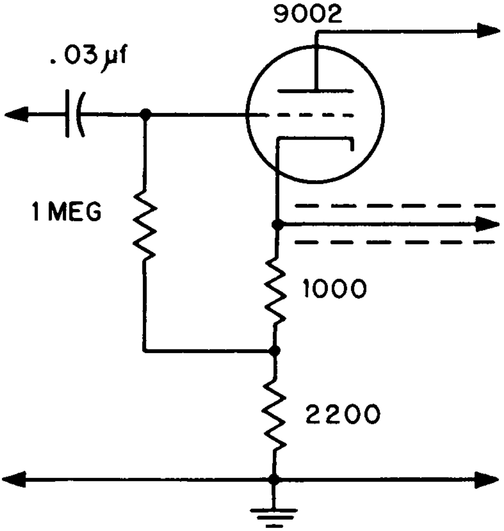

Fig. 9-15. A cathode-follower probe with a high-impedance input and a low-impedance output. The advantages of such probes are discussed in the text.

Composite Probe

While the usual practice is to provide separate probes for d-c and a-c measurements with v-t voltmeters, a composite probe can be used for both with a minimum of change. An example of such a probe is shown in Fig. 9-16.[2] The probe is connected to its v-t

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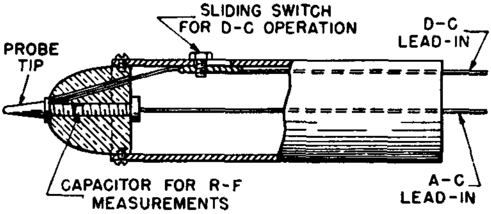
[2] U. S. Patent No. 2,488,328, John F. Rider.

Fig. 9-16. Composite probe used for both a-c and d-c measurements. An air gap in the probe head provides the input impedance for a-c measurements. Various resistors may be adapted to the probe for use in d-c measurements.



voltmeter by means of both a-c and d-c input leads. The tip of the probe is coupled to the a-c lead by means of a very small series capacitor making it suitable for r-f measurements. A simple sliding switch located on the probe connects the d-c lead to the probe tip quickly adapting it to d-c voltage measurements.

REVIEW QUESTIONS

CHAPTER 9

9–1. What is the main function of an isolating-resistor probe?
9–2. How may the voltage range of a d-c VTVM be extended?
9–3. What precautions should be taken when using high-voltage d-c probes for measurements of high voltages?
9–4. How may the voltage range of an a-c VTVM be extended?
9–5. Explain the effect of probe resonance upon the reading of the VTVM at high-frequency measurements.
9–6. How do large connecting clips and long lead wires affect the meter reading at high frequencies?
9–7. Why should the probe ground be close to the point of measurement at high frequencies?
9–8. List the advantages and disadvantages for the use of crystal diodes in r-f probes.
9–9. What is the voltage limitation of crystal-diode probes?
9–10. What is a cathode-follower probe? What are its advantages?

CHAPTER 10

DESIGN AND CONSTRUCTION OF VACUUM-TUBE VOLTMETERS

In this chapter the general considerations relating to the design and construction of v-t voltmeters will be covered, particular emphasis being given to the most desirable operating characteristics. First we will consider what to look for in a VTVM, and then, how to design the circuit so as to obtain the desired features. It is recommended that those who plan to build their own v-t voltmeters study this chapter carefully.

High Input Impedance

Since v-t voltmeters are largely used because of their high input impedance, it is important to take every precaution to obtain this characteristic. Such a circuit will cause a minimum reaction on circuits under test, and in addition, be applicable for measurements of inductance, capacitance, the *Q* of coils and capacitors, and countless other characteristics.

For high impedance, especially at very high frequencies, the proper choice of probe tube is important. The probe tube should have a high resonant frequency to prevent the drop in impedance, which occurs near resonance, from falling within the range of the meter. A tube of small physical size has the advantage that short connections inside the probe are possible, cutting down on shunting capacitances.

As explained in Chapter 9, the resistive or loss component in a probe is largely determined by the dielectric losses in the tube base, and by stray shunting capacitances across the probe input. If a tube is mounted in a socket therefore, low-loss ceramic or polystyrene should be used. All solid dielectric materials used for supporting the input coupling capacitor and other signal carrying parts must be of minimum physical dimensions and should be made of low-loss material. The signal-carrying lead from the probe tip or binding post should be as short as possible, and so positioned as to reduce to a minimum the capacitance between it and ground.

In the d-c v-t voltmeter and in the d-c circuits of rectifier-amplifier v-t voltmeters, minimum grid current in the input signal tube is of utmost importance in maintaining a high input impedance. The proper choice of the d-c amplifier tube, "aging" to reduce the grid current, and operation at low plate voltage and current are methods for securing low grid current. All circuits carrying the d-c signal should be well insulated and kept away from high voltage circuits.

Since the resistance of solid dielectrics decrease considerably with increasing temperature, good ventilation is necessary. Ceramic switches are to be recommended for all d-c signal switching, and short paths which may become low-resistance paths due to dust or moisture are to be avoided.

Wide Frequency Range

For obvious reasons, it is desirable that the frequency range be made as great as possible, consistent with other considerations. Preferably, for general purpose VTVM's, the frequency range should extend from about 30 cycles to 250 megacycles, the higher the better. The low limit makes it possible to measure, for example, the bass response of audio amplifiers, while the upper limit makes possible the measurement of television frequencies. Response to 60 cycles should be considered indispensible since it enables the calibration of the v-t voltmeter at that frequency.

Tubes used to obtain this frequency range are the 6H6 which, with its base removed, is satisfactory up to 100 megacycles; acorn type tubes and sub miniatures, useful to 200 or 300 megacycles; and some special high-frequency diodes which are efficient to over 500 megacycles.

Wide Voltage Range

For the general run of measurements, a range from about 1 volt full scale to 100 volts full scale is desirable. This range should be covered in steps not greater than about 3 to 1 in order to provide sufficient overlapping. Over this range a direct calibration should be provided by means of multiple scales on the same meter face. The scale for the lowest voltage range, which has the poorest accuracy, should be arranged on the innermost arc (shortest scale). The usefulness of the v-t voltmeter can be extended appreciably by providing a low-voltage range which has a full-scale value of several tenths of a volt. While it may not be feasible to calibrate this range directly, it can be calibrated in terms of the outer scale which is usually linear. The stability of this sensitive range will be relatively poor, but it is very useful nevertheless and its accuracy can always be made as high as desired by using it as a comparison v-t voltmeter (see p. 228).

Accuracy and Permanence of Calibration

V-t voltmeter design has progressed to the point where a direct calibration can be readily secured and can be considered almost indispensable. A full-scale accuracy of about 2 per cent can be expected with the usual type of design. The extent to which the original calibration will hold over a period of time depends very greatly on the design and construction. For example, grid rectification v-t voltmeters are notoriously unstable, while the rectifier-amplifier type is relatively stable provided that sufficient degeneration is used in the d-c amplifier circuit. The use of a voltage-regulated power supply is usually an important factor in promoting accuracy and permanence of calibration, although in some balanced amplifier circuits voltage regulation is not essential. In most a-c VTVM circuits, especially those of the rectifier-amplifier type, regulation of the heater as well as the plate voltage is desirable. The use of a relatively sensitive meter of about 100 or 200 microamperes full scale is desirable since this enables the use of additional degeneration which would not be possible were a less sensitive meter to be used.

Type of Response—Waveform Error

In general, the three basic types of readings given by a-c voltage meters are the root mean square, average, and peak, as was explained in Chapter 1. By root-mean-square (or rms) voltage is meant the square root of the mean of the squares of all the voltage components (fundamental and harmonics), in the signal being measured. Since the heating effect of alternating current is proportional to the square of the voltage, meters depending upon the heating effect of alternating current (meters using thermocouples or "hot wires"), are rms meters.

The rms meter indication is least disturbed by harmonics in the signal. Average-response meters which give the average of one-half of the alternating current voltage are more affected by harmonics. The peak-response meter reads the peak value of a-c voltages, and is more affected by the presence of harmonics than either of the two other types. Table 10-1[1] shows the effect of harmonics on the readings of the three basic voltmeter types.

TABLE 10–1

THE EFFECT OF HARMONICS ON THE THREE BASIC TYPES OF READINGS

% Harmonic	*RMS Value*	*Average Readings*	*Peak Readings*
0	100	100	100
10% of 2nd	100.5	100	90–110
20% of 2nd	102	100–102	80–120
50% of 2nd	112	100–110	75–150
10% of 3rd	100.5	96–104	90–110
20% of 3rd	102	94–108	82–120
50% of 3rd	112	90–116	108–150

In the light of the above information, it is fairly safe to use average response meters calibrated for rms values for most measurements. This is necessary because it is extremely difficult to design rms-responsive meters to serve over wide voltage ranges. In general, voltages measured across tuned circuits, particularly receiver circuits, contain few harmonics due to the circuit selectivity and therefore, all three types of meters will give the same indication. When harmonics are present, the rms meter should be used to give a true indication of power.

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[1] Prepared by Hewlett-Packard Corp.

In many electronic circuits, peak indication is most indicative of circuit performance. For example, peak-reading meters will show when grid bias is exceeded in the presence of distortion. When a tube is saturated, the output wave becomes flattened, and a peak voltmeter readily shows this condition. An rms meter connected across the same output would show an increase in power output, an increase due entirely to added harmonic distortion. Square waves and other waveforms of high harmonic content are most significantly measured on a peak-response meter if it is desired to find voltage amplitude rather than power in the wave.

Pulses, especially pulses of relatively short duration and widely spaced, may be measured by special v-t voltmeters available for that purpose. Of course, such pulses may be measured indirectly by means of the cathode-ray oscilloscope. In using the VTVM for the measurement of pulses, the correction which must be applied to an rms-meter reading to obtain the peak amplitude may be computed, if the pulse shape is accurately known. Some manufacturers indicate the computations necessary in the literature accompanying their equipment. For example, to convert the rms-calibrated readings of a peak-to-peak responsive meter to pulse measurements, we need only multiply the reading on the meter by 2.83. This will give us the peak-to-peak value of the measured pulses only if the waveform is not too complex.

The rated frequency response of a voltmeter tells little of value as regards the pulse response of the meter. While many manufacturers supply correction factors for their voltmeters, it may be assumed that general purpose v-t voltmeters are intended primarily for the measurement of sine-wave voltages. They are not to be recommended for the measurement of pulses unless the user is thoroughly familiar with the technique of interpreting the results obtained, and then only when the device is suitable for such measurements. Further information relating to such measurements will be found in Chapter 12.[2]

Stability and Protection Against Overload

An important consideration in v-t voltmeters is that of stability and protection against overload. This is related to the question of

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[2] For further information see Allan Easton, "Pulse Response of Diode Voltmeters," *Electronics,* vol. 19, p. 146, Jan. 1946.

permanence of calibration and the same steps taken to secure that feature will also promote stable operation. Among the factors which tend to improve the stability and prevent shifting of the zero may be included the following: the use of a balanced circuit, regulation of the power supply (including heater voltage when required), and the use of an operating plate current which is not excessively large in comparison with the full-scale meter current.

Adequate protection against overloading of the meter should be provided. This can be done by designing the circuit to operate with a low value of operating plate current, as described in the preceding paragraph. The inclusion of a resistor in series with the grid of the d-c amplifier tube is a simple but effective means for preventing the grid from being driven positive when a heavy overload occurs. With proper design, it is possible to prevent the current through the meter from exceeding about three times the full-scale meter current. This provides adequate protection against meter injury. Overloading precautions are particularly necessary for voltmeters using crystals since permanent injury to the crystal can occur under temporary overloads.

Simplicity of Design and Ease of Operation

As in all instrument design, simplicity of design and ease of operation are highly desirable features. The number of controls appearing on the panel should be limited to those which are absolutely required, and in addition, they should be grouped so as to secure the greatest convenience of operation. In certain applications, portability is a desirable feature and for such applications the design may advantageously be built around 1.4-volt tubes which can be operated directly from a 1.5-volt cell. These tubes also require a minimum of plate voltage for satisfactory operation.

Compensating for the Effect of Variations

It must always be expected that variations will occur in the values of the various resistors, capacitors, voltages, etc., which constitute the nominal design values. For example, variation in the heater voltage will usually cause an appreciable shift in the zero reading. The amount of this variation must be checked and due allowance made so that the instrument will function satisfactorily over a reasonable range of line voltages. Similarly, in degenerative amplifiers some resistors are more critical than others. Thus the cathode resistor determines the sensitivity of the amplifier so that an accurate wire-wound resistor should be used. In some balanced v-t voltmeters it may not be necessary to provide a regulated power supply because of the inherent symmetry and stability of the circuit. These are typical illustrations of the many factors that should always be investigated so that due allowance is made for the variations which will be encountered in operation.

Reducing Errors at High Frequencies

With the increasing importance of frequencies above 30 megacycles, it is very desirable that a general purpose VTVM be of the probe type so as to permit operation at these frequencies with a minimum of error. Even at low radio frequencies, the probe type of construction is a decided advantage because of the lower input capacitance which can be realized and because of the prevention of feedback as a result of long leads to the v-t voltmeter. At high radio frequencies, the probe type of construction is an absolute necessity because leads longer than an inch or so give rise to resonance effects which make measurements impossible as has been explained in the previous chapter.

In commercial voltmeters recommended for use at very high frequencies, the trend has been definitely in the direction of the diode rectifier and the rectifier-amplifier type of circuit. When a large load resistor is used, the input impedance of a diode probe is practically entirely determined by the losses in the stray shunt capacitances as has been pointed out previously. Diodes designed especially for very high-frequency operation in v-t voltmeters have such small losses that they can be disregarded for all practical purposes.[3]

One of the limiting factors in the use of diodes for high frequency measurements is the transit time of the electrons from the cathode of the tube to the plate in response to the incoming signal. At low frequencies, and for normal cathode-to-plate spacing, the transit time is about 0.001 microsecond. This is negligible in comparison with the period of the signal; if the signal frequency were 50 kilocycles for example, its period would be 200 microseconds. If

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[3] E. C. S., Megaw, "Voltage Measurements at Very High Frequencies," *Wireless Engineer*, vol. 13, p. 65, Feb. 1936; p. 135, Mar. 1936; p. 201, Apr. 1936.

however, the frequency of the signal is 200 Mc, its period is 0.005 microsecond, or of the same order of magnitude as of the transit time, and distortion is introduced. For higher frequencies, the distortion and loading factors caused by the transit-time effect complicates all measurements. To cut down on this effect the cathode-to-plate spacing of diodes designed for high frequencies is made very small (of the order of thousandths of an inch). Even with the best tubes however, transit time becomes a limiting factor above about 1,000 megacycles. Hence, the probe tube should be chosen with regard to the frequencies for which the probe and meter will be used.

Resonance in the probe tube and its circuit is usually a more serious limitation than transit time especially if special high frequency diodes are used. The leads and shunting capacitances in the diode itself may resonate at about 1,500 megacycles, but even with the most careful circuit design and parts placement, the over-all probe will probably resonate at not over half this frequency or at about 700 megacycles. With poor design the probe resonant frequency may drop to 200 megacycles, and the advantage of the special diode will be almost entirely lost. Resonance and transit time in probe tubes is more fully discussed in Chapter 9.

Since triodes as probe tubes are not generally used for measurements at frequencies above 10 to 20 megacycles, no special consideration will be given them.

V-t voltmeters using resistor type voltage dividers in the r-f input circuit have in a number of instances been represented as being suitable for use at radio frequencies. It should be clearly understood that such voltage dividers are ordinarily inaccurate at frequencies above about 10 kilocycles. Where special precautions are taken, and capacitance compensation is used as in Fig. 6-3, the divider can be made accurate up to about 500 kilocycles, but this represents about the upper frequency limit at which such dividers will operate.

Bypassing Considerations

To secure accuracy over a wide frequency range, it is essential that the various circuit elements be adequately bypassed. As in all radio circuits, the bypass capacitor should be large enough so that its reactance is small in comparison with the circuit element which is being bypassed. Thus the reactance of the plate bypass capacitor, for example, should be small in comparison with the plate resistance of the tube. In general purpose v-t voltmeters covering a wide frequency range down to about 60 cycles, it is impossible to secure proper bypassing by means of a single capacitor. A large capacitor having sufficient capacitance to bypass at 60 cycles has too much inductance to be effective at high radio frequencies; in addition, it is too bulky to be placed close enough to the points which are to be bypassed. This limitation is usually overcome by using a small mica capacitor directly at the tube elements for the higher radio frequencies, in parallel with a large paper (or electrolytic capacitor in special cases) which can be mounted at any convenient place since the lead length is not critical. In probe type VTVM's, the usual practice is to use 0.01 μf mica capacitors mounted directly at the tube socket in the probe head, while larger capacitors are shunted in parallel with these and mounted in the main instrument case assembly.

Where electrolytic capacitors are used in v-t voltmeters, as for example in bypassing the cathode resistor in a reflex VTVM, it is advisable to use a higher voltage electrolytic than is called for by the working voltage. This will reduce the leakage current of the electrolytic so that the calibration will not be affected.

Selection of Tubes

The factors on which a particular tube is selected for use in a v-t voltmeter include the following: input capacitance, high-frequency losses (input resistance), mutual conductance, amplification factor, size, and heater or filament voltage. In d-c v-t voltmeters, grid current or contact potential is a very important factor since it determines the effective input resistance of the VTVM.

The desired tube characteristics will vary considerably with the type of v-t voltmeter under consideration, the range to be covered, whether square-law response is required, etc. In plate rectification VTVM's, it is generally true that tubes having a low amplification factor and a high mutual conductance are most suitable. Where a relatively high voltage is covered on the lowest range, it is usually desirable to use a tube having a low amplification factor so that a high cutoff voltage will be obtained with relatively low values of plate voltage.

Acorn-type diodes are widely used in v-t voltmeters as are newly developed special diodes having low input capacities, high resonant frequencies, and short transit times.

In general, screen-grid and pentode tubes (used as such) should be avoided in VTVM design since they unnecessarily complicate the circuit by requiring additional components and voltages. Usually they do not make possible improved performance, although in certain special applications they offer greater flexibility than can be obtained with a triode. An example of such an application is the design of a square-law v-t voltmeter where operation of the screen at the proper voltage enables the production of an almost perfect square-law characteristic.[4]

Although high-mu triodes are not very suitable for use in plate-rectification VTVM's, they can be used to advantage in the d-c amplifier section of v-t voltmeters. In this application they provide a relatively high value of mutual conductance at small values of operating current. This feature makes them particularly useful in degenerative d-c amplifiers such as are used in rectifier-amplifier v-t voltmeters. In general, however, high-mu triodes are not suitable for use in the input stage of d-c VTVM's where it is necessary to obtain high values of input resistance and very low grid current.

Selection of the Meter

In most v-t voltmeter circuits, it is desirable to use a relatively sensitive meter of the order of 100 or 200 microamperes full scale. The use of a sensitive meter is desirable because it raises the maximum sensitivity and at the same time permits the use of a greater amount of degeneration on the higher ranges. The development of the d-c moving-coil meter has progressed to the point where a 100-microampere meter is no longer considered a very sensitive meter and to the point where such meters are less expensive and considerably more rugged than they were formerly. In this connection 50-microampere meters are in common use in ordinary analyzer units, and in such service the meter does not have the protection afforded by the v-t voltmeter circuit. This lack of adequate overload protection which is overcome in v-t voltmeter

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[4] J. R. Ragazzini and B. R. Boymel, "Square-Law Vacuum-Tube Voltmeter," *Review of Scientific Instruments*, vol. 11, p. 312, Oct. 1940.

design has been a serious limitation on the use of sensitive meters in ordinary applications.

Where the greatest sensitivity and accuracy of calibration are not required, an appreciable reduction in cost can be secured by designing the circuit so that a milliammeter rather than a microammeter can be employed. This can be done by operating the tube so that the maximum sensitivity is secured. Under such operating conditions it is ordinarily not possible to use an appreciable amount of degeneration.

Resistor Considerations

To secure the greatest permanence in calibration, it is desirable that wire-wound resistors be used at all points in the circuit where the resistance must be held to within close limits. For example, multiplier resistors which directly affect the calibration of the v-t voltmeter should be wire wound if possible. On the other hand, there are many points in the VTVM circuit where a change in the resistance value will not affect the calibration, and in such places resistors of the metallized type may be used to effect a considerable reduction in the cost. A typical place where metallized resistors can be used is in the balancing circuit where a change in resistance over a period of time can be readily compensated by changing the zero adjustment control. In the lower values of resistance up to a few thousand ohms there is relatively little difference between the cost of metallized and wire-wound resistors.

High-Resistance Values

The higher values of resistance required in the voltage dividers of d-c v-t voltmeters present a problem since wire-wound resistors are not available in values above about 10 megohms; in fact, even in the range between 1 megohm and 10 megohms, the cost is prohibitive except for precision laboratory instruments. The practice is to use metallized resistors which are usually matched in pairs to within 1 per cent. Thus a 10-megohm resistor can be made up of two 5-megohm resistors in series. If one 5-megohm resistor is high by 6 per cent, for example, and the other 5-megohm resistor is low by 6 per cent, then it follows that the 10-megohm resistor will be accurate to within 1 per cent. Unfortunately this method of obtaining 1 per cent resistors is usually limited to manufacturers since it requires a large stock of resistors. Also usable are deposited carbon resistors having quite stable characteristics and available in 1 per cent tolerance.

High-Voltage Resistors

Special high-voltage resistors suitable for extending the voltage range of d-c v-t voltmeters up to about 30,000 volts and higher are available. In one type of high-voltage resistor, the unit consists of a spiral element on a tubular form, thus offering a long effective resistance path without an objectionable increase in the over-all length of the resistor. These resistors can be obtained in values as high as 10,000 megohms and higher. The temperature coefficient increases with the resistance value, being approximately 0.2 per cent per degree Centigrade for the higher values. A voltage rating of 5,000 volts dc can be obtained in a resistor 2-inches long, while a voltage rating of 25,000 volts can be obtained in a resistor 6½-inches long.

Slide-Back Voltage Dividers

In slide-back v-t voltmeters, no particular care is required in the design of the voltage dividers which supply the balancing voltage. The only requirement is that the desired voltage range be covered, since the accuracy of the measurement depends upon the accuracy of the d-c voltmeter used to measure the slide-back voltage. In general, the resistance of the slide-back voltage divider should be small in comparison with the resistance of the d-c voltmeter. Since a 1,000 ohm-per-volt meter is generally used, this requirement calls for a voltage divider which has a resistance of about 200 ohms per volt. Accordingly, a voltage divider for a 250-volt supply would have a total resistance of 200×250 or 50,000 ohms.

Grid-Circuit Considerations

Regardless of the type of VTVM, the input circuit must provide a continuous d-c path between the control grid and the cathode. In a-c v-t voltmeters, it is usually desirable to have a blocking capacitor in the input so that the reading will not be affected by any d-c voltage present. An additional reason for the desirability of a blocking capacitor in a-c v-t voltmeters is that possible error as the result of a variation in "contact potential" is prevented, since the total resistance in the grid circuit remains constant when a blocking capacitor is used. The value of the grid resistor should be large enough so that the loading effect is not excessive and at the same time should not be too large or erratic operation will result. The relation between the coupling capacitor and grid resistor should be such that the reactance of the coupling capacitor is small in comparison with the resistance of the grid leak (see Table 2-1).

When an a-c v-t voltmeter is used without a coupling capacitor, the zero reading will usually shift somewhat when the d-c resistance of the circuit being measured is higher than a few hundred thousand ohms. To prevent error from this source, the zero should be checked while the instrument is connected to the circuit under test. To check the zero it is necessary to cut off the a-c voltage in some way, for example by temporarily shunting a capacitor across the input, or by turning off the power in the circuit under test. Of course there should be no d-c voltage present in the circuit under test or an error will be introduced. The advantage in designing the input circuit so that a direct connection can be made to the grid is that the loading effect introduced by the grid leak is eliminated. In addition, the omission of the grid capacitor shortens the effective length of the input circuit so that measurements can be made at a higher frequency. Both of these considerations are important in relatively few applications, and in general it is preferable to work with a grid capacitor and resistor connected semipermanently or permanently in the input circuit.

In d-c v-t voltmeters it has previously been pointed out that the input circuit must be designed so that the grid current is held to a minimum. Among the factors which must be considered in obtaining this high input resistance are the choice of the proper tube, low plate and heater voltages, and proper layout to avoid leakages.

Reduction of Leakage in D-C V-T Voltmeters and V-T Ohmmeters

The proper operation of d-c VTVM's and v-t ohmmeters depends not only upon the use of a suitable tube type and circuit, but also upon proper layout so that leakage effects are prevented from introducing an error. Paradoxical as it may seem, a metal or conducting panel is indispensable if leakages are to be avoided. When a metal panel is used, the panel acts as a guard ring so that whatever leakages take place are prevented from developing a voltage across the high-resistance input circuit of the VTVM or ohmmeter. In combination v-t voltohmmeters, the switch layout should be made so that separate switch sections (wafers) are used for switching the high-resistance input circuits. No leads which contain voltages either above or below ground potential should appear on these switch sections; separate sections on the same gang should be provided for handling these leads. Too much care cannot be exercised in observing this precaution. The switch wafers themselves should preferably be of ceramic, since this dielectric has a lower d-c leakage than the bakelite wafers ordinarily used for wave-band switches.

In high-resistance input circuits, surface leakage can be reduced by using a coating of ceresin wax. The practice of dipping high-resistance units in wax to reduce surface leakage is often followed. Where the control grid of the input circuit is the top cap of a tube, surface leakage over the glass can be reduced by coating the glass with ceresin wax.

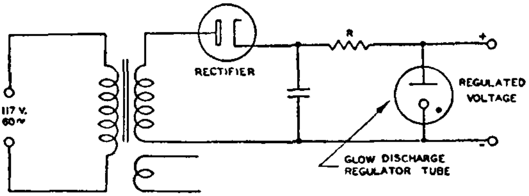

Fig. 10-1. A simple voltage-regulated power supply in which regulated plate voltage is secured by using a large resistance *R* in series with a neon tube or gaseous regulator tube such as the VR-150.

Power Supply Considerations

The ideal power supply for VTVM's is one which supplies completely regulated plate and heater voltages. Although this is desirable, it is not always essential that a regulated supply be used, and the extent to which regulation is required depends upon the particular circuit, whether or not it is balanced, its sensitivity, etc. In some circuits no regulation is required, whereas in others complete regulation of both plate and heater voltages is required.

A simple circuit using a neon-tube regulator or a gaseous regulator tube of the VR-150 type is shown in Fig. 10-1. This circuit is suitable in applications where only the plate voltage need be regulated. To secure a good degree of regulation, the voltage supplied by the transformer should be about twice the desired output voltage; this permits a large value of *R* to be used. Relatively little filtering is ordinarily required since the regulator tube contributes to the filtering of the output. The resistor *R* should be chosen so that the current drawn by the regulator tube is near the middle of the operating characteristic as specified by the tube manufacturer.

Any one of the small neon tubes can be used satisfactorily in this type of circuit to obtain about 60 volts of regulated plate voltage at a few milliamperes of output current. These neon tubes are available without a current-limiting resistor in the base. If the latter type is used, the tube must be debased, the resistor removed, and the base recemented. Since the latter procedure is time consuming, it is recommended that the resistorless type of neon tube be used. Where either higher voltages or higher output current is required than is available from a neon tube, one or more VR-105 or VR-150 tubes may be used.

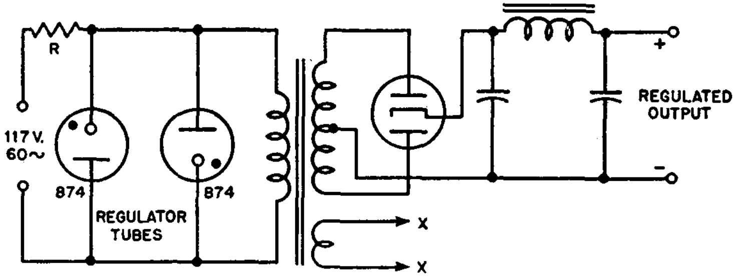

Fig. 10-2. Regulation of both the plate and filament voltages is secured by regulating the voltage applied to the primary of the power transformer. Note that the polarity of the two regulator tubes is reversed so that both halves of the cycles are regulated.

Completely Regulated Voltage Supply

A power supply which is particularly suitable where regulation of the plate and heater voltage is required is shown in Fig. 10-2.[5] In this circuit, two VR-90 type regulator tubes are used in the primary circuit to regulate both the positive and negative half

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[5] G. F. Lampkin, "A Simple A-C Voltage Regulator," *Electronics*, vol. 10, p. 30, Aug. 1937.

cycles of the voltage applied to the primary of the power transformer. To obtain good regulation, R should have the largest value which will permit ignition of the regulator tubes on the lowest line voltage encountered. Since the regulator tubes reduce the primary voltage, the output voltages will be lower than if a conventional circuit were used. If a special transformer is used, due allowance can be made for this drop. A regular transformer, however, can readily be adapted so that the desired voltages will be obtained. A suitable voltage divider can be used to obtain the desired plate voltage, while the reduced heater voltage can be used directly in most cases, or else the 5-volt filament winding can be placed in series with the 2.5-volt winding. Because of the small emission required in most v-t voltmeter circuits, it is usually practical to operate at a heater voltage as low as 4 or 5 volts. As previously pointed out, this has the advantage of providing longer tube life and lower grid current.

Extending the Voltage Range of A-C V-T Voltmeters

In many applications, especially in transmitter engineering and maintenance, it is often necessary to measure voltages greater than about the 300- to 1,000-volt upper limit of conventional general purpose VTVM's. There are two general ways of accomplishing this. One is by using a high-voltage rectifier tube such as a type 2X2-A (see Fig. 2-11) to rectify the voltage, and then to measure the rectified voltage with a d-c v-t voltmeter or microammeter. The other method, which was described in the sections on multipliers in Chapters 5 and 9, is to use a capacitive type multiplier which is attached directly to the input of the a-c v-t voltmeter.

Constructional Notes

The construction of v-t voltmeters follows along the same line as the construction of any measuring instrument. The layout should be carefully planned before any constructional work is started. In the r-f section of the unit, the usual practice of short leads and direct bypassing at the tube socket should be followed. As far as is possible, the parts should be arranged so that everything is accessible. The precautions with regard to the circuit design, leakages, adequate low-frequency bypassing, etc., have already been covered.

Articles on the construction of v-t voltmeters are to be found in the popular radio and television magazines. Some of the more helpful ones are listed in the footnote[6] on this page and in the bibliography.

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[6] Ernest J. Schultz, "Cathode Follower VTVM," *Radio & TV News,* vol. 42, p. 52, Aug. 1949.

J. H. Carlisle, "Home Constructed VTVM," *Radio News,* vol. 37, p. 54, Jan. 1947.

N. M. Smith, "Vacuum-Tube Voltmeter," *Radio News,* vol. 36, p. 48, July 1946.

REVIEW QUESTIONS

CHAPTER 10

10–1. To obtain a high input impedance for a VTVM, we must select the probe tube and its base carefully (among other considerations). What must be considered in the selection of these elments?

10–2. What is a desirable frequency range for a general purpose VTVM? Why?

10–3. Give three methods for improving the permanence of calibration of a VTVM.

10–4. What factors help to protect a v-t voltmeter against overload?

10–5. What governs the size capacitor to use for bypassing in a particular circuit?

10–6. Where in VTVM circuits is it advisable to use high-mu triodes? Low-mu triodes? Pentodes?

10–7. Inspect the schematic diagrams of commercial v-t voltmeters given at the end of Chapter 13. Where are low tolerance resistors (wire wound, etc.) used?

10–8. Why is it desirable to have a blocking capacitor in the input of a-c VTVM's?

10–9. Explain how to set up a wafer switch in v-t voltohmmeters.

10–10. What determines whether a partially regulated or a completely regulated power supply is necessary for a VTVM?

CHAPTER 11

CALIBRATION AND TESTING OF VACUUM-TUBE VOLTMETERS

The accuracy of a v-t voltmeter depends to a greater or lesser extent upon a relatively large number of variables, including the tube characteristics, operating voltages, resistors and other circuit elements, and the sensitivity of the meter itself. In some VTVM circuits an accuracy can be attained which is independent of variations in the tube characteristics and operating voltages, and in such cases calibration is very seldom required. To go to the other extreme, some sensitive amplifier types of v-t voltmeters require calibration at relatively frequent intervals.

The calibration of a VTVM consists essentially of interpreting the reading of the indicating meter in terms of the input voltage required to produce the given current reading. This idea was clearly brought out in Fig. 1-3 so that it requires no further discussion here. In the case of directly-calibrated v-t voltmeters, adjustments are usually provided so that the scale can be made to read directly. Where no adjustment is provided, a correction curve can be drawn, or a new calibration curve plotted.

Choice of Standards

In all calibration work some standard of voltage must be used and it is in terms of this standard that the calibration is carried out. In the simplest form of calibration, it is only necessary to place the VTVM to be calibrated in parallel with the known standard source of voltage and to note the reading of the v-t voltmeter which corresponds to each known value of voltage.

The calibration of the general purpose a-c VTVM presents relatively little difficulty since its wide frequency range makes it possible to calibrate the instrument at 60 cycles. This frequency calibration will then hold at frequencies up to as high as approximately 100 megacycles depending upon the design of the v-t voltmeter. Because calibration is possible at 60 cycles, the standard calibrating voltages can be measured by any one of the following meters which are listed in their approximate order of accuracy: (1) dynamometer, (2) thermocouple, (3) moving iron, and (4) copper-oxide rectifier. The copper-oxide rectifier type of a-c meter should be used only when there is no other available meter since its reliability is usually only about 5 per cent. The other meters range in accuracy from 1/4 per cent to about 2 per cent of full scale.

For calibration at frequencies higher than 60 cycles (often necessary for meters whose range extend to higher than 100 megacycles), the oscilloscope may be used to advantage. Many accurate oscilloscopes are calibrated for a deflection sensitivity of 0.06 rms volts per inch of screen, and these, because of their wideband amplifiers, will give accurate representation of the calibrating voltage up to a few megacycles. Oscilloscopes are certainly useful when calibrating a VTVM for pulse measurements, or for the measurement of distorted waveforms, as will be explained in Chapter 12.

In the calibration of d-c v-t voltmeters, the problem of standards is very simple indeed since the ordinary moving-coil voltmeter can be relied on to within 2 per cent of full scale. Where greater accuracy is required, a precision meter can be used which will provide an accuracy as high as 1/4 per cent. Ordinarily an accuracy of 1/2 per cent is desirable in the standards which are used to calibrate d-c v-t voltmeters, since a degenerative type d-c v-t voltmeter is stable enough to hold an accurate calibration. In general there is no point in using a standard which is far more accurate than the reliability of the VTVM which is being calibrated.

General Precautions

There are a number of precautions which should be observed in calibrating v-t voltmeters. To obtain the greatest accuracy, it is desirable to use the standard voltmeter near full scale (where its accuracy is greatest) and to use a voltage-divider arrangement for obtaining fractional voltages. An adequate warm-up period should be allowed for the VTVM to reach a stable operating temperature before calibration is attempted. D-c v-t voltmeters in particular should never be calibrated when the room temperature is either extremely hot or cold, since the resistors used in high-resistance voltage dividers have a relatively high temperature coefficient. As a safety precaution, where the 60-cycle line is used as a source of calibrating voltage, it is advisable to fuse both sides of the line to prevent possible cross grounds. The waveform of the calibrating voltage should preferably be checked with an oscilloscope, since an error will usually result if the calibration is carried out with a distorted wave. *In general, it is desirable to calibrate the v-t voltmeter under the conditions of line voltage, temperature, method of connection, etc., which most closely approximate the actual conditions under which the VTVM is to be used.*

Variac or Other Variable-Ratio Transformers

An extremely useful device in the calibration of the a-c v-t voltmeter is the variable-ratio transformer of which the Variac is one widely used type. It is a variable-ratio autotransformer which provides a continuously variable voltage output from 0 to 130 volts when connected to the 115-volt a-c line. The usefulness of such a device in simplifying the calibration of v-t voltmeters is immediately obvious.

To obtain voltages extending up to about 10 or 20 volts, the Variac may be combined with a filament transformer, tube-tester transformer, or other low-voltage transformer. If the low-voltage transformer is connected to the output of the Variac instead of directly to the a-c line, it is possible to obtain a very smooth control of low voltages without any supplementary rheostats to act as a "fine" adjustment. For voltages above about 20 volts, this arrangement is not necessary since the direct output of the Variac provides the desired voltage with a sufficient degree of control.

Several companies now make variable controlled voltage sources particularly suited to v-t voltmeter calibration. These devices generally include an adjustable voltage source, accurately designed attenuators, and a standard meter. A regulating transformer to maintain the voltage constant is sometimes included since this prevents errors due to sudden changes in line voltage. Another important feature is a filter which is often included to insure that the calibrating source is a pure sine wave. A good piece of equipment of this type is rather expensive and probably not warranted unless it is to be used by a manufacturer or in a laboratory where many voltmeters are maintained.

Set-Up for A-C Calibration

A convenient set-up for calibrating a-c v-t voltmeters is shown in Fig. 11-1. As described in the preceding section, a Variac is employed to feed a low-voltage transformer, the output of which supplies the calibrating voltage. An accurate a-c voltmeter (2% or better) used to measure the voltage is placed in shunt with the output of the transformer and a 1-to-10 voltage divider. A "fine" adjustment is included in the circuit (although it is not required when the Variac is used) in order to show how such a rheostat is used in calibrating circuits.

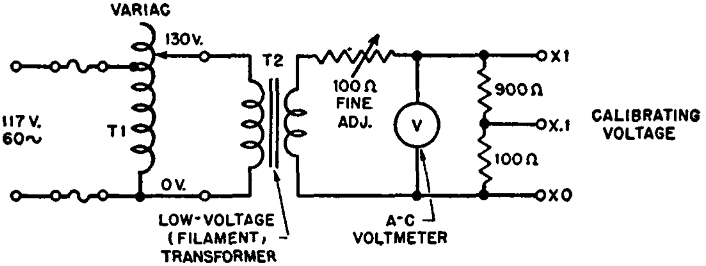

Fig. 11-1. A set-up for calibrating a-c v-t voltmeters. The low-voltage transformer is used only when calibrating the low-voltage ranges.

The voltage divider is extremely useful making it possible to obtain values of voltage smaller than can be read directly by the standard voltmeter against which the calibration is being made. Through the use of such a divider the meter can be read well up on the scale so that good accuracy can be obtained.

For voltages higher than about 10 or 20 volts the low-voltage transformer may be eliminated, and the output of the Variac connected directly to the voltmeter. The usual precaution of fusing the line should be taken.

Use of Decade Voltage Divider

An extremely useful piece of laboratory equipment in the calibration of both a-c and d-c v-t voltmeters is the laboratory *decade voltage divider* or potentiometer. In one commercial form of decade voltage divider, any fraction of the input voltage can be obtained from 0.001 to 1.0 in steps of 0.001. For example, if a voltage of 100 volts is applied to the input, any output voltage ranging from 0.001 volt to 100 volts can be obtained in steps of 0.001 volt. The voltage divider being described is manufactured by the General Radio Company. In appearance it is similar to an ordinary three-dial decade resistance box. Actually it consists of two resistance boxes arranged so that resistance is automatically taken from one arm of the potentiometer and added to the other arm, so as to keep the total resistance of the divider constant.

Where a decade voltage divider is used, the accuracy of any of the smaller voltages is as good as the accuracy of the input voltage which can be read near full scale on the standard meter. The error introduced by the voltage divider is negligible since it is standard practice to calibrate the resistors used in the voltage divider within about 0.1 per cent. This is far better than the accuracy with which either the VTVM or the standard meter can be read.

Extra Capacitors for 60-Cycle Calibration

In v-t voltmeters designed especially for r-f measurements, it is sometimes necessary to use additional capacitors when carrying out the calibration at 60 cycles. The points at which additional capacitance may be required are across the cathode resistor and in the input coupling circuit. The manufacturer's instructions should be referred to especially when the instrument is intended for operation far up in the r-f region.

Waveform Considerations

Since most a-c v-t voltmeters have a certain amount of waveform error, it is best to carry out the calibration with a pure sine wave. This ordinarily introduces no difficulty since the 60-cycle line is usually pure enough to be satisfactory without any additional filtering.

When a VTVM which is calibrated to read correctly on a sine wave is used to measure a distorted wave, its reading will be subject to error. The exact amount of error depends upon the type of v-t voltmeter and the amount and type of distortion present in the wave. The amount of error to be expected is summarized in Table 11-1[1], in correspondence with the figures in Table 10-1.

At this point the sections in Chapters 1 and 10 dealing with waveform considerations should be reviewed. In this connection it should be noted that a peak-reading v-t voltmeter will always respond to the peak value regardless of whether it is calibrated to read rms values. Since ordinarily, v-t voltmeters are calibrated against sine-wave sources, the rms-to-peak relation of these meters is not the same for complex waveforms, *and must not be so interpreted.* In general, the rms value of a complex wave *is not* 0.707 times the peak value. Particular emphasis is given to the action of the peak-reading VTVM which is calibrated in terms of rms values since this type of voltmeter is very widely used commercially.

TABLE 11-1

PER CENT CHANGE OF V-T VOLTMETER READINGS IN THE PRESENCE OF HARMONICS

	Full-Wave Square Law	*Half-Wave Square Law*	*Average*	*Peak*
Turnover	No Change	Reading Changes	No Change	Reading Changes
50% Second Harmonic	±12%	−6 to +27%	0 to ±10%	−25 to +50%
50% Third Harmonic	±12%	±12%	−10 to +16%	+ 8 to +50%

Turnover—In connection with waveform error, the manner in which a distorted wave is connected to the input of the v-t voltmeter will often affect a reading. For example, if an unsymmetrical wave, such as is shown in Fig. 1-6, is applied to a peak-reading VTVM, readings of 100 volts or 60 volts will be obtained depending upon the polarity of the connection. This effect is known as *turnover,* and the manner in which the various types of v-t voltmeters are subject to turnover error is indicated in the above table.

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[1] I. Wolff, "A-C Measuring Instruments as Discriminators Against Harmonics," *Proc. IRE,* vol. 19, p. 647, Apr. 1931.

In particular it will be noted that the full-wave square law (peak-to-peak rms) and the average-reading types of v-t voltmeters are not subject to turnover error; the same reading will be obtained regardless of whether or not the input connections are reversed. This is so because these readings depend upon both the positive and negative parts of the voltage. The other meters however, measure either the positive or negative portion of the voltage, and if these are different, as in unsymmetrical waveforms, the reading will be different. In those cases where turnover is indicated (because there is a difference in the two readings when the input connections are reversed), it is generally true that the average of the two readings is a closer approach to the desired reading than either of the separate values.

It is very important to make certain that what appears to be turnover is really turnover and not stray pickup or leakage which may result when one side of the voltage being measured is grounded. In such cases a discrepancy between the two readings may occur because of stray pickup, leakage, and cross ground effects.

Consistency Check

In calibrating multirange v-t voltmeters, it is desirable to check the various ranges against each other to see that they are consistent. For example, a voltage which reads 10 volts (full scale) when the range switch is in the 10-volt position, should also read 10 volts on the 30-volt scale when the range switch is in the 30-volt position. Because readings taken at a fraction of full scale are not as accurate as readings near full scale, perfect agreement cannot be expected.

Use of Outer Linear Scale

The general purpose VTVM usually has a considerable number of separate scales, often as many as six or more. As a result, the relative length of the inner scale is considerably less than the length of the outer scale. This makes it difficult to read accurately voltages on the shorter inner scales. Where the greatest accuracy is desired, this shortcoming can be overcome by using the outer scale as an arbitrary scale in conjunction with a calibration curve specially made for the purpose. Usually this outer scale is linear or very closely linear so that it provides a convenient reference scale.

In this way the effective length of the inner scales can be greatly increased, although there is the disadvantage that a calibration curve must be used. Since the direct-reading inner scales are sufficiently accurate for practically all measurements, the calibration curve need be used only when the greatest accuracy is required.

Correction Curve for Slide-Back V-T Voltmeters

As pointed out previously, slide-back v-t voltmeters are relatively inaccurate on a-c voltages below about 10 volts because of the rectification error. This applies to both the diode slide-back types, as well as to the triode types. For reasonably accurate work, it is desirable to make a correction curve or separate calibration curve for the low-voltage ranges so that the slide-back voltage may be corrected to determine the true a-c peak voltage.

This calibration or correction curve can be made by applying known values of voltage between about 0.1 volt and 10 volts and noting the value of slide-back voltage which gives the reference value of plate current. A curve can then be plotted which shows the true value of peak voltage in terms of the indicated d-c slide-back voltage. Alternatively, a correction curve may be plotted which shows the amount which must be added to the slide-back voltage in order to obtain the true peak voltage. To avoid error, the same reference value of plate current which is employed for making the calibration must be used whenever the slide-back v-t voltmeter is subsequently employed.

Calibration of V-T Voltmeters at Ultra-High Frequencies

The calibration of v-t voltmeters at frequencies above about 30 megacycles presents a great many difficulties. At these frequencies, the ordinary standards which are adequate at low frequencies are entirely unsatisfactory. A description of the apparatus and methods for ultra-high frequency calibration of VTVM beyond the scope of this book.[2]

Measuring the Input Impedance of A-C V-T Voltmeters

The input impedance of a-c v-t voltmeters may be measured by any of the methods which are used for measuring impedance at

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[2] L. S. Nergaard, "A Survey of Ultra-High-Frequency Measurements," *RCA Review*, vol. 3, p. 156, Oct. 1938.

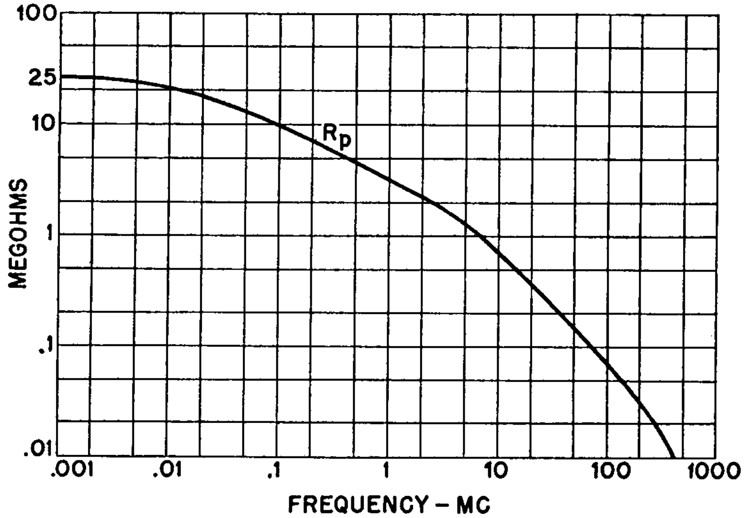
radio frequencies. It is convenient to consider the input impedance as consisting of a capacitor which is shunted by a resistor, the former representing the input capacitance of the VTVM, while the latter represents the input resistance or loading effect.

The capacitance of the v-t voltmeter may conveniently be measured at low frequencies using the standard substitution method. Care should be taken to see that the length of the leads to the input terminals are not measured as being part of the input capacitance.

Measuring the loading effect of the VTVM is more difficult, since the input resistance varies very widely with the frequency, so that the measurement must be carried out at radio frequencies. A convenient method for measuring the input resistance is to connect the v-t voltmeter across a high-Q tuned circuit. If the losses introduced by the VTVM across the tuned circuit are high in comparison with the losses of the tuned circuit itself, the v-t voltmeter resistance can be determined by using the capacitance or frequency variation methods for measuring resistance. In both of these methods the unknown resistance is determined by the effect of the resistance on the sharpness of the selectivity curve, using the VTVM which is being measured to provide the relative output readings (see p. 264). Where the v-t voltmeter losses are very small, it is necessary to have two identical v-t voltmeters in order to determine the exact losses. The procedure is to shunt the second v-t voltmeter across the same tuned circuit and to note the additional effect on the selectivity curve. The input resistance of the v-t voltmeter may then be determined with good accuracy. The second VTVM need consist only of the input tube and need not have a d-c amplifier or meter.

The manner in which the input resistance of v-t voltmeter drops as the frequency is increased is shown in Fig. 11-2. The upper frequency limit of this meter is about 500 megacycles.

The input resistance of a-c v-t voltmeters at 60 cycles may be determined readily by noting the value of series resistance required to drop the full-scale deflection to half-scale deflection. The value of resistance required is equal to the input resistance of the VTVM. Metallized resistors are satisfactory for this measurement because of their lower shunt capacitance and because high accuracy is not required.



Courtesy General Radio Corp.

Fig. 11-2. Graph showing the variation of input resistance with frequency for a typical v-t voltmeter.

V-T Voltmeter As a Comparison Voltmeter

In sensitive v-t voltmeters where it is not possible to make a direct calibration which will be accurate over an appreciable period of time, it is common practice to use the VTVM in conjunction with a standard source of voltage, as is shown in Fig. 11-3. The procedure for measuring an unknown voltage is first to connect the v-t voltmeter to the unknown voltage and to adjust the VTVM sensitivity so that a full-scale reading is obtained. The standard source of voltage, which may be either a standard signal generator or a potentiometer set-up, is then connected to the v-t voltmeter, and the standard voltage adjusted to obtain the same reading on the v-t voltmeter. It follows that the unknown voltage is then equal to the standard voltage. No adjustments should of course be changed on the VTVM, and the frequency of the standard voltage source should preferably be the same as the frequency of the unknown voltage, especially where the v-t voltmeter has a nonuniform frequency response. This type of set-up, while it does not have the convenience of a directly calibrated VTVM, has the advantage of combining the high input resistance characteristic of the v-t voltmeter with the high order of accuracy made possible by using either a low-frequency source of comparison voltage or a standard signal generator.

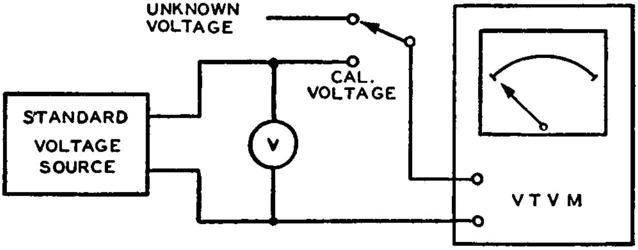


Fig. 11-3. Highly accurate voltage measurements can be made by noting the standard voltage required to obtain the same deflection on the v-t voltmeter.

Use of Log-Log Paper for Square-Law V-T Voltmeters

The calibration of square-law v-t voltmeters can be simplified by plotting the calibration on log-log graph paper instead of on the conventional linear graph paper. Because of the square-law relationship between the plate current and the input voltage, the calibration curve plotted on log-log paper will be a straight line over the portion of the calibration which shows a square-law re-

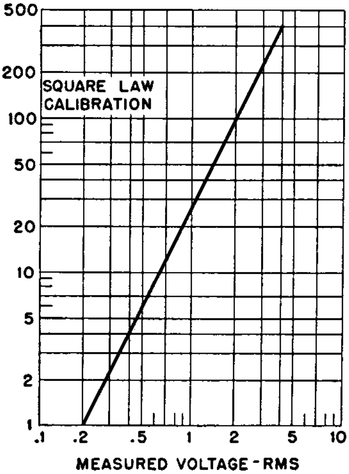


Fig. 11-4. The calibration of square-law v-t voltmeters can be simplified by using log-log graph paper. Compare this curve with the equivalent curve shown in Fig. 3-7b.

sponse. The calibration curve of Fig. 3-7b plotted on log-log paper is shown in Fig. 11-4. Note that the calibration procedure is simplified considerably since only relatively few points are required to determine the straight line.

Checking a Decibel or Logarithmic Calibration

In the calibration of decibel or logarithmic v-t voltmeters, it is frequently desirable to check the accuracy of the scale calibration. This can readily be done without any special equipment since VTVM's of this type are usually provided with a calibrated input attenuator which covers a wider range than the direct-reading decibel scale.

To check the accuracy of the scale calibration, the input attenuator (use an external attenuator if the instrument does not have one) can be adjusted to the middle of its range, and a signal applied so that a mid-scale reading is obtained. The input attenuator can then be varied on both sides of the initial setting, and the meter reading noted to see whether it agrees with the attenuator reading. Thus if the attenuator is changed by 6 db, the meter reading should also change 6 db. In commercial instruments, adjustments are usually provided for making the scale track accurately. The manufacturer's instructions should be followed in making these adjustments, since the procedure varies depending upon the design of the circuit.

Calibration of D-C V-T Voltmeter

The calibration of d-c v-t voltmeters is considerably simpler than that of a-c VTVM's because frequency response is not a factor. Essentially, the calibration procedure is to place the v-t voltmeter in parallel with a good d-c voltmeter which is known to be accurate to within ½ to 1 per cent, depending upon the desired accuracy. Various values of d-c voltage are then applied, and the reading of the VTVM compared with the reading of the standard voltmeter at a sufficient number of points on each range. Usually d-c v-t voltmeters are provided with a calibration adjustment for each range. This adjustment should be set so that the VTVM reading is accurate at full-scale deflection. If a decade voltage divider or calibrated potentiometer is available, the calibration procedure can be simplified considerably as previously explained. In this case the input voltage to the decade voltage divider is standardized, and then any desired value of output voltage can be obtained.

Sensitive d-c v-t voltmeters which do not have sufficient accuracy to hold a calibration over a long period of time may be used in conjunction with a standard source of d-c voltage to make possible the accurate measurement of small voltages, while retaining the high input resistance characteristic of the VTVM. The decade voltage divider is extremely useful for this application.

Measuring Grid Current and Input Resistance of D-C V-T Voltmeters and V-T Ohmmeters

The importance of low grid current and high input resistance in d-c v-t voltmeters has already been covered. The following procedure may be used to measure the grid current: First insert a high value of resistance in the grid circuit, of the order of 100 megohms or higher, and set the zero adjustment so that a zero reading is obtained on the most sensitive range. The control grid should then be shorted to ground, and the change in the zero reading noted. The grid current can then be computed by dividing (1) the voltage reading corresponding to the change by (2) the resistance inserted in the grid circuit. The grid current is of course not constant, but depends upon the value of resistance in the grid circuit. However, the above method can be used to check the grid current for any value of grid resistance which is large enough to cause a change in the voltage reading of the instrument on the most sensitive range.

In connection with the above measurement, any leakage currents which may exist in the input circuit will cause a change in the reading which is not due to grid current. As previously mentioned, these leakage currents can be completely eliminated by proper design and layout. An important precaution to note in making the above measurement is that the resistor through which the grid circuit is completed must be mounted close to the control grid in order to minimize leakage and stray a-c pickup in the grid circuit.

The input resistance of d-c v-t voltmeters can readily be measured by inserting a resistance in series with a source of d-c voltage which is sufficient to drop the voltage reading to one-half. The input resistance will then be equal to the above required value of series resistance. The input resistance varies with the value of applied voltage, so that the measurement should be made at those voltages which are of interest.

A rapid check for the presence of grid current in v-t ohmmeters can be made by rotating the range switch from the low-resistance ranges to the highest-resistance range. If there is negligible grid current, no change in the full-scale position of the meter pointer will be observed, while the presence of grid current will be indicated by a decrease in the deflection.

REVIEW QUESTIONS

CHAPTER 11

11–1. What does the calibration of a voltmeter consist of?

11–2. In calibrating a VTVM, what determines how accurate the standard must be?

11–3. Give six precautions to follow when calibrating a VTVM.

11–4. Why is an error introduced into the reading of an rms-calibrated peak voltmeter when measuring complex waveforms?

11–5. What are the possible causes for a difference in meter reading when the input connections are reversed for the same unknown voltage?

11–6. How would you plot a calibration curve for a v-t voltmeter? Where would you use such a curve?

11–7. Outline the steps you would take to calibrate: (1) a d-c v-t voltmeter; (2) an a-c v-t voltmeter.

11–8. What is a rapid check for the presence of grid current in v-t ohmmeters?

CHAPTER 12

APPLICATIONS OF V-T VOLTMETERS

The applications of VTVM's are so numerous and varied that without exaggeration they can be said to cover the entire field of radio measurements. This is to be expected since voltage is one of the fundamental electrical quantities, and the v-t voltmeter provides virtually the only means for measuring voltage with a reasonably small reaction on the circuit under test, especially when the circuit has high resistance and the voltage is low. In view of the practically unlimited number of applications, we must consider only those in this chapter that are fundamental in character. In this connection, we might remark that the measurement of resistance introduces some interesting applications which we will deal with also.

The various types of v-t voltmeters which have been described provide for every type of voltage measurement which need be made. Thus, VTVM's are available for measuring d-c voltages; the peak, average, and rms values of a-c voltages; and the peak and trough values of pulsating voltages. In addition, amplifier type v-t voltmeters make it possible to measure very small voltages such as those often encountered in the various kinds of electronic equipment, stages of amplifiers and receivers, etc.

Some special and related meters, not strictly speaking vacuum-tube voltmeters, are also considered here. Electronic microammeters, electrometers, and pH meters are examples of these types.

General Considerations

Before using a vacuum-tube voltmeter it is well to study its rating, circuit diagram, and general characteristics. The most obvious question is whether or not the frequency of the voltage to be measured is within the range of the instrument. If the frequency is near or beyond the primary range limits, a correction may be required. Another consideration is the voltage being measured and its effect on the voltmeter reading. *Sine-wave voltage is assumed* in most voltmeter calibrations; an input with a waveform *other than sine wave will cause varying errors.* An oscilloscope is useful in such cases for interpreting the voltmeter reading.

Still another important consideration is the effect of the voltmeter input impedance upon the circuit under test. If detuning and loading is to be kept to a minimum in making measurements on tuned and other high impedance circuits, the highest possible input impedance meter must be chosen. All of the above factors influence the accuracy of the meter in all of the applications to follow, and must be considered when determining the accuracy with which a measurement is desired. In this chapter a number of specific applications will be considered, as well as general instructions for making various types of measurements, together with precautions to be taken.

General Precautions

The initial setting of the voltmeter range switch should be for the *highest* voltage; the ranges are then progressively reduced until there is a sufficient deflection of the pointer to allow a convenient reading. It is conceivable that two settings of the voltage range switch may result in two different voltage readings. If the error on either range exceeds the *rated accuracy* of the instrument, it indicates a defect in the instrument on one of the two ranges. It must be remembered that the *rated* accuracy applies to *full scale* readings.

The importance of such error is controlled by the importance of the quantitative determination. In view of the variables encountered in the device under investigation, a difference of one or two per cent in indications on two scales in excess of the rated accuracy is generally unimportant, and seldom warrants returning the instrument for repair. Of course one always is desirous of attaining maximum accuracy, but practical considerations should not be lost sight of.

The higher the frequency of operation the greater the possibility of errors in excess of the manufacturer's rating. Generally speaking, accuracy ratings are a compromise. No device is *absolutely* flat in its response over a wide frequency range; as the outlying portions of the frequency range are approached the greater will be the possible departure from the rated accuracy.

Changing the physical location of a probe relative to the circuit being measured while voltage ranges are being changed on the voltmeter can conceivably cause a change in indication. This is not a fault of the instrument and must be expected. If the position of the probe ground is altered while making r-f measurements on two voltage ranges, changes in readings may be expected first, because the difference of potential between the probe tip location and the ground point may be different due to standing waves; second, because resonance conditions are subject to change along a ground bus at high frequencies; and third, because the new "ground" may be ineffective as a ground. Signal voltages are often present at "grounded" points decreasing the effectiveness of the point as a ground. In the final analysis, the importance of such variations depends upon the criticalness of the measurement.

Whenever possible, the *high* side of the voltmeter input system should be joined to the *exact* point where the voltage is to be measured, particularly at high frequencies. A very *substantial* difference in indication results if the input tip makes contact with the plates or the control grid of a tube rather than with the high side of the tuned circuit located in these systems. This is a very important precautionary note because many systems contain circuit elements between the tube electrodes and the tuned circuits, so that the signal voltage at the tuned circuit is not the same as will be found at the tube electrodes. When the aforementioned intermediate circuit elements are absent, it is quite satisfactory to measure at the tube electrode terminals.

Amplifier Stage Measurements

One of the most important measurements for which the vacuum-tube voltmeter is particularly suitable is the r-f stage-gain measurement. The object is to find the voltage gain of an r-f amplifier stage under various conditions. Stage gain measurements may be made on a stage by itself, as in design, or with the stage as part of a circuit. The gain of a given stage may be considerably modified in an actual complete circuit by over-all regenerative or degenerative effects.

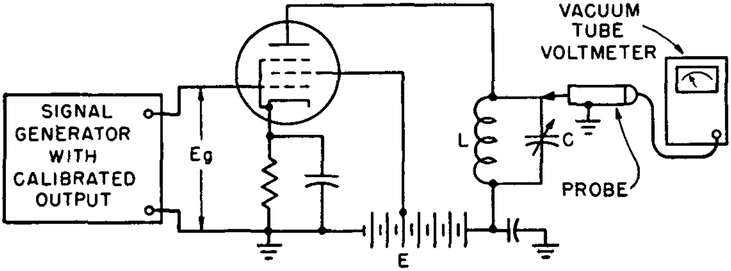


Fig. 12-1. Test setup for single-stage gain measurements on an r-f amplifier using a v-t voltmeter. Stage gain measurements are used to find the frequency response of an amplifier by varying the frequency of the signal generator and measuring the amplifier gain for each frequency.

Figure 12-1 shows a typical setup for single-stage gain measurements. The gain is a function of the tube characteristics, operating voltages, and resonance conditions (tuned impedance) of the plate circuit. If the signal generator has a known output (calibrated in microvolts), the value of the grid voltage E_g is known and it is only necessary to measure the signal voltage across the tuned circuit by means of the VTVM. The stage gain is then the voltage across the tuned circuit as read on the v-t voltmeter divided by the grid voltage as shown on the signal generator output attenuator dial.

To explain the significance of the stage gain in terms of the circuit components, refer to the equivalent circuit of the single stage shown in Fig. 12-2. The grid voltage E_g is effectively multiplied by μ, the amplification factor of the tube, and this amplified signal voltage appears in series with the dynamic plate resistance, R_p, and the tuned circuit *L-C*. At resonance, the plate load *L-C* is equivalent to a resistance having a value of $2\pi QLf$, and the signal current, I, around the loop will be μE_g divided by $R_p + 2\pi QLf$. The signal voltage across the tuned circuit at resonance will be $2\pi QLf \times I$ (the signal current times the load of the tuned impedance), and the

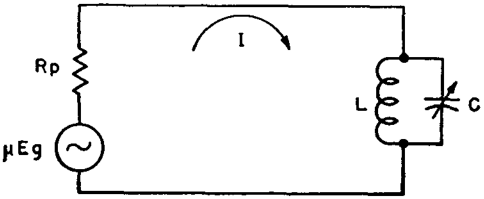


Fig. 12-2. Equivalent circuit of a single r-f amplifier stage.

stage gain will be this output signal voltage divided by E_g, the input signal voltage:

$$\text{Stage Gain} = \frac{2\pi QLfI}{E_g} = \frac{2\pi QLf\mu}{R_p + 2\pi QLf}.$$

While the stage gain is always taken at resonance, that is, with *L-C* tuned to the frequency of the signal generator output, the off-resonance gain may also be measured. A resonance curve will give both the resonance and off-resonance gain.

The gain of a stage is a function of the *Q* values of each of the tuned circuits in the stage. To understand the resonance curve it is necessary at this point to discuss the factors upon which the *Q* of a tuned circuit depend.

For series-tuned circuits of the type shown in Fig. 12-3, when resonance is reached X_L, the inductive reactance, equals X_C, the capacitive reactance, so that the impedance of the circuit is *R*. At this value the current in the circuit is greatest, for as the frequency changes, the balance between X_L and X_C is destroyed and the total impedance consists of *R* plus some value of reactance as is seen from the following equation for the impedance of a series circuit:

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

where *Z* is the total impedance of the circuit.

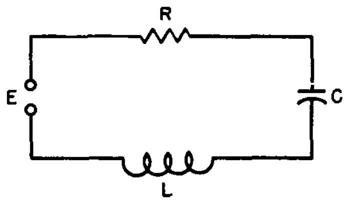


Fig. 12-3. A series-tuned circuit with *R*, *C*, and *L* components. At resonance, the total impedance equals *R*.

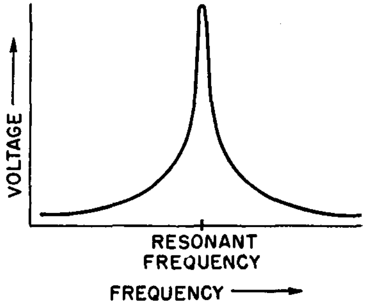


Fig. 12-4. Graph showing the variation of voltage across *L* in Fig. 12-3 with the frequency of the input voltage.

Since the current at resonance is largest, the voltage drop across L and C will be largest. (The total effect of the voltage drops is zero since they are 180° out of phase, so that only the voltage across R, equal to the applied voltage, is effective.)

Q is defined as the ratio of reactance to resistance in a series circuit at resonance. The reactance is equal to:

$$X_L = \frac{E_L}{i_{\text{res}}}$$

where X_L is equal to the inductive reactance at resonance.
E_L is equal to the voltage across the inductance at resonance
i_{res} is the current flowing in the circuit at resonance.

The resistance is:

$$R = \frac{E_R}{i_{\text{res}}} = \frac{E}{i_{\text{res}}}$$

where E_R is the voltage across R at resonance and is equal to the applied voltage E.

Q, therefore, may be found from the following equations:

$$Q = \frac{X_L}{R}$$

$$Q = \frac{\dfrac{E_L}{i_{\text{res}}}}{\dfrac{E}{i_{\text{res}}}} = \frac{E_L}{E}\cdot$$

Since X_L is equal to $2\pi fL$ we get from the last equation:

$$E_L = EQ = E\frac{2\pi fL}{R}\cdot$$

From these equations we see that the Q of a tuned circuit increases as the resistance of the tuned circuit decreases. Also, if the applied voltage is held constant, and the frequency is varied, the voltage across the inductance will vary as is shown in Fig. 12-4. This is a resonance curve for the L-C circuit. Note how sharply the voltage rises for a small difference in frequency about the resonance frequency. The higher the Q value of the circuit, the sharper is this rise.

For parallel circuits of the type shown in Fig. 12-5, the current flow is smallest at resonance. (This is so because at resonance $X_L = X_C$ so that the only branch drawing current is *R*.) This may be expressed in another way by saying that the impedance of the circuit is greatest at resonance. Actually, if we plotted the impedance of the circuit vs. the frequency, we would obtain an impedance curve of the kind shown in Fig. 12-6. Any parallel *L-C* circuit, with or without a resistance branch will give the same type results as those described for the circuit of Fig. 12-5. To actually plot an impedance curve, we measure the voltage across the circuit and the current in the circuit for various values of frequency. For parallel circuits, the higher the Q value, the sharper the impedance curve.

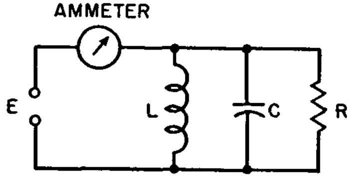


Fig. 12-5. A parallel-tuned circuit. At resonance only *R* draws appreciable current while the *L-C* combination offers maximum impedance.

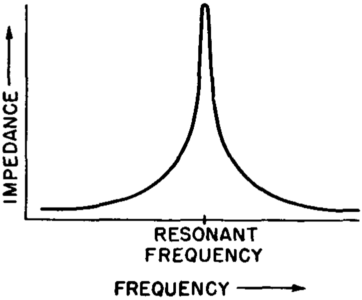


Fig. 12-6. An impedance vs. frequency curve for the circuit in Fig. 12-5. The steepness of the curve about the resonant frequency depends on the *Q* of the circuit.

Since for both types of circuits, the gain is a function of the *Q* value, we see that the selectivity curves (which are plots of the gain of a stage versus the frequency of the signal input), will be roughly similar to the resonant impedance curves of the tuned circuits of the stage.

The selectivity of the single stage is obtained by measuring the gain for several frequencies as the generator frequency is varied above and below resonance. The effect of cathode, screen, and plate voltages on the stage gain may be found by varying these voltages independently.

In making these measurements, the probe is usually connected from the high side of the plate load circuit to ground as shown in Figs. 12-1 and 12-7. This places a considerable d-c voltage across

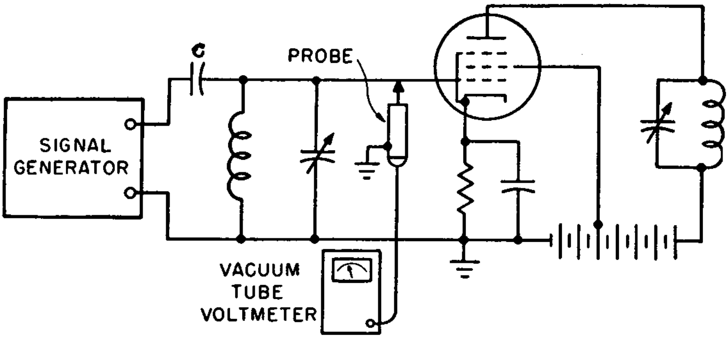


Fig. 12-7. Test setup for measuring the regenerative rise of an r-f amplifier. This effect is one of the causes of oscillation in amplifiers.

the probe. If therefore, the probe input coupling capacitor has leakage, an initial reading will be observed on the voltmeter with no signal present. If the reading is small, it may be corrected by resetting the voltmeter zero adjust. If it is large, a low leakage capacitor should be placed in series with the probe input, or the probe capacitor should be changed.

In making stage gain and selectivity measurements, care should be taken not to overload the tube. This may be especially important when a calibrated signal generator is not available and gain is obtained by measuring E_g and L-C voltages with a voltmeter. A good rule to follow is never to allow the peak of the signal voltage on the grid to exceed the cathode or grid steady-bias voltage.

The above technique applies as well to gain measurements in a mixer or converter stage, except that a second r-f signal is required in the case of the mixer to represent the local oscillator voltage.

Another important design factor which may be measured by means of the stage gain setup is called "regenerative rise." When both plate and grid circuits of an amplifier stage are tuned to the same frequency there may be feedback which causes the gain to increase above that normally expected in the stage. It is more useful to look at this as an increase in grid signal voltage due to tuning the plate circuit. The ratio of this voltage increase to the initial signal voltage on the grid is then the regenerative rise. If the rise voltage is greater than the initial signal voltage, that is, if the ratio is greater than 1, the stage will oscillate. A conservative design for example, might dictate that the regenerative rise be not more than 20 per cent (or 1 : 5).

Figure 12-7 shows the circuit for measuring regenerative rise. Tuned circuits are placed in series with both the plate and the grid. The signal generator is loosely coupled to the grid circuit through a small capacitor C (of the order of 2 $\mu\mu$f). The VTVM is placed across the signal-grid tuned circuit which is tuned to the frequency of the signal generator. The signal voltage at the grid is noted. Then the plate circuit is tuned to resonance and the increase in signal voltage at the grid is observed. This increase divided by the amplitude of the original signal is the regenerative rise.

The measurements outlined above as well as others may be made in actual circuits utilizing r-f amplifier stages as in radio and television receivers. Care should be taken when making such measurements that short leads are used to connect the v-t voltmeter probe to the circuit under test, and that the volmeter input connecting lead does not increase regenerative coupling effects in the circuit. For accurate measurements, the circuit across which the probe is connected should be tuned with the probe connected, and retuned after the probe is removed.

A typical outline for the measurement of stage-by-stage gain for an a-m receiver follows:

1. Connect an unmodulated signal generator to the antenna terminals of the set.
2. Adjust the signal generator for maximum voltage output. A generator output of at least 0.1 volt is desired for satisfactorily determining the gain of the *first* r-f stage.
3. Tune the receiver to the signal generator. Short out the receiver avc.
4. Set the v-t voltmeter range switch to the most sensitive scale in the a-c range, the selector switch to "A-C Volts."
5. With the probe shell grounded, measure the voltage at the plate of the r-f tube. Similarly, measure the grid voltage of the r-f tube. The ratio of the voltages gives the gain of the r-f stage, as previously stated.
6. Reduce signal generator to zero output and check receiver oscillator voltage at oscillator grid and plate, and at converter tube injector grid.

7. Restore signal generator to output level which gives *readable* signal level at r-f tube plate. Measure the signal generator output voltage and voltage at converter tube plate. The ratio of these voltages is the conversion gain of converter tube.
8. Measure voltage at the plate of first i-f tube. This voltage is divided by the voltage at the plate of the converter tube for the stage gain.
9. Repeat for succeeding stages, reducing signal generator output to keep from overloading stages under test or adjacent stages, since avc is not operating.
10. Restore avc voltage.

As an example of what may be expected in the r-f portion of a small ac-dc receiver, the following figures are given. With 0.1 volt of rf fed to the receiver through a standard IRE dummy antenna, the avc on the control grid of the 12SA7 tube was 5.8 volts dc. Rf appeared on the various tubes as follows:

12SA7 converter grid	0.13 volts rf
12SA7 converter plate	0.7 volts rf
12SK7 i-f grid	0.2 volts rf
12SK7 i-f plate	6.4 volts rf
12SQ7 diode plate	3.6 volts rf

These figures will, of course, vary with different receivers and circuits, but in general, a minimum of 3 volts should always be found at the diode plate of the second detector.

For triode-detector circuits, the gain may be found from the following equation:

$$\text{Gain} = \frac{\text{Audio Output Voltage across Detector Load}}{\text{Input Carrier Voltage} \times \%\ \text{Modulation}}\ .$$

Stage-by-stage gain measurements for f-m receivers are made in the same way as those described above for a-m receivers, since the sets are similar up to the limiter and discriminator. F-m i-f circuits will probably be found to be less sensitive to detuning caused by the application of the r-f probe.

For each measurement be sure that the shell of the r-f probe makes contact with the receiver chassis, or that it is connected to the chassis by an alligator clip, or short lead.

It is not always appreciated that while the vacuum-tube voltmeter is a high impedance device, its input capacity should not in many cases be neglected. As an illustration, a probe having an input capacitance of 5 $\mu\mu$f was placed across a tuned circuit with a 200-$\mu\mu$f capacitor, a *Q* of 160, and a resonant frequency of 600 kc. The probe caused a drop in voltage due to detuning of 73 per cent. When the circuit was retuned, however, with the probe as part of the circuit, the error introduced was of a minor magnitude.

Oscillator Strength Measurements

The operation of an oscillator stage may be determined by checking the d-c voltage on the grid of the oscillator. The strength of this d-c voltage is proportional to the strength of oscillation. The measurement of the grid voltage should be made while tuning from one end of the band to the other, or while switching bands and varying the main tuning capacitor, depending upon the type of equipment being checked. Normally, a negative voltage of from 5 to 30 volts will be found at the grid of the oscillator tube. The manufacturer's data should be checked for this information. If the voltage drops to an abnormally low reading, or to zero, the tuning capacitor may be defective, or the defect may be in the oscillator coil.

The oscillator stage may also be checked by measuring the r-f voltage either in the tube circuits or in the coupled load circuit. The magnitude of the r-f voltages should range from 0.1 to 15 volts depending upon the circuit and the point of measurement. Again, for the correct voltage at each point check the manufacturer's data.

Correcting Electrical Frequency Instability of Test Oscillators—Erratic changes in the output frequency of an oscillator after the warming up period may be caused by abnormal changes in the characteristics of the oscillator tube or in a component of the oscillator circuit. If the trouble is the latter (the tube is best checked by substituting a good tube for the original), the component at fault must be changed. To check for frequency instability, connect a VTVM across the oscillator grid leak and measure the d-c voltage here while the tuning capacitor is varied over its range.

To check for loose trimmer screw or moisture absorption by trimmer capacitor (these cause drift), disconnect the suspected component and test as above.

If resistors are at fault check their values with the ohmmeter section of the VTVM while they are warm and with the oscillator tube removed to do away with conduction current. Wide variation between the warm and cold resistance of carbon resistors will cause drift.

Crystal Oscillators—In crystal oscillators, the crystal replaces the tuned tank circuit used in other type oscillators. The measurement of d-c voltage on the grid of the oscillator will, as before, serve as a check on the operation of the oscillator. If the crystal oscillator is of the fixed-frequency type, only one measurement need be taken. If the oscillator uses a number of crystals to vary its frequency, measurements should be taken for each crystal in the circuit.

Oscillators with high harmonic outputs cannot be adequately checked with most VTVM's. To determine the quality of the output of such oscillators, an oscilloscope should be used. Wave analyzers making use of VTVM's are also useful for such measurements. A discussion of wave analyzers is given later in this chapter.

Audio Voltage Measurements

Measurements of the audio stage output are useful for primarily two reasons: (1) they furnish the audio stage gain, (2) they are a means to better i-f alignment.

To determine the gain of the audio stage, simply inject an audio signal onto the grid of the a-f amplifier tube and measure the output voltage on the a-c voltage range of the VTVM at the plate of the tube. The gain is equal to the output reading divided by the input reading.

If an output meter is used for alignment rather than the method of listening for the strongest signal, better alignment results since peak amplitudes are readily shown on a v-t voltmeter. For such measurements, the voltmeter should be placed *across* the voice coil since the latter is usually not grounded.

When making measurements on audio stages, if there is a possibility that the circuit under test will be detuned by the input capacitance of the voltmeter, the input impedance may be increased by using an unshielded lead rather than the shielded lead generally supplied with the instrument for such measurements.

Measuring Output-Tube Plate Loads—Connect VTVM as indicated in Fig. 12-8:

1. Note reading with a-f voltage applied to the output tube.
2. Make another measurement with the same input voltage but with high-impedance choke connected in parallel with variable *R* substituted as output transformer load.
3. *R* is varied until reading on VTVM is the same as first obtained.
4. Disconnect *R* from choke and measure its value on ohmmeter. The resistance represents the equivalent output transformer primary winding impedance. Receiver speaker should be connected during tests.

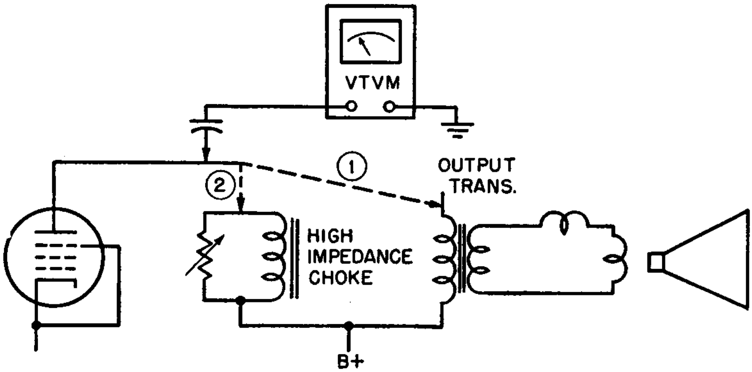


Fig. 12-8. Shown here is a setup for measuring the impedance of the primary winding of an audio output transformer. The method of measurement is outlined in the text.

Signal Tracing—Checking Amplifier and Receiver Operation

In Chapter 6 a number of sensitive audio-frequency v-t voltmeters which permit measurements of audio-frequency voltages from a millivolt to several hundred volts were described, while in Chapter 5, the tuned-amplifier type of VTVM was described. Using both of these v-t voltmeters, it is possible to check the operation of an amplifier or receiver by connecting a source of voltage to the input and measuring the signal voltage developed at every point of interest in the amplifier. Most commercial signal-tracing instruments contain two v-t voltmeters of the type described, one for measuring audio-frequency signal voltages and one for measuring radio-frequency and intermediate-frequency voltages. With such an instrument it is possible to measure the signal voltage at the input and output of each stage in a receiver and in this way to check gain, hum, and distortion, and to localize any defective condition which may be present. In servicing intermittent receivers in particular, these VTVM's or signal-tracing instruments have proved to be extremely valuable since they permit a continuous monitoring of the signal voltage at key points in the receiver.

It should be remembered that most r-f amplifiers in receivers have automatic volume control. The true gain and selectivity of such a circuit can be measured only if the automatic volume control circuits are temporarily disconnected for these measurements. Similarly, in frequency-modulation receivers with limiters, measurements of stage gain and selectivity must be made on the signal before the point at which limiting takes place. If these precautions are not observed, the control action of the automatic volume control or the limiting action of the limiter will cause the gain to be apparently much lower than it actually is and the selectivity to be greatly reduced.

Typical Signal Tracing Procedure for Superheterodyne Receiver—Conventional a-c superheterodyne receivers with one r-f stage, a combination mixer-oscillator, one i-f stage, a second detector, and an avc diode may be serviced by using the following procedure (check points refer to numbers in Fig. 12-9):

1. Connect test oscillator as shown between antenna and ground terminal.
2. Tune test oscillator and receiver to 600 kc.
3. Put VTVM across test oscillator terminal and adjust output of oscillator until a convenient reading is obtained on the VTVM. This will be the "reference level" for stage-by-stage gain measurements.
4. Set the probe of the VTVM at ①. If no reading can be obtained either the antenna coil is shorted, or the antenna terminal is grounded.
5. Set the probe of the VTVM at ②. The signal should be stronger than at ①. If there is no signal here, *C1* or *C2* may be shorted, the tube may have a short, or the secondary of *T1* may be open.
6. Place probe on ③. No signal indicates either that primary of

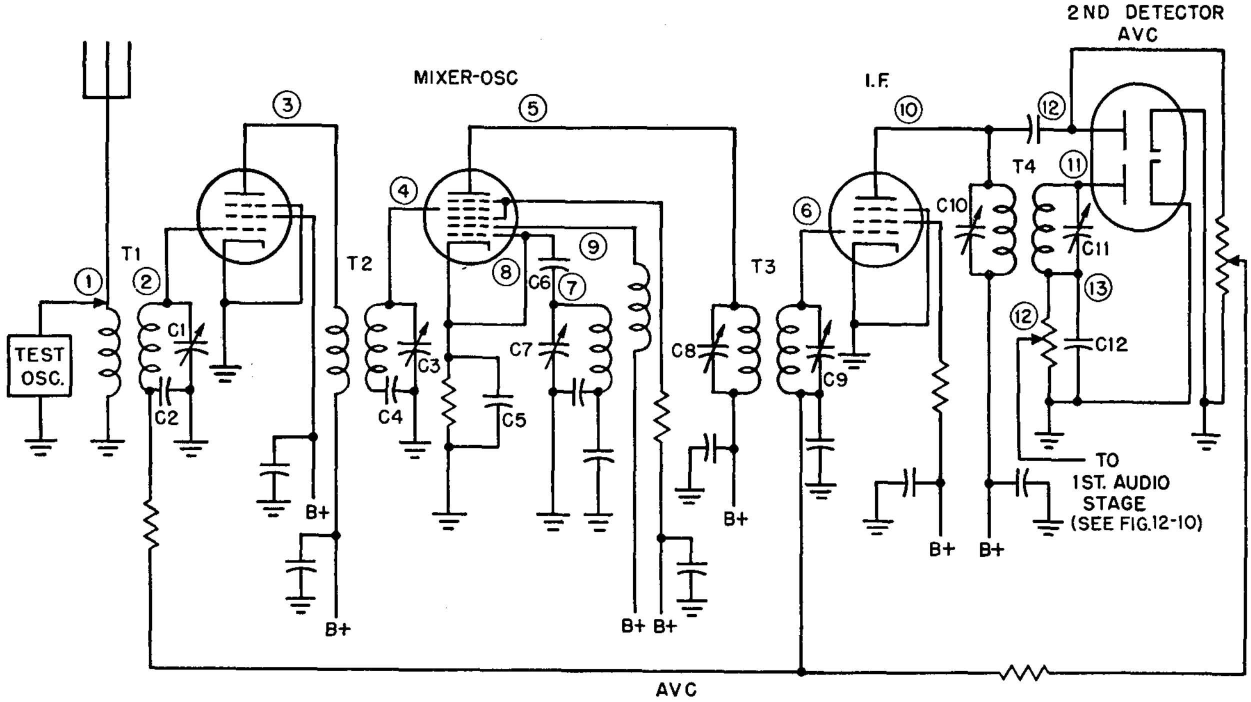


Fig. 12-9. Circuit diagram of the first four stages of a typical superheterodyne receiver. The circled numbers refer to check points for signal tracing with a v-t voltmeter.

T2 is open, there is no voltage supply to screen grid or plate, the cathode circuit is open or the tube is bad.

7. Check point ④. No signal here caused by same defects in mixer circuit as in ⑤.
8. Place probe at point ⑦ and check the pentagrid converter. The conversion gain for this stage is:

$$\text{Conversion Gain} = \frac{\text{I-F Signal Voltage (at Plate)}}{\text{R-F Signal Voltage (at 4 ④)}}\cdot$$

The conversion gain will vary from 10 to 40 with no avc, and will be about $\frac{1}{5}$ of this with the avc working.

9. To check the oscillator, measure point ⑧ to ground. The VTVM should give a negative value. If zero or positive voltage is present, oscillator is inoperative.
10. Check the i-f signal at points ⑤ and ⑥ and then at ⑩ and ⑪. If a tuned VTVM is used, the tuned circuit should be set at the i-f frequency for these points.
11. Check the avc (see procedure at the end of this section). It is sometimes advisable to check the avc first. If there is avc voltage it indicates that all the sections ahead of the 2nd detector are in working order, so that the signal tracing can start at the 2nd detector. If there is no avc, check the stages ahead of the 2nd detector. The presence of an i-f voltage at ⑪ when there is no avc indicates that the 2nd diode detector is defective.
12. With volume control at maximum, place VTVM prod at ⑫. No signal here indicates bad components in this part of the circuit.
13. Check point ⑬ (refer to Fig. 12-10). Absence of signal here indicates open circuit. A short in this circuit would also have shown up at point ⑫.
14. Check point ⑭. No signal here indicates open plate resistor, open cathode resistor, or a grounded plate.
15. Check points ⑮, ⑯, and finally ⑰ for signal voltages in each of these portions of the audio system.

In the above, we have followed the signal from the antenna to the speaker coil, intent only on finding whether there was continuity in the various stages. If, at any of the check points listed, we do not get a reading on the VTVM as indicated above, we would check the components in that particular section to find the defect. Thus, we localize the trouble in the receiver. If we do have an operative receiver, but the signal output is weak, we can use the same procedure as above for finding the stage or section of the receiver where the fault lies. In this connection however, we are interested in the *strength* of the signal at each of the test points, so that the VTVM reading with respect to the "reference level" is of primary importance. For such tests, stage gain measurements as described elsewhere in this chapter will determine at which stage the drop in operating efficiency occurs. The stage gain measurements obtained for any receiver should be compared with the values given by the set manufacturer as found in Rider Manuals or similar sources of such information.

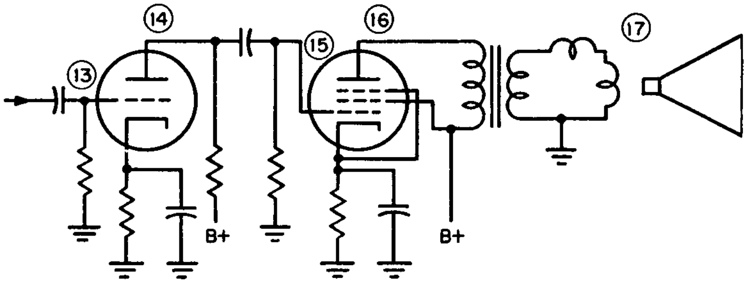


Fig. 12-10. Audio stages of the superheterodyne receiver of Fig. 12-9. The check points are for signal tracing (see text).

Signal Tracing of AVC—Use the following procedure for checking the avc (refer to Fig. 12-11):

1. Feed in an i-f signal (strong, modulated) at ①.
2. If *C* is functioning properly, then there should be low i-f reading at ② but a high audio reading.
3. At point ③, the audio voltage should be less than $1/5$ that at ②. At point ④, there should be almost no audio voltage.
4. Faults in operation are evident through the above procedure. I-f signal at ① is normally about $1/2$ to $1/3$ that at ⑥.
    a. If *C* is shorted or either *R1* or *R2* grounded at ②, the signal voltage at the diode plate would be greatly reduced.

b. Shorted turns in *L3* would reduce signal voltage at ①.

c. Open circuit at *R2, C2,* or *L3* would reduce voltage at ① to low value or zero.

d. If *C1* is open, audio voltage at ③ will be about ⅓ that at ②.

5. D-c voltage for avc diode should be the same at ①, ②, ③, ④, and ⑤, since normally no current flows in avc circuit. Since VTVM does impose some slight loading, the readings will not be exactly the same but will differ by some very small amount. Points ② or ① should be used as reference readings since there is no appreciable drop across *L3.* Use strong signal voltage at diode plate to allow d-c measurements to be made. If *C1* were leaky for example, the reading at ③ would be appreciably less than at ②. To prevent detuning use isolating probe.

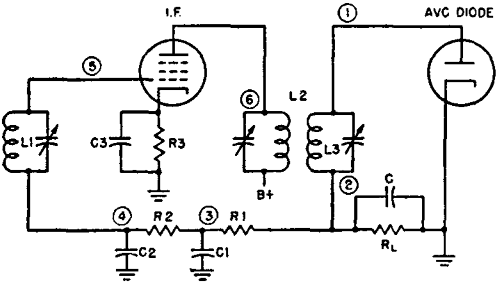


Fig. 12-11. Basic avc circuit for superheterodyne-type receivers. The method for checking such circuits is explained in the text.

Signal tracing as a method for servicing communications equipment as well as other electronic apparatus is widely applicable in many fields. A further discussion of this subject can be found in "Servicing by Signal Tracing," by John F. Rider.[1]

AGC and AVC Measurements

The measurement of automatic volume control and automatic gain control voltages is of the utmost importance in modern radio and television receivers. Incorrect voltages in this part of the circuit result in distortion and irregular variation in audio volume of radio and television receivers, and varying contrast in the video circuits of television receivers. In Fig. 12-12 is a simplified reproduction of an agc circuit of the type found in many television receivers. In this circuit, the agc voltage is furnished to the first, second, and

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[1] Rider, John F., *Servicing by Signal Tracing,* John F. Rider Publisher, Inc., New York, N. Y., 1st ed., 1939.

third i-f amplifiers, and the r-f amplifier, by the filter network consisting of *R1*, *R2*, and *C1*.

A convenient place to measure the agc voltage is across *R1*. With the v-t voltmeter there is no need to worry about the extra loading on the circuit. Another place where voltages may be checked is between pins *2* or *5* and the chassis. The correct voltages for these positions will be found in the data for the set in Rider Manuals, or some other source of manufacturer's information. Other places where agc voltage may be measured are at the grids of the tubes being controlled.

In the alignment of a-m and f-m receivers with avc, the d-c control voltage across the avc diode load resistor may be used to indicate the output level.

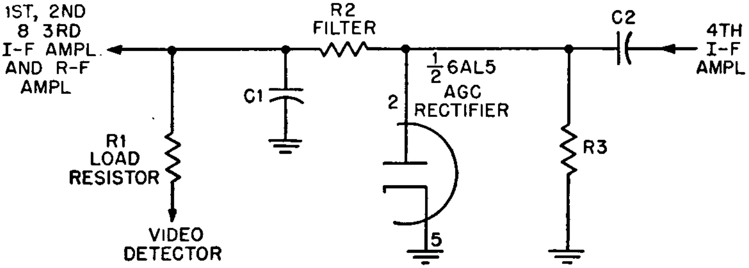


Fig. 12-12. Typical agc circuit of the type found in many television receivers. The agc voltage may be measured across *R1*.

Measurements on AFC and F-M Discriminator Circuits

Since a v-t voltmeter has a negligible loading effect it is ideal for measuring discriminator output voltage for f-m receiver alignment and for checking the associated afc circuit. In the typical afc discriminator circuit shown in Fig. 12-13, the diode plates are at the same d-c potential with respect to the center tap of the load resistors therefore, this stage may be accurately aligned.

If a zero-centered meter is used, misalignment is indicated by a positive or negative reading with the meter connected across the load resistor, with the proper i-f frequency feeding the limiter. An off-tune condition will result in a d-c voltage whose polarity depends upon whether the stage is tuned above or below the correct resonant frequency of the stage.

To set up for this measurement:

1. Short the d-c probe and common or ground lead together.
2. Set the meter pointer to midscale corresponding to the "0" mark on the d-c center-zero scale.
3. Set the signal generator to feed the proper frequency to the grid of the limiter or last i-f stage.
4. Connect the probe of the v-t voltmeter to point *X* and adjust the trimmer *C1* to give a maximum reading of the meter.
5. Adjust the trimmer *C2* to yield a zero reading on the meter.

If the v-t voltmeter available has no center-zero scale, the following procedure may be used:

1. Connect the VTVM across *X-Y* and advance the zero adjust control to bring the normal position of the needle to some arbitrary position on the scale where the pointer movement, either positive or negative, may be noted.
2. Make the necessary alignment, using steps 3 to 5 above, to bring the needle back to the position at which it had been set prior to the connection to the discriminator load.

Whichever type meter is used, the most sensitive d-c scale should be utilized when aligning. The afc system in any receiver may be adjusted in the same way.

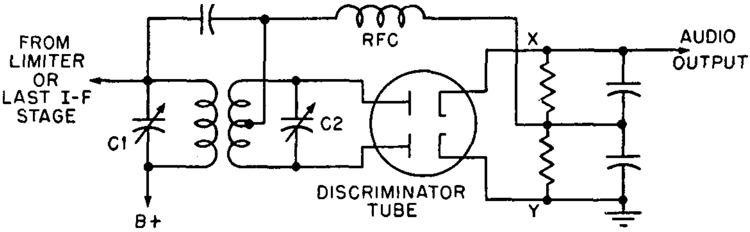


Fig. 12-13. Simplified discriminator circuit of an f-m receiver, showing also the afc circuit.

Television Receiver Adjustments

The v-t voltmeter has proved to be one of the most versatile and accurate of all test instruments for the servicing and testing of television receivers. They may be used with equal facility for d-c, a-c, and r-f measurements.

D-C High-Voltage Tests—To measure the high anode voltages used on cathode-ray tubes, multipliers must be attached to the leads used on the d-c ranges. The use of multipliers for increasing the d-c range of a v-t voltmeter was covered in Chapter 9; when using these multipliers care must be taken that the manufacturer's instructions are followed.

To measure the high-voltage points on the TV receiver follow these simple instructions:

1. Turn off the power to the receiver.
2. Securely connect the common or ground lead of the meter to the receiver.
3. Set the proper range and polarity on the meter.
4. Connect the v-t voltmeter with attached multiplier to the set where the voltage is to be measured.
5. Turn the television receiver on and note the reading on the meter.

Readings should be taken with the "brightness" control of the set at a minimum, so that the screen of the picture tube will be dark. Under these conditions, the current drawn by the VTVM will be approximately equal to that drawn by the picture tube at high brilliance, and the voltage reading will be reasonably accurate in spite of the fact that r-f and flyback type power supplies have very poor regulation.

Alignment—The d-c ranges of the v-t voltmeter may be used also for alignment of the r-f and i-f amplifiers of the television receiver as well as for the accompanying f-m receiver. In each case, the VTVM is connected across the diode load resistor, turned to the "D-C Volts" position, and a signal of the frequency of the stage under test fed into the set. The avc or agc must be temporarily grounded or disconnected for these adjustments. Fig. 12-14a shows the connection to the first limiter grid of an f-m set for alignment of this stage; Fig. 12-14b shows the connection to the typical video detector stage. In each case the reading on the voltmeter will be higher the closer the r-f and i-f tuning of the receiver is to the frequency of the signal set on the signal generator.

Broad-band television i-f stages are quite frequently "stagger-tuned." This usually means that the odd stages are tuned to one frequency, and the even stages to another. For alignment of this type of intermediate-frequency amplifier, insert one unmodulated video i-f frequency (as given in the instructions for the receiver under test), at the grid of the converter tube, and align proper alternate i-f stages so that a maximum reading is obtained on the voltmeter. Then shift the signal generator to the other i-f frequency, and align the remaining i-f stages for maximum indication of the meter.

For the alignment of the discriminator see the instructions given previously.

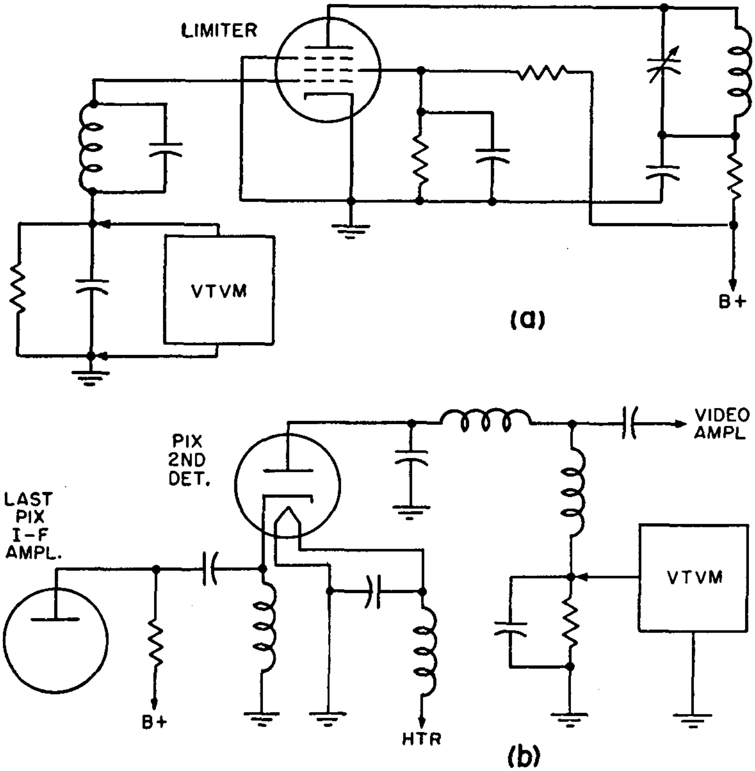


Fig. 12-14. Alignment setups for (a) the limiter stage of an f-m receiver, and (b) the video detector stage of a television receiver. The agc and avc must be temporarily disconnected for these measurements.

Other D-C Voltage Tests—The measurement of the dc developed across the second detector load resistor is useful when adjusting antenna orientation and position as well as when adjusting antenna matching sections.

Television traps may be tuned by applying a signal of the rejection or pass frequency to the trap and reading the r-f voltage appearing on the other terminal of the trap. Adjust the trap tuning for maximum or minimum output according to whether the trap is tuned to the pass or rejection frequency respectively.

A-C Voltage Tests—High voltage power-line frequency tests may be made on television power supplies which use transformers for the high voltage source. External multipliers will usually be required for a-c measurements over 1,000 volts. However, use of the a-c ranges of the v-t voltmeter is not recommended for measuring the value of the voltage ahead of the rectifier tube when flyback type supplies are used, as the current drain of the meter would lead to inaccurate results. The rectified dc may be measured however, using the proper multiplier. For frequencies up to about 15 kc the regular a-c probe should be used, up to 1,000 volts; for higher frequencies use the r-f probe up to its rating.

Readings of a-c deflecting voltage may be taken across the deflecting plates of electrostatic type cathode-ray tubes to indicate the proper functioning of sweep oscillators and amplifiers. An a-c probe may be used on the vertical plates, and an r-f probe on the horizontal deflecting plates. *Do not use the r-f probe on the deflecting coils of electromagnetic type tubes, as very high peak voltages may appear there.* Measurement of the deflection oscillator voltage may be made at points where the inductive kick is not present such as at the plate circuit of the oscillator tubes.

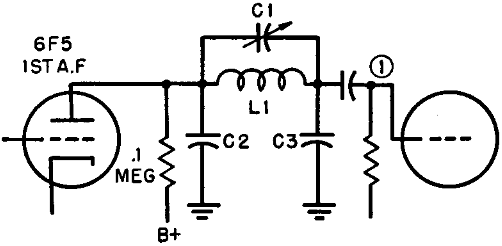
R-F Voltage Tests—Such tests include the measurement of the amplitude of the local oscillator voltage, the measurement of the stage gain of the r-f portion of the receiver, and the measurement of the primary voltage of r-f power supplies. For all such applications the r-f probe should be used in conjunction with the meter.

In measuring the amplitude of the local oscillator voltage, no extensions should be used to the probe (leads, clips, or gimmicks), as inaccuracies will result from the inductance of even a small length of wire at the frequencies present. On channel 13 for example, the local oscillator frequency (the sum of the intermediate frequency and the signal frequency) is of the order of 240 Mc. It is necessary of course to consult the manufacturer's data on the particular v-t voltmeter used to be certain that measurements in this frequency range will be accurate.

When making the measurement, touch the probe tip to the plate circuit of the oscillator tube, or to the anode grid of the oscillator section of the converter tube if a separate oscillator tube is not used. Hold the probe so that its metal case or ground clip comes in contact with a ground point close to the point where the tip is applied, or to a common ground if possible. To check the frequency of the oscillator the VTVM should be used with a tuned input circuit.

Adjustments in the r-f portion of television receivers are very critical and are not usually attempted unless absolutely necessary. If measurement of stage gain is desired, an unmodulated signal of about 0.1 volt from an r-f signal generator may be applied to the input of the receiver, and the voltage gain measured by using the r-f probe and following the procedure for stage gain measurements outlined previously. In comparing voltage measurements to determine stage gain, the impedance of the circuits must be considered so that the transformer voltage gain will not be confused with the tube gain.

Fig. 12-15. A 10-kc wavetrap of the type used in many high-frequency receivers. This wavetrap can be adjusted for maximum impedance by using the v-t voltmeter.



Checking Wavetraps

The 10-kc filter (such as is shown in Fig. 12-15) used in many high-frequency receivers may be adjusted by means of a VTVM and a modulated r-f signal. When the parallel circuit *L1-C1* is tuned to resonance with a 10-kc signal it offers maximum impedance to that frequency, so that little signal voltage of that frequency will be applied to the following grid. To check this condition for a 10-kc filter, feed a 10-kc signal to the grid of the 6F5, then adjust *C1* until the VTVM connected between point ① and ground shows a minimum reading. This can be checked by varying the oscillator frequency above and below 10 kc and notice whether the voltmeter reading increases each side of resonance.

Determination of Gassy Tubes

When a tube is gassy is has a positive charge on the control grid instead of the negative charge that should normally be there. The v-t voltmeter can measure the charge on the grid directly because of its high input resistance, and so determine whether a tube is gassy or not. Remember however, some circuits are designed to operate with a relatively large amount of grid current. Since the test mentioned here is actually a measurement of grid current, check the circuit characteristics first to be certain that the grid should be negative normally. Also, a bad coupling capacitor will result in a positive charge on the grid. Substitute a good tube for the suspected gassy one. If the coupling capacitor is bad the grid will still be positive.

The presence of a considerable amount of gas in a tube will cause the tube to cease operating normally and will usually produce distortion. In the case of an audio amplifier tube where the control grid is connected directly to the contact arm of the volume control a small amount of gas may in time cause the volume control to become very noisy. This amount of gas will not always produce a noticeable change in the continuous operation of the receiver, therefore, if the volume controls become excessively noisy, but if the receiver is not otherwise affected, check the amplifier tubes for gas.

Measuring Transformer Turns Ratio

The v-t voltmeter provides a rapid method for measuring the turns ratios of all types of audio and power transformers. The procedure for this measurement is to apply a 60-cycle or 400-cycle voltage to the primary winding and to measure the voltages across the primary and secondary. The ratio between the secondary and primary voltages, both of which can be measured with the v-t voltmeter, is then equal to the turns ratio. This may be expressed in the following equation:

$$\text{Turns Ratio} = \frac{n_p}{n_s} = \frac{E_p}{E_s}$$

where n_p is the number of turns in the primary
n_s is the number of turns in the secondary
E_p is the voltage across the primary
E_s is the voltage across the secondary.

Although it is usually more convenient to make this measurement at 60 cycles, greater accuracy will be secured if 400 cycles is used since the voltage drop across the resistance of the primary will then be negligible in comparison with the inductive voltage drop across the primary. If the measurement is made at a high audio frequency, an error will be introduced because of a resonance effect due to the capacitance of the secondary winding.

Power-Supply Measurements

The various types of v-t voltmeters can be used to advantage in power-supply measurements. Thus the peak VTVM can be used to measure the peak voltage which is applied to the first filter capacitor. The conventional a-c v-t voltmeter can be used to measure the ripple voltage at any point in the filter circuit (across the bleeder resistor, for example). For this application, a blocking capacitor having low d-c leakage should be used. Where the output is exceptionally well filtered a more accurate indication of the hum voltage can be secured by using the amplifier type of audio-frequency v-t voltmeter described in Chapter 6. The d-c VTVM can of course be used to measure any of the d-c voltages, although a conventional voltmeter is usually satisfactory because the loading is of no consequence.

Special precautions must be taken for the measurement of voltages derived from the power line when the line is also used to power the vacuum-tube voltmeter. These measurements may be in error due to residual hum (a stray inductive effect) in the voltmeter circuit. Reversing the voltmeter power plug will change the sign of this error and the true reading may be found by averaging the two.

Another effect to watch out for is that caused by beat-frequency oscillators in the neighborhood of v-t voltmeters. When the frequency of the oscillator is near 60 or 120 cycles, the needle of the meter may swing with the beat frequency. This effect may be avoided by changing the frequency at which the measurements are being made until the meter needle is no longer affected.

Low-Frequency Impedance Measurements

A simple circuit for the measurement of impedance at low frequencies is shown in Fig. 12-16. In this arrangement the impedance to be measured Z_x, is placed in series with a variable resistance R_s, and connected to a source of low-frequency voltage. The impedance to be measured may consist of a capacitor, a choke, or any combination of resistance, capacitance, and inductance. When the resistor R_s is adjusted so that the voltage *E1* across R_s is equal to the voltage *E2* across the unknown impedance, the unknown impedance is equal to the value of R_s. R_s can be measured readily with a good ohmmeter or bridge, if a direct-reading resistance box is not available. For any other relation between the voltages *E1* and *E2*, the unknown impedance can be found from the following equation:

$$Z_x = R_s \frac{E2}{E1}.$$

Because of the effect of stray circuit capacitance, including shunt capacitance across R_s, this method of measuring impedance is most suitable for power and audio frequencies. Where the impedances involved are relatively low, the method will give accurate results up to low radio frequencies, although the circuits shown in the following section are more suitable for use at radio frequencies. A transformer, delivering approximately 1 watt, should be used between the oscillator and the impedance-measuring circuit in order to secure an ungrounded voltage source.

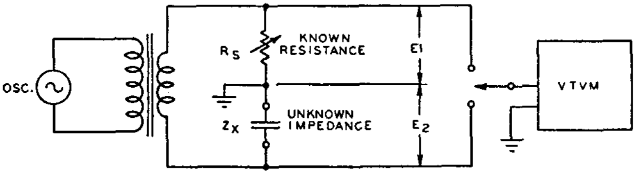


Fig. 12-16. The unknown impedance Z_x is measured by comparing the voltage drop across Z_x with the voltage drop across the standard resistor R_s.

Measuring Inductance, Capacitance, and Resistance

Resistance—Many resistors, especially of the composition type, have a voltage coefficient, that is, the actual value of the resistor varies with the voltages across it. The voltage coefficients of large resistors (over 1 megohm) cannot be neglected. For example, a resistor valued at 5 megohms measured 5 megohms at 3 volts, and 5.8 megohms at 200 volts.

Since the ohmmeter section of the VTVM operates on 3 volts, at which value the voltage coefficient of resistors is negligible, it is necessary that the reading on the meter be multiplied by a correction factor when the resistor is to be used under several hundred volts or more. The correction factor used depends upon the type resistor and the voltage to which it is subjected; this factor in most cases is supplied by the manufacturer of the component.

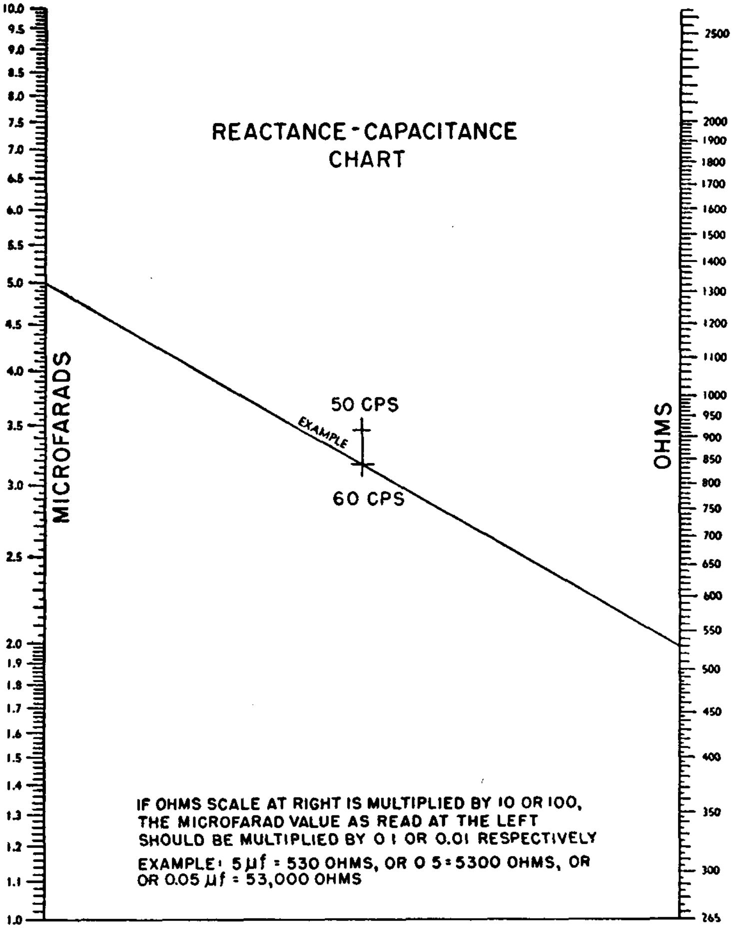
In addition to the measurement of resistors, the ohmmeter section of v-t voltmeters may be used to measure the d-c resistance of coils, filter reactors, and transformers, as well as the leakage through the insulation of capacitors and coil windings.

Bypass and coupling capacitors may be checked in several ways. If an audio coupling capacitor is suspected of being faulty, a d-c voltage measurement from the grid of the following tube to ground will reveal trouble quickly. Normally all audio amplifiers operate with negative bias. If the coupling capacitor is bad a positive voltage will appear on the grid and frequently, *the plate load resistor of the preceding stage will get hot,* since effectively, it is connected from B+ to ground.

Faulty screen and plate bypass capacitors can cause abnormally low voltage readings at the tube prongs. With the receiver turned off, disconnect the high side of the capacitor and measure the resistance of the capacitor. A good mica or paper capacitor will show a slight deflection on the "$R \times 1$ Meg" range and the reading will quickly approach full scale. An electrolytic on the other hand will discharge more slowly and it is recommended that this type be checked on the "$R \times 10$ k" range. An 8-μf, 400-volt electrolytic as an example, checked 40,000 ohms for an instant and then gradually rose to above 100,000 ohms. This is normal.

An open capacitor of any type would not give any meter deflection from the full-scale point. A faulty capacitor will have resistance values far below those discussed.

Capacitance—It is possible to make a good approximate measurement of capacitors between 0.01 and 10 μf (not electrolytics) using the v-t voltmeter and the chart shown in Fig. 12-17.



Courtesy Sylvania Electric Products, Inc.

Fig. 12-17. Chart for finding the capacitance of a capacitor from its capacitive reactance.

Connect the unknown capacitor and a variable resistor in series across a variable source of ac (3–125 volts). Adjust the variable resistor until the voltmeter reads the same a-c voltage drop across the capacitor as across the resistor. Disconnect the a-c voltage and with the ohmmeter measure the amount of resistance used. Using the chart in Fig. 12-17, the capacitance can be found as follows:

1. Locate the resistance value on the right-hand scale.
2. Locate the cross in the center of the chart corresponding to the frequency used (if 25 cps is used, divide the resistance measured by 2 and use the 50-cps mark).
3. Through these two points lay a straight edge and read the capacitance at the point it crosses the left-hand scale.

As an example, if the measured resistance was 530 ohms at a frequency of 60 cps, we would draw a line through these 2 points and read the value where the line crosses the left-hand scale (5.0 μf for the capacitance).

Inductance—For the measurement of inductance, the usual procedure is to employ a standard capacitor in parallel with the unknown coil in a circuit such as is shown in Fig. 12-18a and b. With the standard capacitor set at some convenient value such that the total capacitance across the coil is equal to several hundred micromicrofarads, the signal-generator frequency should be varied until the VTVM indicates resonance by a maximum output indication. For this condition the inductance of the coil can be found by the following equation:

$$L_x = \frac{25.330}{f^2C_s}$$

where L_x is in millihenrys
f is in megacycles
C_s is in micromicrofarads.

The same general procedure may be followed for the measurement of capacitance with the exception that a standard coil, L_s,

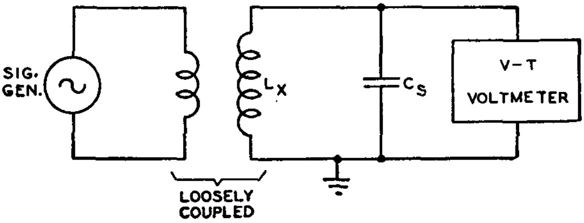


Fig. 12-18a. By using the v-t voltmeter to determine the resonant frequency and selectivity of the tuned circuit, it is possible to measure inductance, capacitance, and resistance.

having a known value of inductance is used. This coil is placed in parallel with the unknown capacitor and the frequency varied until the v-t voltmeter shows a maximum output indication, indicating resonance. For this resonant condition, the unknown capacitance, C_x, may be obtained from the following equation:

$$C_x = \frac{25.330}{f^2 L_s} \cdot$$

The r-f resistance (and Q), of a tuned circuit can also be determined with this same setup. One method for making this measurement is the so-called *frequency-variation* method. As the name implies, the procedure is to vary the frequency of the input voltage on either side of resonance, using the VTVM to measure the voltage across the tuned circuit. First the voltage is measured for a frequency f_1 below resonance and for which the reading is some convenient number; then the frequency is increased byond resonance to some value f_2, for which the voltmeter reading is the same as for f_1. The series resistance of the tuned circuit is then derived from the following equation:

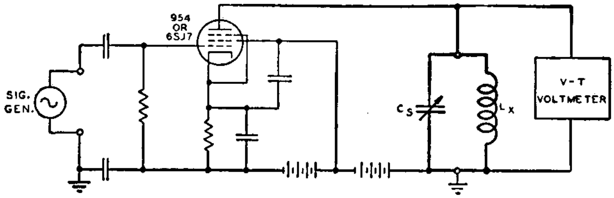


Fig. 12-18b. An arrangement for measuring the characteristics of tuned circuits in which the voltage is fed to the tuned circuit through the plate of an r-f pentode.

$$R_{\text{series}} = 2\pi L(f_2 - f_1)\sqrt{\frac{E_1^2}{E_0^2 - E_1^2}}$$

where E_1 is the voltage reading with the signal generator at f_1 and f_2

E_0 is the voltage reading at resonance

L is the inductance of the circuit.

The Q of the circuit may be found from the following equation:

$$Q = \frac{\dfrac{f_0}{f_2 - f_1}}{\sqrt{\dfrac{E_1^2}{E_0^2 - E_1^2}}}$$

where f_0 is the frequency of resonance.[2]

Another method for measuring Q is that using the circuit shown in Fig. 12-19. Since the voltage across the inductance at resonance equals QE (where E is the output of the oscillator), it is necessary only to measure the output of the oscillator and the voltage across the inductance.

The voltage from the oscillator should be introduced across a low value of resistance (about $1/_{100}$ of the anticipated radio-frequency resistance of the *L-C* circuit to obtain errors of not more than 1 per cent). For average measurements this resistor may be of the order of 0.1 ohm.

When the oscillator at hand is not designed to operate into impedances of 0.1 ohm, it is necessary to use some sort of matching device, a transformer for example, whose primary impedance matches that of the oscillator and whose secondary impedance is about 0.1 ohm.

The voltage across the resistor is made some small value—say 0.1 volt. Then the *L-C* circuit is adjusted for resonance and the resultant voltage across *C* is measured. The Q of the coil is then:

$$Q = \frac{\text{Resonant Voltage Across Capacitor}}{\text{Voltage Across Resistor}}$$

With suitable modifications, this circuit can be used to measure r-f resistance over a wide range. In general, low values of resistance are measured by inserting them in series with the tuned circuit so that they may be considered as part of the coil resistance, while relatively high values of resistance are measured by shunting them across the tuned circuit and noting the effect on the selectivity of the tuned circuit.

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[2] For further data on the use of the v-t voltmeter for such measurements see F. D. Terman, *Measurements in Radio Engineering,* 1st ed., McGraw-Hill Book Co., New York, N.Y., 1935, p. 80–85.

Other methods for making similar measurements are described in the standard engineering texts on radio-frequency measurements. A widely-used method employing the v-t voltmeter is the *capacitance-variation* method, in which the selectivity curve resulting from the capacitance variation of a standard is determined.

In all of these circuits employing VTVM's, it is essential that the losses of the v-t voltmeter be small in comparison with the losses of the tuned circuit under measurement. Preferably the v-t voltmeter should be of the probe type to minimize losses in the VTVM itself. For accurate measurements, an allowance must be made for the input resistance of the voltmeter.

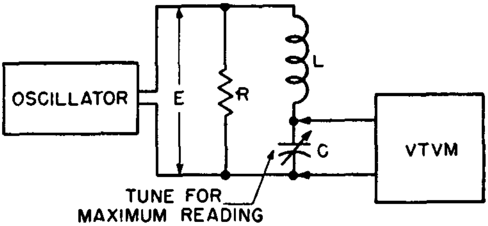

Fig. 12-19. Method for measuring the Q of a series tuned circuit. For average measurements R should be about 0.1 ohm.

V-T Voltmeter for Measuring Alternating Currents

The a-c v-t voltmeter can be used for measuring alternating currents by providing a suitable shunt across the input of the instrument. In general two types of shunts are used for this purpose. Where a wide frequency range must be covered, the resistive type of shunt should be employed. Where the measurements are to be carried out at a single frequency, as for example in working with resonant circuits, it is preferable to use a capacitor as a shunt in order to reduce the losses introduced into the tuned circuit.

The v-t voltmeter used in this way as a current meter has the advantage that greater sensitivity can be secured and that less power is taken from the circuit under test. The sensitive audio-frequency VTVM described in Chapter 6, can be readily adapted to the measurement of very small a-f currents with a minimum of power consumption from the circuit under test and with a minimum of voltage drop across the current meter.

Where the capacitive type of shunt is used, there will be an appreciable waveform error in measuring complex or distorted currents since the capacitor shunt offers a smaller reactance to the high-frequency components of the current wave.[3]

A-C Measurements with DC Present

A 1-μf or larger capacitor can be used in series with either one of the test leads when using the a-c voltage ranges of the v-t voltmeter to eliminate the d-c component and allow the a-c component to be measured with a greater degree of accuracy. Such an arrangement makes possible the use of the a-c voltmeter to measure ripple voltage in a filter circuit and as an output meter for alignment purposes.

V-T Voltmeters in Modulation Indicators

The modulation indicator illustrates an application of v-t voltmeters in which three types of VTVM's are used in one instrument. In measuring the modulation percentage of a modulated wave, it is necessary to know the average amplitude of the modulated wave (the carrier), the peak amplitude, and the trough amplitude. To determine these values, it is customary to use an *average-reading* VTVM to measure the carrier, a peak VTVM to measure the positive peak modulation, and a *trough* VTVM to measure the negative peak modulation. In one widely used arrangement, the r-f input to the modulation indicator is first adjusted so that the carrier v-t voltmeter indicates some fixed reference value of input voltage. A positive peak v-t voltmeter can then be calibrated directly in terms of the positive percentage modulation, while a trough v-t voltmeter can be calibrated directly in terms of the negative percentage modulation. A phase-reverser stage may be used so that the same peak v-t voltmeter will also indicate the negative percentage modulation.[4]

V-T Voltmeters in Wave Analyzers

The VTVM is the basis of several types of harmonic or wave analyzers which are used to determine the harmonic content of complex waves. These instruments are extremely useful in many

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[3] D. B. Sinclair, "The Type 726-A V-T Voltmeter as an R-F Ammeter," *General Radio Experimenter,* vol. 13, p. 1, Aug.-Sept. 1938.

[4] L. B. Arguimbau, "Monitoring of Broadcast Stations," *General Radio Experimenter,* vol. 9, p. 1, Feb. 1935.

applications, particularly in analyzing the distortion of audio amplifiers.

In one type of harmonic analyzer, the voltage wave to be analyzed is fed to the input of a square-law v-t voltmeter. At the same time a search or exploring frequency is fed into the input in series with the unknown voltage. When the search frequency is adjusted to within a few cycles of any of the harmonics, a beat frequency will be obtained, and the pointer of the v-t voltmeter will oscillate slowly about the mean reading. From the amplitude of this swing, it is possible to determine the amplitude of the harmonic component.[5]

In some wave analyzers a highly selective calibrated superheterodyne-amplifier type of v-t voltmeter is employed. In one commercial instrument, a superheterodyne amplifier having an intermediate frequency of 50 kc is used and a selectivity within a few cycles obtained by using a crystal filter in the i-f amplifier. By tuning the amplifier to each of the harmonics in turn, it is possible to determine the harmonic content of the wave.[6]

To Observe Transients in Simple R-C and R-L Circuits

The VTVM is a valuable aid for instructing students in the fundamentals of circuits and current flow. For example, the circuits shown in Fig. 12-20a and b, may be used in conjunction with a v-t voltmeter to illustrate the effect produced by capacitors and inductances in electric circuits. Using the circuit in Fig. 12-20a, to study capacitance effects:

1. Set the 200K resistor to maximum.
2. Close switches SW-2 and SW-3.
3. Connect the VTVM across terminals ③ and ④, set its range to 50 volts.
4. Turn switch SW-1 to position ① to charge the three capacitors.
5. Observe the direction, polarity, and variation with time of voltage across the 200K resistor as read on the VTVM.
6. Turn switch SW-1 to position ② and observe the VTVM as

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[5] C. G. L. Suits, "A Thermionic Method for Analysis of Electrical Waves," *Proc. IRE,* vol. 18, p. 178, Jan. 1930.

[6] L. B. Arguimbau, "Wave Analysis," *General Radio Experimenter,* vol. 8, p. 12, June-July 1933; vol. 13, p. 1, Dec. 1938.

the capacitors discharge. The time of charge and discharge of the capacitor may be compared with the time constant computed from the formula:

$$T = RC$$

where T *is the time constant*
R is the total resistance in the circuit
C is the total capacitance in the circuit.

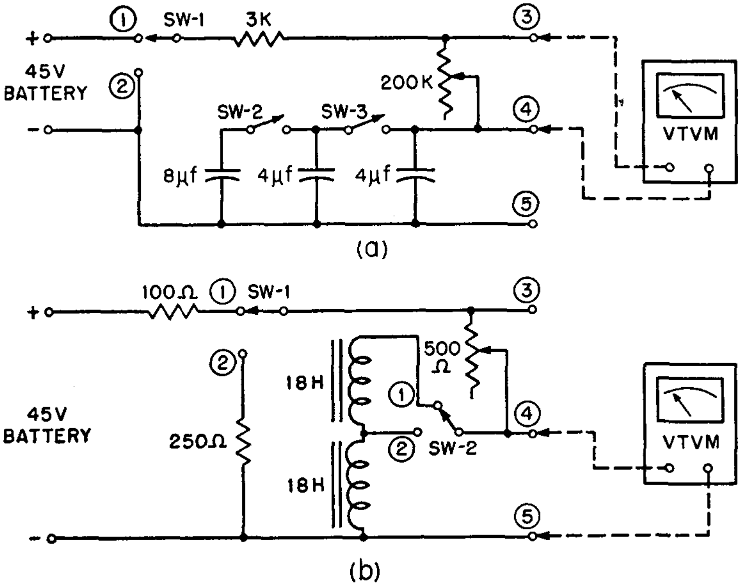

Fig. 12-20. Circuits for the measurement of transient effects in capacitive and inductive circuits. (a) is used to study capacitive effects; (b) demonstrates the effects of inductance.

Using the same circuit, the voltage across the capacitors while they are charged and discharged may be observed by connecting the VTVM across terminals ④ and ⑤.

To study the affect of inductance on a circuit, use the circuit in Fig. 12-20b. Set the 500 ohms resistor to zero, switch SW-2 to position ①, and connect the VTVM across ④ and ⑤. Turn switch SW-1 to ① and observe the VTVM reading until the steady flow prevails; then turn switch SW-1 to ② and again observe the VTVM.

From these observations, the time elapsed before the voltage reached a steady state, and the manner in which an inductance affects the current flow in a circuit may be noted.

The procedure outlined will give only the fundamentals of *R-C* and *R-L* transient effects. The instructor or student may use the same components used in the above circuits and combine them to observe more advanced transient phenomena.

Pulse Measurements

The use of pulse signals for synchronization (in television reception), in microwave and radar applications, and in industrial and scientific analysis calls for new techniques in voltage measurement. V-t voltmeters are admirably suited for this work because of their fast response and freedom from lag, as well as the other advantages mentioned previously. The use of the slide-back v-t voltmeter for pulse measurements was covered in Chapter 7; the application of other type VTVM's for pulse measurements will be discussed here.

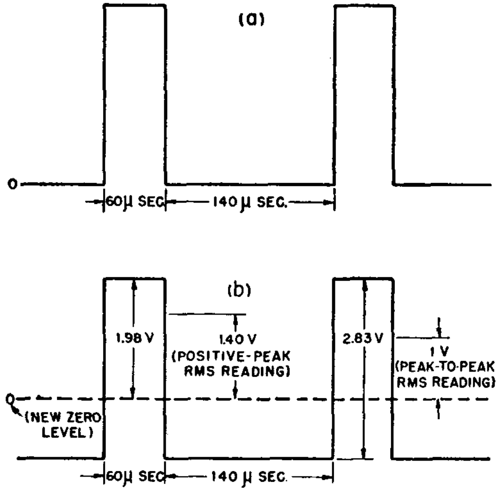

Fig. 12-21. (a) A positive pulse of 2.83 volts amplitude and 5,000 cps repetition rate. (b) An rms-calibrated, positive-peak-response meter reads the positive-peak value divided by 1.414. An rms-calibrated, peak-to-peak-response meter reads the peak-to-peak value divided by 2.83. The rms values are not accurate for this waveform because the meters were calibrated using the sine wave.

The most useful v-t voltmeters for pulse measurements are the peak-to-peak and positive-peak responsive ones. Although the dials of these meters are generally calibrated to give rms values (for sine waves), they can be converted to give the peak values of the pulse being measured with relative ease. For example, to find the value of the pulse signal shown in Fig. 12-21a, which is a positive pulse of 2.83 volts with a repetition rate of 5,000 cycles per second, we should remember that the positive-peak responsive meter calibrated to read in rms volts gives the positive peak divided by 1.414. Similarly, the peak-to-peak responsive meter calibrated for rms readings gives the peak-to-peak reading divided by 2.83. However, because the input to v-t voltmeters is capacitance coupled, the d-c component is removed, leading to a displacement of the zero level as shown in Fig. 12-21b. This does not affect the reading of the peak-to-peak voltmeter since it responds to the difference between the positive and negative peaks and not between the zero level and the positive peak as does the positive-peak response meter.

To obtain the total amplitude of the pulse therefore, using the peak-to-peak voltmeter, it is only necessary to multiply the rms reading on the meter by 2.83. For the positive-peak meter, however, we must consider the displacement of the zero level. To obtain the total amplitude of the pulse on such a meter therefore, we must first find the positive pulse amplitude, then the negative pulse amplitude, and finally, the sum of the two. For the example given (60 μsec pulse with 140 μsec interval between pulses), we find that the *positive* amplitude is:

$$1.40 \times 1.414 = 1.98 \text{ volts.}$$

To find the negative peak we use the simple proportion: the pulse duration divided by the interval between pulses (both in like time units), is equal to the negative peak value (unknown) divided by the positive peak value.

For example:

$$\frac{60\ \mu\text{sec}}{140\ \mu\text{sec}} = \frac{\text{Negative Peak Value}}{1.98 \text{ volts}}$$

with the result that:

$$\text{Negative Peak Value} = \frac{60\ \mu\text{sec}}{140\ \mu\text{sec}} \times 1.98 \text{ volts}$$

or

$$\text{Negative Peak Value} = 0.85 \text{ volt.}$$

The total amplitude of the pulse is therefore:

$$1.98 + 0.85 = 2.83 \text{ volts.}$$

Similarly, when measuring negative pulses allowance must be made for the rms calibration of the meter as well as for the characteristics of the meter itself. By this we mean the response of the meter (whether peak-to-peak, or positive peak), and the capacitance-coupling effect. For example, in measuring the negative pulse shown in Fig. 12-22a, the positive-peak responsive meter gives 0.5 volt, which is the positive peak amplitude divided by 1.414. This is not the rms value of the pulse because the rms values were calibrated according to the meter's response to a sine wave which this obviously is not. The peak-to-peak amplitude of this negative pulse may be obtained from the reading on the positive-peak meter by first finding the positive peak as follows:

$$\text{Positive Peak} = 0.5 \times 1.414 = 0.707 \text{ volt.}$$

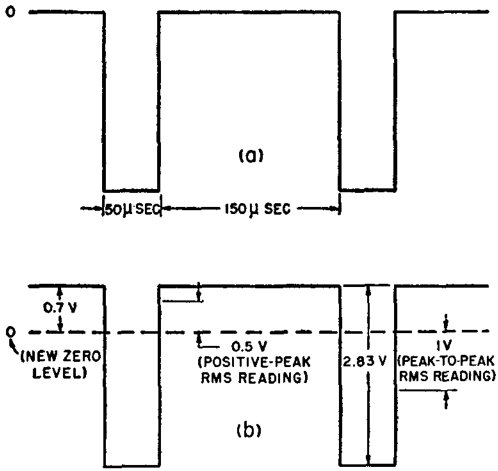

Fig. 12-22. (a) A negative pulse of 2.83 volts amplitude and 5,000 cps repetition rate. The pulse duration is 50 microseconds, and the time between pulses is 150 microseconds. (b) A negative pulse after passing through the capacitor-coupled input of the v-t voltmeter. Note the displacement of the zero level due to the averaging action of the input capacitors.

Then the negative peak value is obtained by equating the interval between pulses divided by the pulse duration to the negative peak value divided by the positive peak value. Using the values for these quantities from the above example, we get the equation:

$$\frac{150\ \mu\text{sec}}{50\ \mu\text{sec}} = \frac{\text{Negative Peak Value}}{0.707\ \text{volt}}$$

or

$$\text{Negative Peak Value} = \frac{150\ \mu\text{sec}}{50\ \mu\text{sec}} \times 0.707\ \text{volt}$$

$$\text{Negative Peak Value} = 2.12\ \text{volts.}$$

The peak-to-peak value equals the sum of the positive peak and the negative peak:

$$\begin{aligned}\text{Total Amplitude of Negative Pulse} &= 2.12 + 0.707 \\ &= 2.827\ (\text{or } 2.83)\ \text{volts.}\end{aligned}$$

If a peak-to-peak responsive meter is used, the total amplitude of the negative pulse is found by multiplying the rms reading by 2.83 as in the case for the positive pulse.

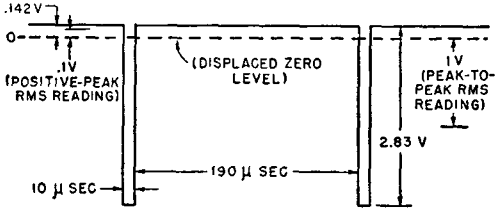

Fig. 12-23. A 5,000-cps negative pulse of 10 microseconds pulse duration. Note how close the positive-peak-response, rms-calibrated reading is to the zero level.

It should be obvious from the above discussion that the peak-to-peak responsive meter is preferable to the positive-peak responsive meter not only because of the simplicity of calculation of peak-to-peak pulse amplitude associated with the former, but also because measurement with the positive-peak meter becomes inaccurate as the pulse duration time is decreased. This may be seen by comparing the rms readings of the positive-peak responsive meters in Fig. 12-22b and Fig. 12-23. With the values shown in Fig. 12-23, the positive-peak responsive meter would read 0.1 volt, which is generally the low limit of sensitivity of such meters. The shorter the pulse duration of a pulse signal, the smaller is the rms meter reading of the positive-peak v-t voltmeter, in other words, the zero line approaches the base line.

Figure 12-24 shows a simplified circuit of a "kickback" high voltage power supply of the type found in many television receivers. A high-voltage pulse is developed in the primary of the transformer during the flyback period and is rectified by the high-voltage rectifier tube. Resistor *R1* and capacitors *C1* and *C2* filter the rectifier output to remove a-c ripple and supply a substantially pure d-c voltage to the second anode of the picture tube.

From the circuit it can be seen that the high-voltage pulse (see Fig. 12-25), will appear at the plate of the high-voltage rectifier and also at the plate of the horizontal output tube. The frequency of this pulse is 15,750 cycles per second and its amplitude is in the neighborhood of 5,000 volts. This type voltage is one that can be measured with a great degree of accuracy by a v-t voltmeter of the peak-to-peak type using a multiplier of the type described in Chapter 9.

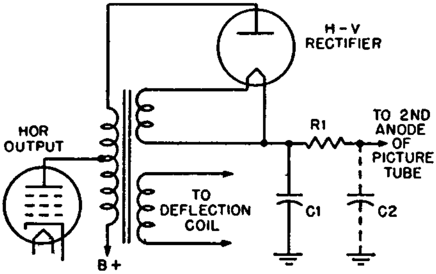

Fig. 12-24. Simplified schematic of a high-voltage power supply of the "kickback" type used in television receivers.

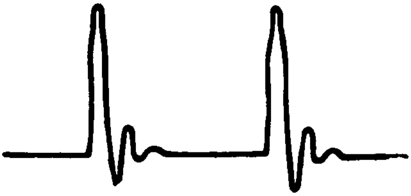

Fig. 12-25. High-voltage pulse of the type obtained at the plate of the horizontal output tube and the plate of the high-voltage rectifier shown in Fig. 12-24.

Ultra High Frequency Measurements[7]

It is beyond the scope of this book to go into details concerning measurements at ultra high frequencies. One reason for this is that above about 300 megacycles it is necessary to build voltage and

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[7] For further information on uhf measurements see J. G. Brainerd et al, *Ultra-High-Frequency Techniques*, 1st ed., D. Van Nostrand Co., Inc., New York, N.Y., 1942, p. 483–492.

power measuring rectifiers or detectors into the equipment for precision measurements. Measurements become a special problem for each design. General purpose v-t voltmeters, even if they respond properly to a uhf voltage at their input terminals, may still badly upset the circuit to which they are connected. It should be remembered that a 5-$\mu\mu$f capacitance has a reactance of only about 100 ohms at 300 megacycles. The circuit of course will be less affected when the voltmeter probe is used, but even then, the circuit is very likely to act unnaturally due to coupling between stages which may be increased or decreased by the presence of the probe clip or even by a small prod tip.

A technique which is often used at ultra high frequencies is to remove all fittings and unnecessary components from the probe and to wire the probe directly into the circuit. Often a special probe circuit is made up for this purpose, with a connecting cable going to the main unit of the voltmeter. If a crystal, or a tube differing from the standard probe tube is used, it is usually necessary to make a new calibration, especially if voltages below 1 or 2 volts are to be measured.

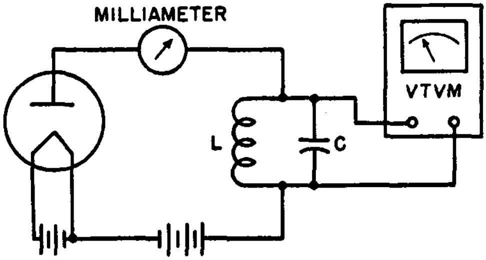


Fig. 12-26. Circuit setup for the measurement of the "shot effect" with the v-t voltmeter.

Measurement of the Shot Effect

In a vacuum tube, the flow of electrons from the filament or cathode to the plate is not a continuous stream but rather a barrage of individual charges, uneven in flow. This effect is called the "Shot Effect" after W. Schottky who first investigated it. To observe this phenomenon, the circuit in Fig. 12-26 may be set up.

The minute changes in current which occur with the irregular travel of negative charges from the filament to the plate of the tube "shock" the *L-C* circuit into oscillation. As a result of this oscillation, an average voltage is developed across C which may be measured with the high input-impedance VTVM without seriously affecting the conditions in the tank circuit. This voltage may be checked against the following theoretically derived equation based upon Schottky's assumptions:

$$\bar{V}^2 = \frac{Lie}{2RC^2}$$

where $\bar{V}$ is equal to the average voltage across the L-C circuit in volts
L is the inductance of the coil in henries
C is the capacitory of the capacitor in farads
i is the current in the circuit as measured on the milliammeter
R is the resistance of the L-C and plate circuits of the tube in parallel
e is the charge carried by an electron and is equal to 1.602×10^{-19} coulombs. This is the negative charge carried by each particle from the filament to the plate of the tube.

In this circuit the plate voltage must be high enough to eliminate any space charge which may exist in the tube, otherwise there will be errors introduced. The fact that a voltage does appear across the L-C circuit is proof of the "Shot Effect," since if the electron flow through the tube had been a regular one, the voltage across C would have been equal to zero or at most, a negligible amount.

This same setup may be used to find the quantity e, the charge on the electron, simply by rearranging the equation used above to read:

$$e = \frac{2RC^2\bar{V}^2}{Li}.$$

Low Frequency Measurement and Observation

Oscilloscopes, even d-c ones, often lack the screen persistency necessary for the observation of low-frequency waveforms, of the order of 3 cps or lower. The v-t voltmeter can be used not only to measure the frequency of these waves, but also to observe their waveform.

To measure 3 cps or lower frequencies, connect the VTVM across the voltage source using the d-c input terminals of the VTVM.

Adjust the VTVM needle so that it reads on the center-zero scale (the method of converting a left-zero scale to a center-zero one is described in Chapter 8). Using a tachometer or ordinary watch with a sweep-second hand, start the timing as the needle passes through the center-zero position moving to the right. Note the time it takes for the needle to complete about 20 to 30 cycles. A complete cycle is equivalent to the needle moving to the right from the center zero, back to the left through the center zero, and back to the center zero again. Dividing the number of cycles (as indicated by the needle), by the time as indicated on the watch (in seconds), gives the frequency of the voltage in cycles per second.

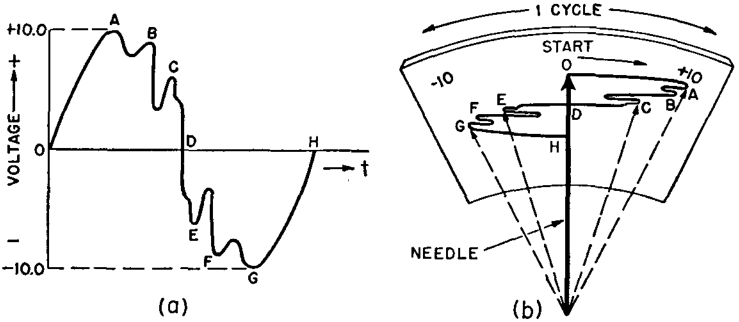


Fig. 12-27. The complex-wave voltage of low frequency (up to 3 cycles per second) shown in (a), can be measured and observed on the d-c v-t voltmeter. The needle of the voltmeter will move across the scale unevenly, stopping briefly at the various peak values of the input wave as shown in (b).

If the input voltage is a sine wave, the needle will move continuously and smoothly to the right, to the left, and to the right again to complete one cycle. If however, the input is a complex waveform, this will be indicated on the meter by a nonuniform, jerking type of movement, corresponding to the waveform. If for example, the waveform is of the type shown in Fig. 12-27a, the meter needle will move as indicated in Fig. 12-27b. The values chosen are relative ones only.

REVIEW QUESTIONS

CHAPTER 12

12–1. To what type readings does the *rated accuracy* of a VTVM refer?

12–2. Why shouldn't the position of the r-f probe ground be changed during r-f measurements?

12–3. How would you measure the gain of the r-f stage of a 5-tube, superheterodyne receiver with a VTVM?

12–4. What must be done to the avc circuit of a receiver before gain measurements can be made?

12–5. In making measurements of the high anode voltages in cathode-ray tubes used in television receivers, how should the contrast control be set? Why?

12–6. How could you check a faulty bypass or coupling capacitor with a v-t voltmeter?

12–7. Outline one method for determining the *Q* of a tuned circuit.

12–8. How would you adapt an a-c VTVM to measure current?

12–9. Explain why the peak-to-peak response VTVM is more reliable for pulse measurements than other type meters.

12–10. What is a simple test for the frequency stability of an oscillator?

CHAPTER 13

COMMERCIAL VACUUM-TUBE VOLTMETERS

A number of commercial v-t voltmeters were mentioned in previous chapters to illustrate the various circuits discussed. In this chapter will be found a table comparing most of the commercial v-t voltmeters available, and listing the specifications and special features of each. In addition, included in this chapter is the complete schematic diagram for each voltmeter covered in the table, with the values and tolerances of the various components.

In considering the various specifications given for VTVM's, those which best serve to compare the various makes from the standpoint of function have been listed in the table. No attempt has been made here to describe individually the circuit of each v-t voltmeter listed. This is adequately covered in the schematic for the voltmeter, as well as in the previous chapters of this book where each type of VTVM circuit was discussed completely. However, the general type circuit of each voltmeter is given in the table under the column headed "TYPE CKT."

Among the specifications thought to be most important in considering VTVM's are the voltage ranges of the instrument, both a-c and d-c. The ranges shown in the table are full-scale ones. It is also important in determining the sensitivity of an instrument to know the *number* of ranges; this is given immediately below the range scale in the "VOLTAGE RANGES" column. In showing the a-c ranges, all scales are to be assumed to be rms calibrated unless otherwise noted.

The accuracy of a VTVM (both for the d-c and a-c ranges), is given in terms of per cent deviation from the true value at full scale. In other words, if a meter has a d-c range accuracy of ±3%, it would indicate that the reading on the 10-volt scale for 10 volts could be either 10.3 or 9.7 volts, i.e., a *maximum* error of 0.3 volts higher or lower than the true value. In most cases, the per cent error shown is for a majority of the ranges of a meter; for some scales the per cent error may go as high as three or four times that given. This is true particularly for meters with extended upper frequency limits where the per cent error may be as high as 15%, depending upon the voltage range, and a calibration chart must be used with the meter for accurate readings. Such is the case for example, with the Millivac Instrument Company model MV-18B.

The input impedance for v-t voltmeters is of primary importance because it is this characteristic which makes the VTVM useful where other meters may not be used. Whereas the input resistance for d-c measurements is in most cases constant, the input impedance for a-c measurements may vary anywhere from $\frac{1}{1000}$ to 2 or 3 times the value given in the table, depending upon the voltage and frequency to be measured. For example, the Supreme Instrument Corporation model 565 has an input impedance of from 20 to 40 megohms on low frequency ac and only about 20,000 ohms at 100 megacycles. The value given in the table for the input impedance of each meter is that impedance found over the comparatively flat portion of the measurement curve for the meter. Shown also with the a-c impedance is the input shunt capacitance of the VTVM, subject to the same qualifications with respect to frequency as is the input impedance.

It should be recognized that the frequency range of almost any v-t voltmeter may be extended by using special probes, if the VTVM amplifier is of the wideband type. The frequency range shown in the table for each meter is the range obtainable with the use of such probes furnished with the meter or as standard accessories with the meter. It should be noted that in general the accuracy listed for the meter will not hold for the high side of the frequency range as mentioned previously. The General Radio Company type 727-A for example, has an accuracy of +5% up to 65 Mc, and of +10% up to 100 Mc.

Under the heading "METER RESP.," will be found a letter identifying the response of the meter as either input-signal average (A), peak-to-peak (B), positive peak (C), or square law (D). These various types of response have been described completely in previous chapters. A check in the "MEAS. RES." column means that the meter so identified will measure resistance, i.e., has an ohmmeter included. The "SPECIAL FEATURE" column lists any particular feature offered by any of the meters which enhances their value as a measuring instrument.

If a correction curve is included with a meter it is generally used to extend the normal range of measurements possible with the meter. For example, most frequency correction curves show flat response to about 300 kc. This is the normal range for most v-t voltmeters indicating that when the meter is used for measurements of r-f voltage within this range, the readings are true indications of the voltage across the meter terminals. However, if the meter is to measure voltage frequencies above 300 kc, some correction must be made for the drop in input impedance of the meter at these higher frequencies. Normally, either this impedance drop is too great, or else, transit-time, resonance, and other effects become so large that the VTVM cannot handle high-frequency voltages. Meters measuring high-frequency voltages invariably use correction curves to compensate for the impedance drop and other effects, for example, the frequency correction curve for the General Radio Co. model 1800-A. This meter reads linearly up to about 2 Mc. Above this, the measured voltage frequency is found on the X-axis and a line is drawn up to the curve of the voltage range used. Where the line intersects the curve, draw a horizontal line to the Y-axis. The value obtained at the Y-axis for this horizontal line is the correction factor by which the voltmeter reading must be multiplied to obtain the true voltage across the voltmeter terminals.

The voltage ratio versus the db curve included on page 340 may be used to convert voltage gain ratios into db gain figures for amplifier gain measurements. The impedance ratio versus db correction curve can be used with meters having a db scale based upon a reference level of 1.0 milliwatt and 600 ohms for zero db. When measuring across a load impedance higher or lower than 600 ohms, correct the db power level by taking the ratio of the load impedance to 600 ohms. On the graph, the equivalent db correction for this ratio is obtained on the X-axis. For a load impedance less than 600 ohms, add the db correction factor to the db gain; for more than 600 ohms, subtract the db correction.

Comparison Table of

NAME & MODEL	VOLTAGE RANGES DC	VOLTAGE RANGES AC **	ACCURACY DC	ACCURACY AC	INPUT IMPEDANCE DC	INPUT IMPEDANCE AC*
Ballantine Labs.						
Model 300		5R .01-100		±3%		500K/30mmf
Model 302		.01-100 5R		±3%		500K/30mmf
Model 304		.01-100 3R		±5%		1 Meg/9mmf
Model 305		.01-100 6R (peak-to-peak)		±2%		2.2 Meg/15mmf
Barber Labs.						
Model 31A		5R 100-10000		±5%		2 mmf
Model 33	3-1000 6R		±5%		11 Meg.	
Model 72	1-100 5R	1-1000 5R	±2%	±2%		2.5 Meg/5mmf
Clippard						
Model 406	7R 1-1000	7R 1-1000	±5%	±5%	30 Meg.	7 Meg/7mmf
Eico						
Model 210	5-5000	5-1000	±2%	±2%	26 Meg.	2 Meg/7mmf
General Electric						
Type AA-1		01-300 10R		± 5% to 1Mc ±10% to 1.5Mc		2 Meg/40mmf
Type PM-17	1-1000	1-100			10-200 Meg.	6.6mmf
General Radio						
Model 727-A		7R .3-300		±3%		3 Meg/16mmf
Type 728-A	7R 3-3000		±3%		1000 Meg.	
Model 1800-A	.01-150 6R	.1-150 6R	±2%	±2%	10 Meg.	25 Meg/3.1mmf
Type 1802-A		1-1		±5%		40K/5mmf
Heath						
Model V-2	6R 3-1000	6R 3-1000	±3%	±5%	11 Meg.	6.5 Meg.
Hewlett-Packard						
Model 400A		.03-300 9R		±5%		3 Meg/15mmf
Model 400C		.001-300 12R		±5%		9 Meg/15mmf
Model 404A		.003-300 11R		±5%		10 Meg/20mmf
Model 410A	1-1000	1-300	±3%	±1db	100 Meg.	6 Meg/1.3mmf
Hickock						
Model 209	6R 3-1200	5R 3-300			15 Meg.	12 Meg/6mmf
Model PR203	Same as above; smaller in size.					
Jackson						
Model 645	6R 4-1000	7R 1-1000			12 Meg.	4.4 Meg.
McMurdo Silver						
Model 1900-A	6R 3-3000	6R 3-1200	±3%	±5%	40 Meg.	20 Meg/7mmf

Commercial V-T Voltmeters

FREQUENCY RANGE	POWER SUPPLY	TYPE CKT. ‡	METER RESP. †	MEAS. RES.	SPECIAL FEATURE
10cps-150Kc	A.C.	(E)	(A)		
5cps-150Kc	BAT.	(E)	(A)		
30cps-5.5Mc	A.C.	(E)	(A)		R-F probe part of meter.
10cps-100Kc	A.C.	(E)	(B)		Measures pulses.
100Kc-100Mc	A.C.	(F)			Coupling unit permits high-voltage measurements.
	BAT.	(G)		√	Pocket size.
30cps-150Mc	A.C.	(F)			
30cps-100Mc	A.C.	(E)	(C)	√	
	A.C.	(F)		√	
10cps-1.5Mc	A.C.	(E)	(A)		Meter has db calib. Amplifier may be used separately.
200cps-100Mc	A.C.	(F)		√	Zero-center scale provided.
20cps-100Mc	BAT.	(F)			
	BAT.				
20cps.300Mc	A.C.	(F)	(C)		10:1 multiplier available for r-f measurements. Measures d-c current.
30Mc-1000Mc	BAT.	(F)			Crystal galvanometer 10:1 and 100:1 multipliers available.
20cps-100Mc	A.C.	(F)		√	Kit form.
10cps-1Mc	A.C.	(E)	(A)		
20cps-2Mc	A.C.	(E)			
2cps-20Kc	BAT.	(E)	(A)		Amplifier may be used separately.
20 cps-700Mc	A.C.	(F)	(C)	√	
20cps-400Mc	A.C.			√	Measures capacitance, inductance and current.
50cps-200Mc	A.C.	(E)		√	Measures current.
20cps-100Mc	A.C.	(F)		√	db scale provided.

Comparison Table of

NAME & MODEL	VOLTAGE RANGES DC	VOLTAGE RANGES AC **	ACCURACY DC	ACCURACY AC	INPUT IMPEDANCE DC	INPUT IMPEDANCE AC*
Measurements Corp.						
Model 62	5R 1-100	5R 1-100	±2%	±2%		5 Meg/7mmf
Model 67		5R .03-300 (peak-to-peak and rms)		+10 to -30%		1 Meg/30mmf
Millivac Instr.						
Model MV-17A	.001-1000 13R				6-60 Meg.	
Model MV-18B	.001-1000	.01-1000			6 Meg.	150Kc/5mmf
Precision						
Model EV-10	8R 3-6000		±5%		10-100 Meg.	
Radio City Products						
Model 665	6R 6-6000	7R 3-6000	±4%	±5%	16-160 Meg.	16 Meg/50mmf
RCA						
Voltohmyst WV-65A	6R 3-1000	5R 10-1000			11 Meg.	1K/V
Audio WV-73A		11R .01-1000		±5%		1 Meg/25mmf
Master Voltohmyst WV-95A	6R 5-1000	7R 1-1000			11 Meg.	5 Meg/125mmf
Senior Voltohmyst WV-97A	6R 1.5-1500	1.5-1200 (rms) 4-3400 (peak-to-peak) 7R	±3%	±5% -10%	11 Meg.	1 Meg/85mmf
Voltohmyst 195-A	5-1000 6R	5-1000 6R			10 Meg.	200K/170mmf
Reiner						
Model 451	6R 2.5-1000	6R 2.5-1000	±2%	±2%	11 Meg.	/10mmf
Simpson						
Model 303	5R 1.2-1200	5R 1.2-1200	±3%	±5%	10 Meg.	275K/210mmf
Supreme						
Model 656	6R 1-500	5R 1-250			40-80 Meg.	30 Meg/9mmf
Sylvania						
Polymeter 221	6R 3-1000	6R 3-1000			17 Meg.	2.3 Meg/3mmf
Triplett						
Model 2451	6R 2.5-1000	5R 2.5-500			11 Meg.	335K/4.5mmf
Weston						
Electronic Analyzer Model 769	3-1200 6R	3-120 4R	±4%	±5%	15 Meg.	5 Meg/5mmf

NOTES:

* Capacitance Given is Equivalent Shunt Capacitance. The A-C Input Impedance Usually Depends On The Scale Used And May Vary Considerably.

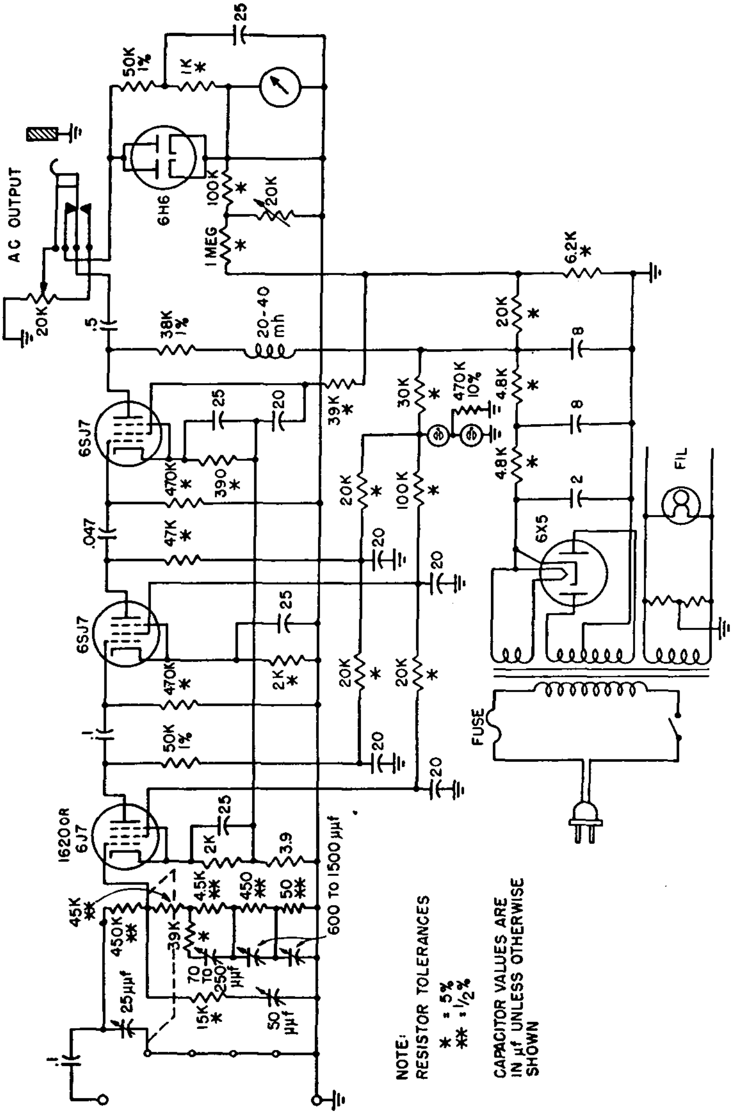
‡ (A) Indicates Average Of Input Signal; (B) Indicates Peak-To-Peak; (C) Indicates Positive Peak; (D) Indicates Square Law.

Commercial V-T Voltmeters

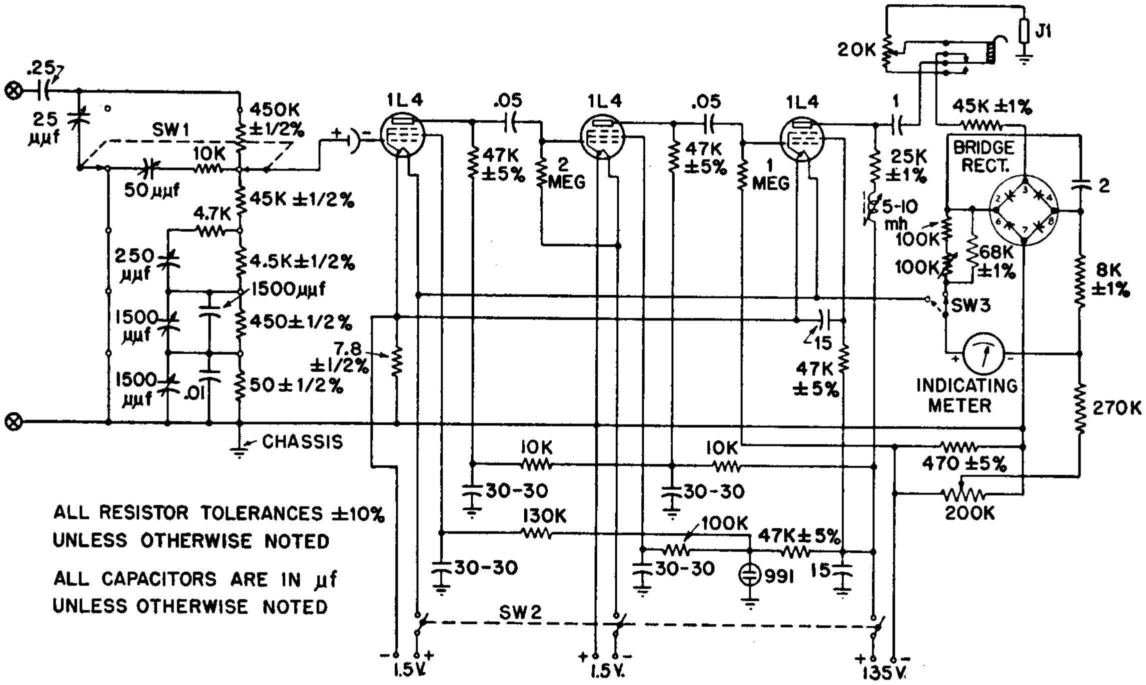
FREQUENCY RANGE	POWER SUPPLY	TYPE CKT. ‡	METER RESP. †	MEAS. RES.	SPECIAL FEATURE
60cps-150Mc	A.C.	(F)			
5cps-100Kc	A.C.	(E)	(B)		Useful for pulse meas. Provision for graphic recorder.
	A.C.				Zero-center scale for low ranges.
1Mc-2500Mc	A.C.	(F)	(D)		Zero-center scale for low ranges.
	A.C.			√	Zero-center scale. Nonelectronic a-c & d-c voltmeter and d-c ammeter included.
10cps-250Kc	A.C.			√	Measures capacitance.
	BAT.	(F)		√	Measures d-c current.
20cps-20Kc	A.C.	(E)	(A)		Amplifier may be used separately. d-b scale provided.
30cps-250Mc	A.C.	(E)		√	Measures capacitance d-c current.
30cps-250Mc	A.C.	(F)	(B)	√	Zero-center scale.
30cps-100Kc	A.C.	(F)		√	
50cps-700Mc	A.C.	(F)		√	Measures d-c current.
20cps-100Mc	A.C.	(F)		√	
20cps-100Mc	A.C.	(F)			
20cps-300Mc	A.C.	(F)		√	Measures d-c current.
20cps-400Mc	A.C.	(F)		√	Measures d-c current.
50cps-300Mc	A.C.	(F)		√	Measures d-c current. Nonelectric ranges provided.

‡ (E) Indicates Amplifier-Rectifier; (F) Indicates Rectifier-Amplifier; (G) Indicates D-C Amplifier.

** All A-C Meter Scales are RMS Calibrated Unless Otherwise Indicated.



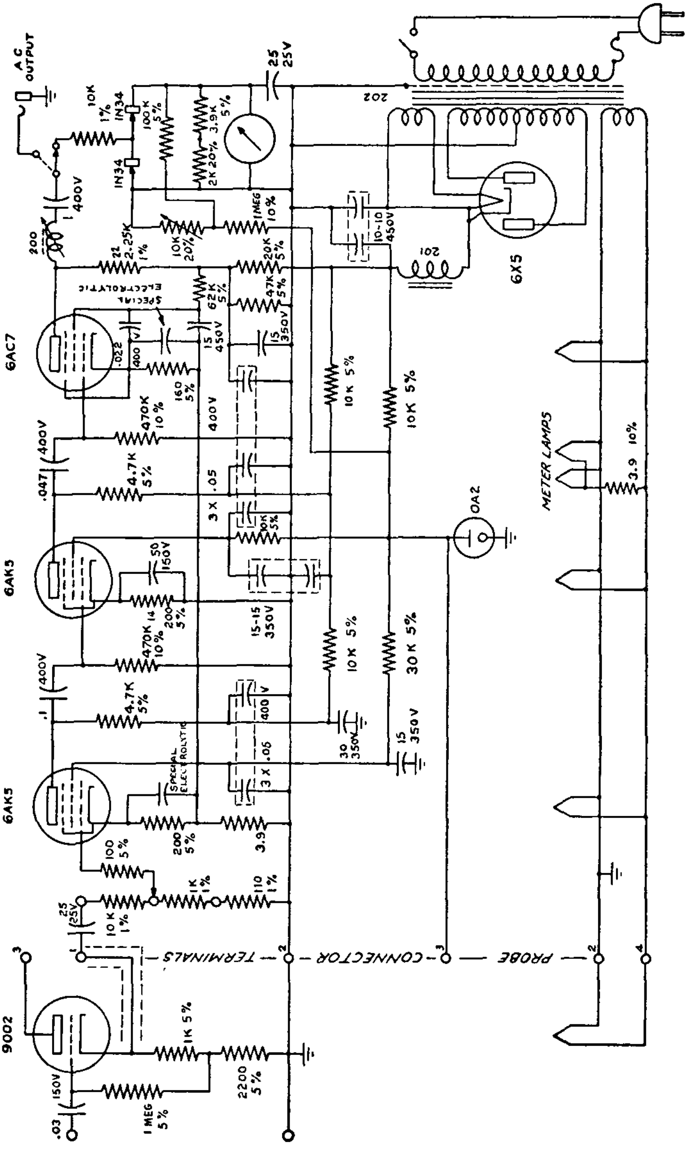
Ballantine Laboratories Model 300.



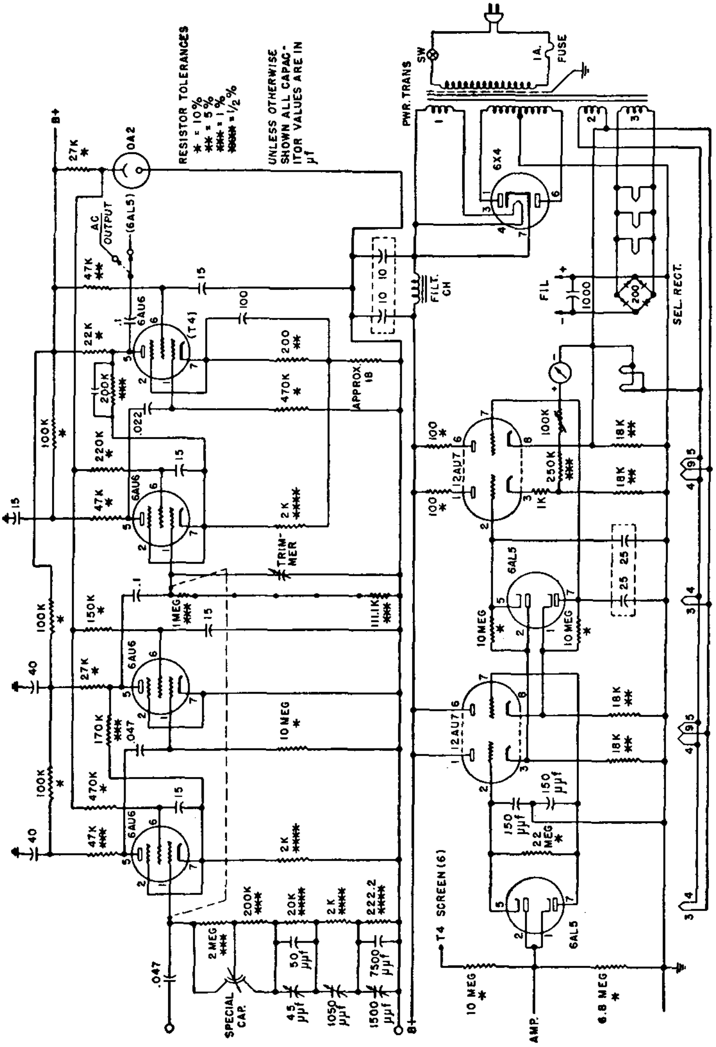
Ballantine Laboratories Model 303.

ALL RESISTOR TOLERANCES ±10%
UNLESS OTHERWISE NOTED

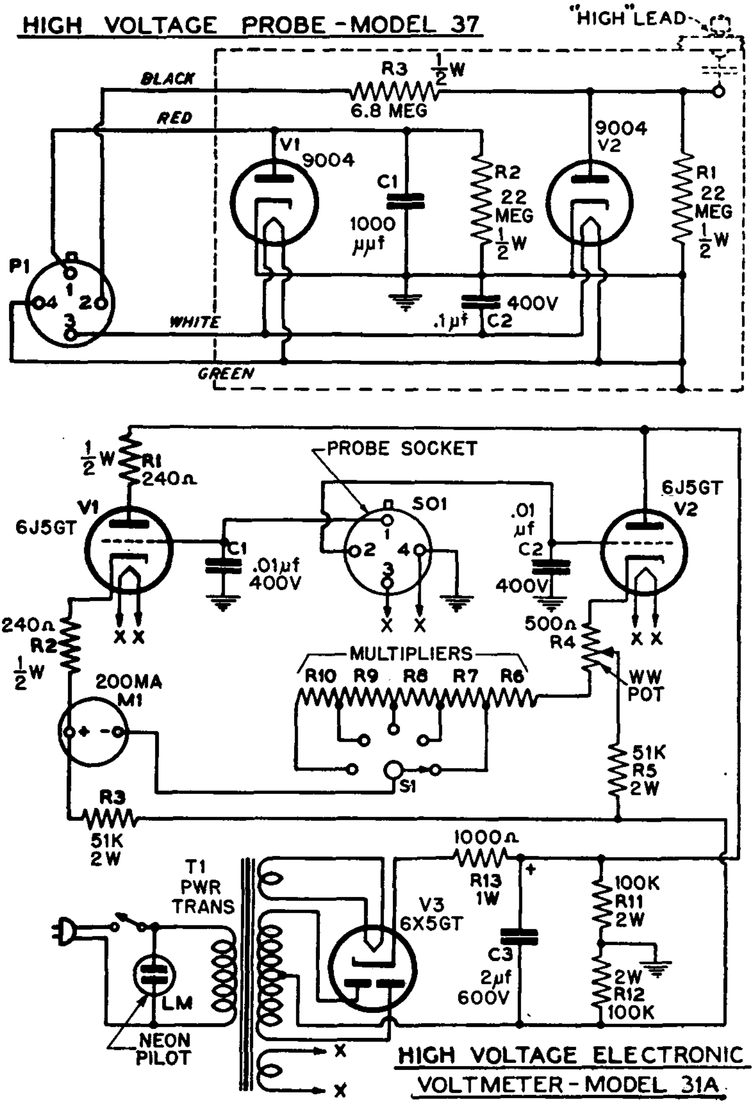
ALL CAPACITORS ARE IN μf
UNLESS OTHERWISE NOTED



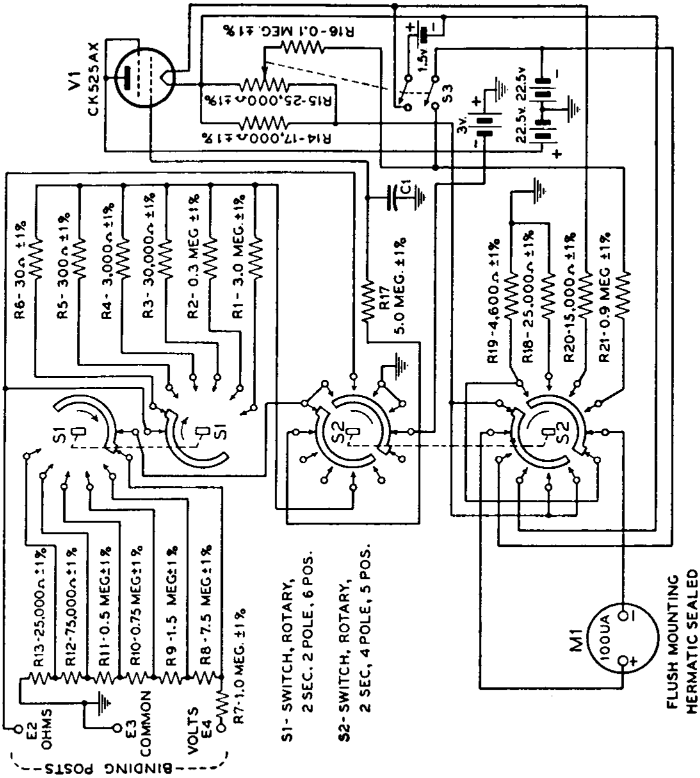
Ballantine Laboratories Model 304.



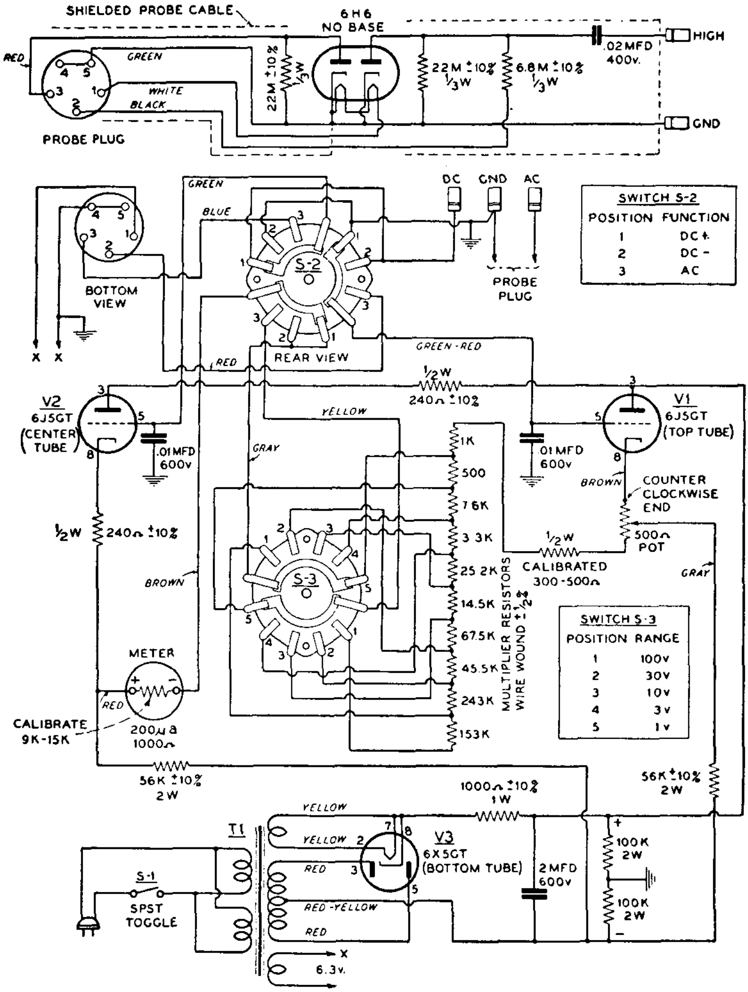
Ballantine Laboratories Model 305.



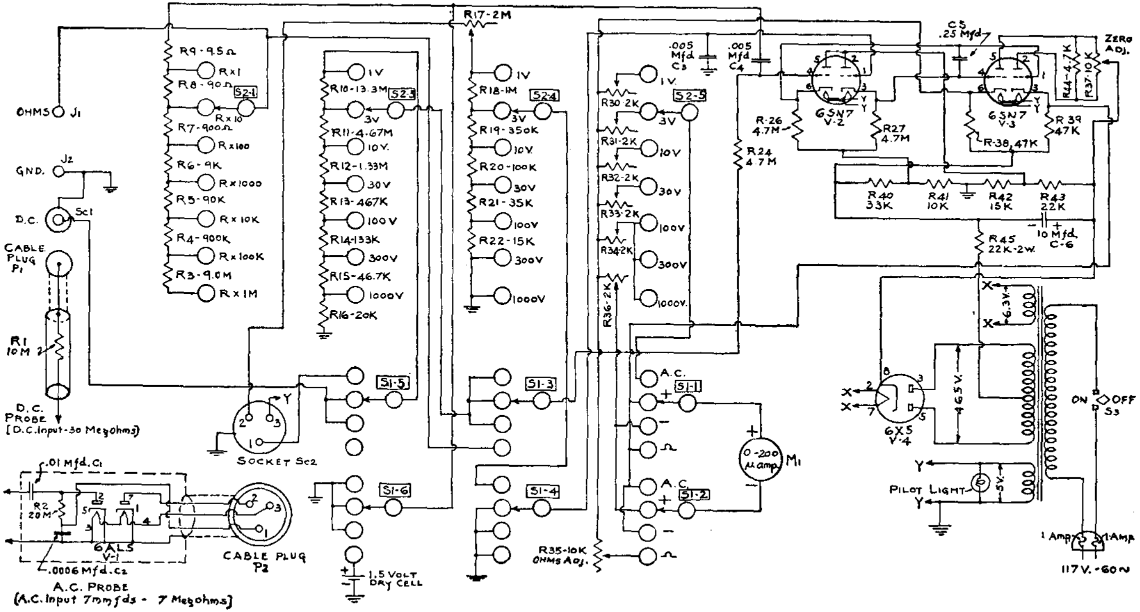
Barber Laboratories Model 31A.



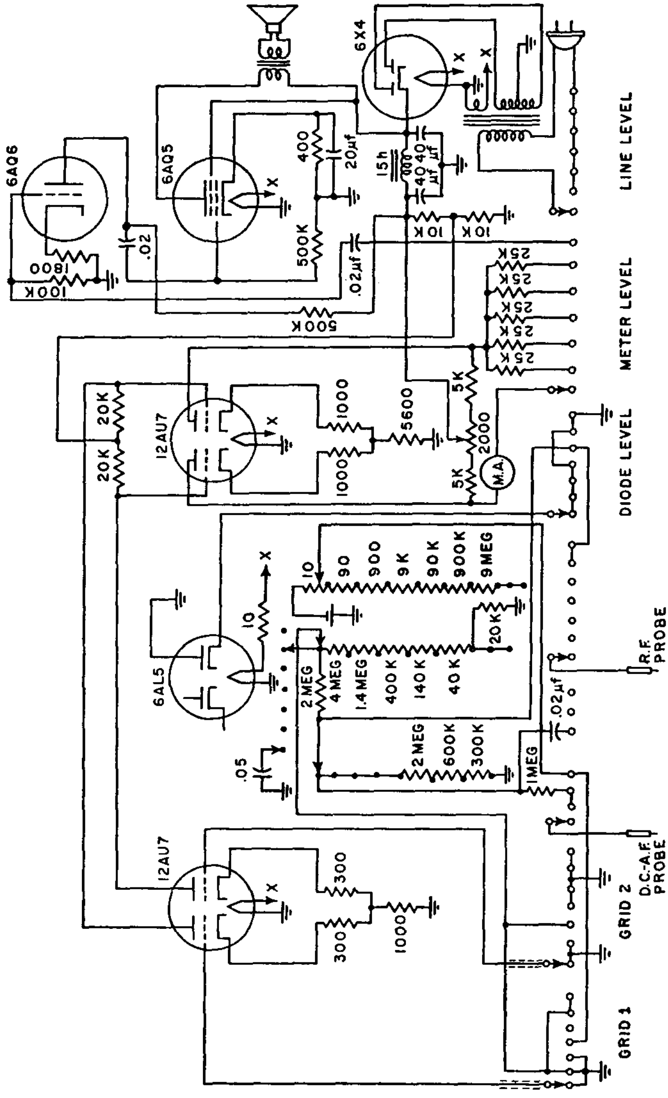
Barber Laboratories Model 33.



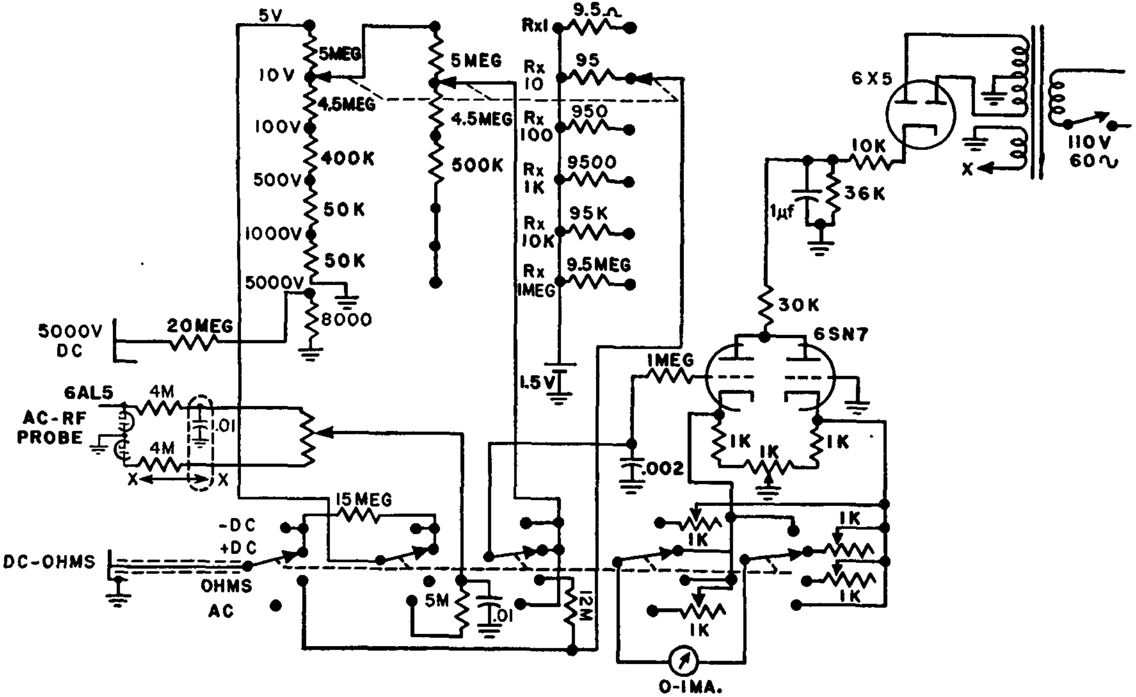
Barber Laboratories Model 72.



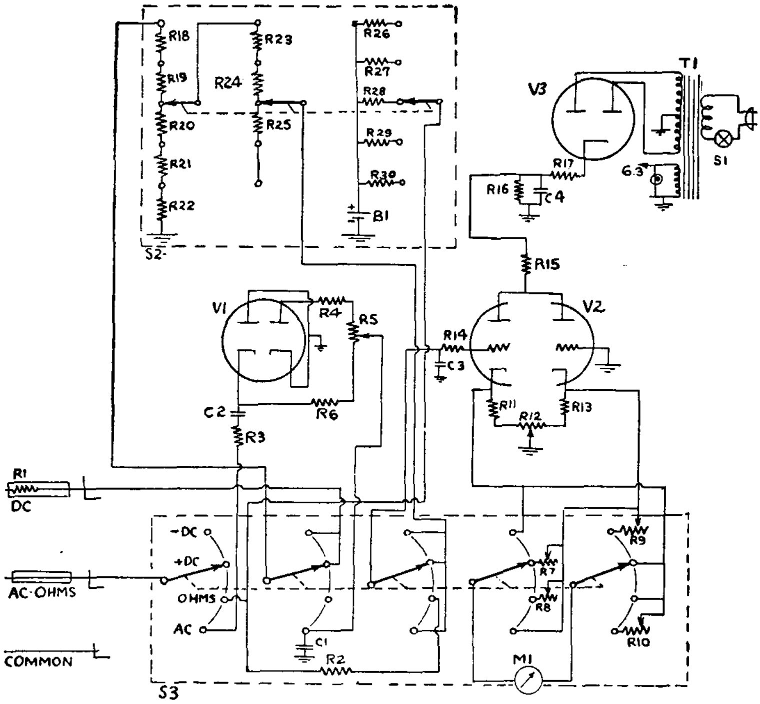
Clippard Instrument Laboratory, Inc., Model 406.



Coastwise Electronics Model 730.

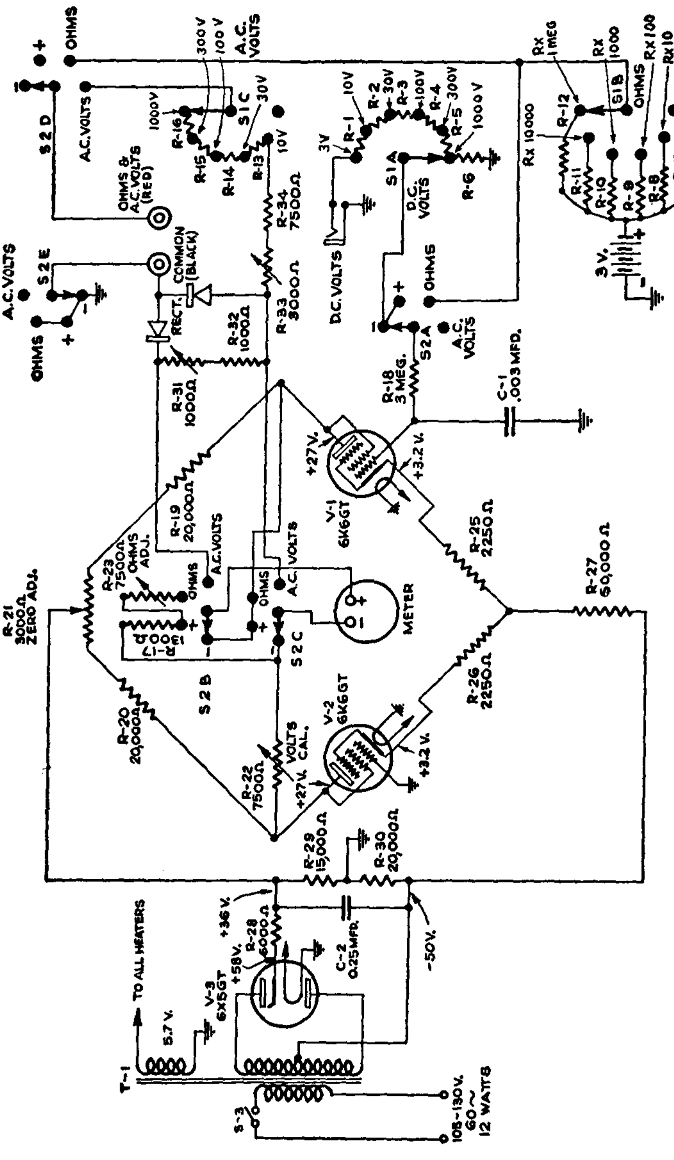


Eico (Electronic Instrument Co.) Model 210.

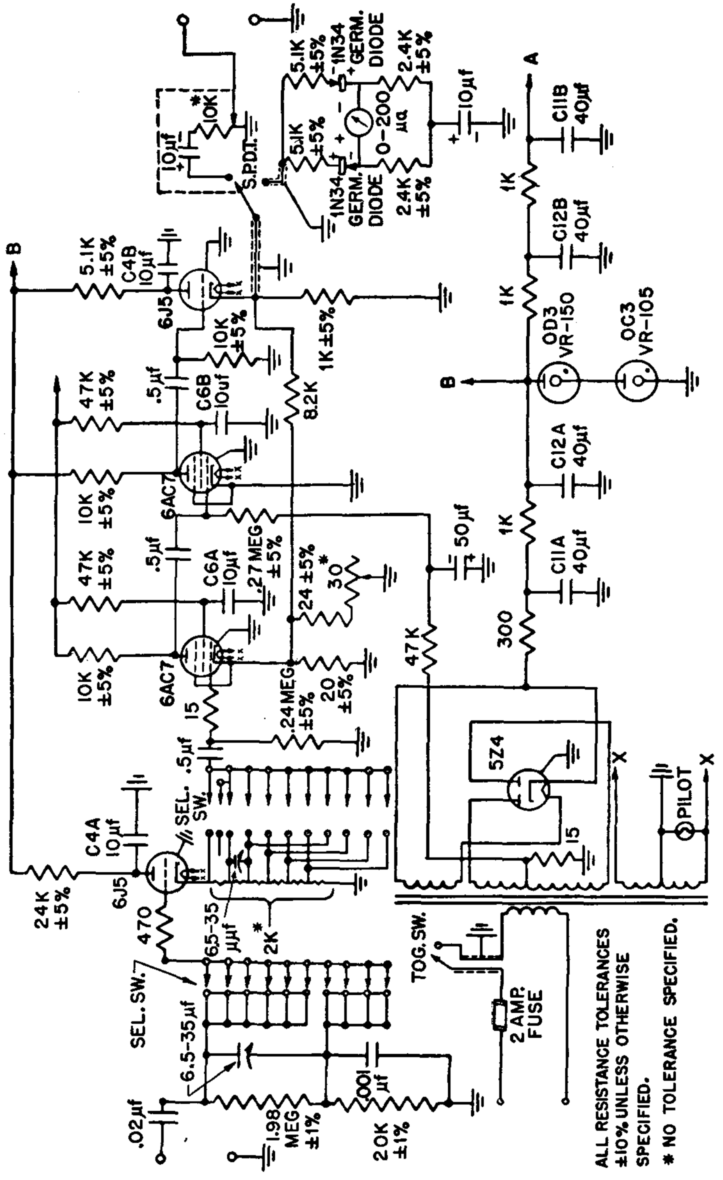


ITEM	PART	SPECIFICATION
R1	41	15 MEG. RES.
R2	42	12 MEG. RES.
R3	46	500,000Ω
R4	44	1.5 MEGOHM
R5	53	2 MEG AC ZERO POT
R6	44	1.5 MEGOHM
R7	51	1K +D.C. CAL. POT
R8	52	1K OHMS ADJ. POT
R9	51	1K -DC CAL. POT
R10	51	1K AC CAL. POT
R11	50	1,000Ω BTS
R12	52	1K ZERO ADJ. POT
R13	50	1,000Ω BTS
R14	45	1 MEGΩ BTS
R15	49	20,000Ω
R16	47	33,000Ω 2W
R17	48	10,000Ω 2W
R18	32	5 MEGΩ 1%
R19	33	4.5 MEGΩ 1%
R20	34	400,000Ω 1%
R21	35	50.000Ω 1%
R22	35	50,000Ω 1%
R23	43	5 MEGΩ BTS
R24	57	4.7 MEGΩ BTS
R25	46	500,000Ω BTS
R26	36	9.5Ω 1%
R27	37	95Ω 1%
R28	38	9500Ω 1%
R29	39	95,000 1%
R30	40	9.5 MEGΩ 1%
C1	55	.01 CONDENSER
C2	55	.01 COND.
C3	54	.002 COND.
C4	56	2MFD COND.
V1	25	6H6 TUBE
V2	24	6SN7 TUBE
V3	23	6X5 TUBE
T1	22	TRANSFORMER
M1	3	0-1 MA. METER
B1	28	1.5 VOLT BATTERY
S1	9	ON-OFF SWITCH
S2	4	RANGE SWITCH
S3	5	FUNCTION SWITCH

Eico (Electronic Instrument Co.) Model 221.



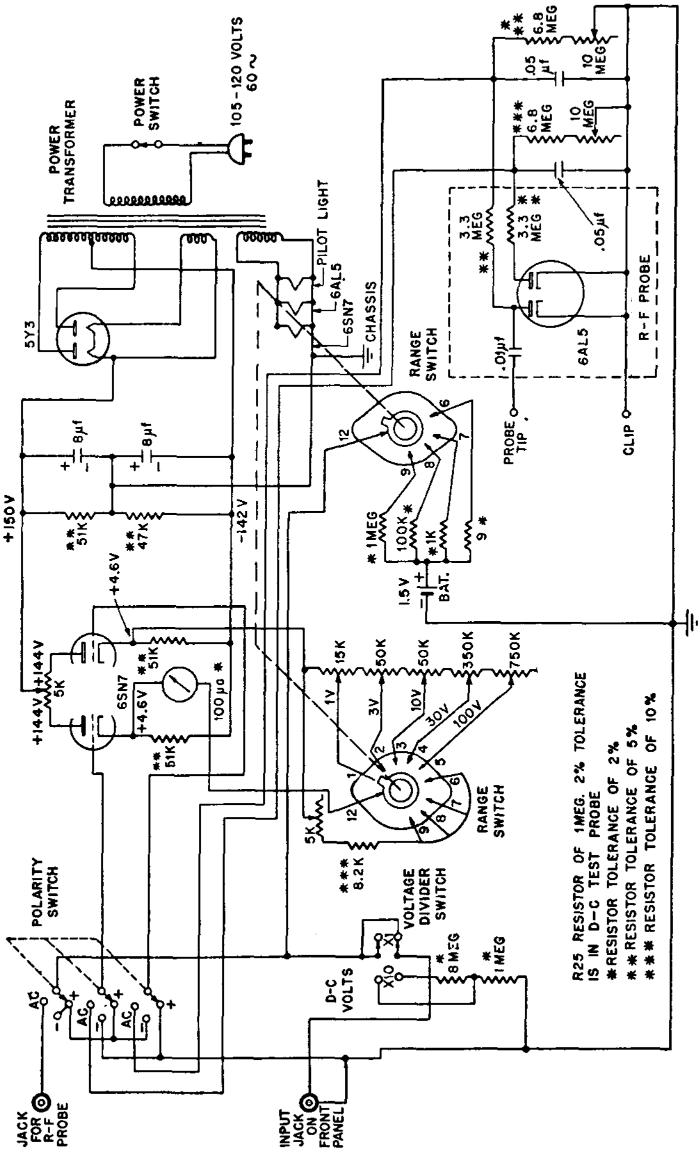
Electronic Designs Model 100.



ALL RESISTANCE TOLERANCES ±10% UNLESS OTHERWISE SPECIFIED.

* NO TOLERANCE SPECIFIED.

General Electric Co. Type AA-1.



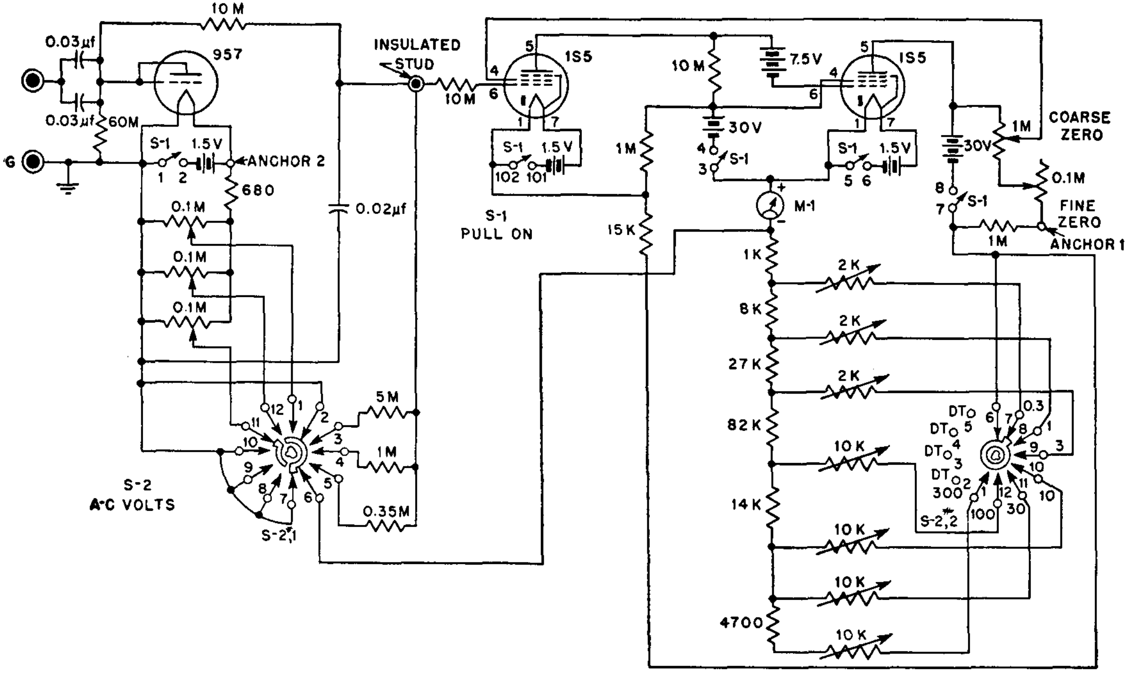
R25 RESISTOR OF 1MEG. 2% TOLERANCE IS IN D-C TEST PROBE

* RESISTOR TOLERANCE OF 2%

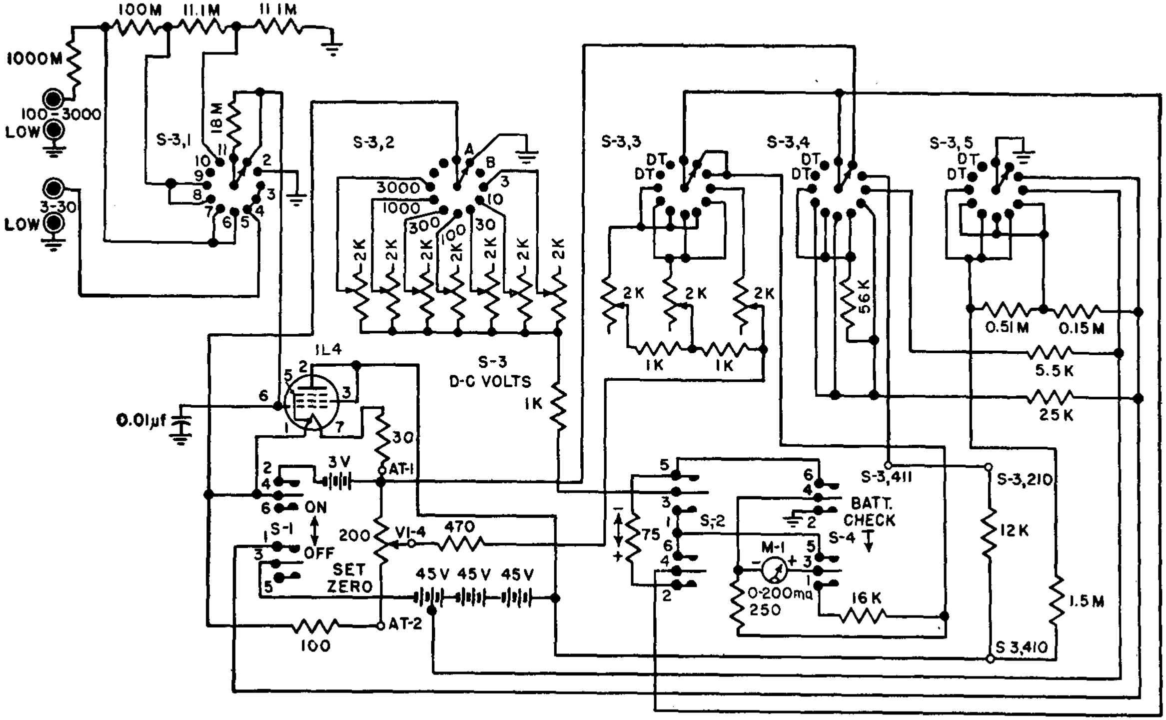
** RESISTOR TOLERANCE OF 5%

*** RESISTOR TOLERANCE OF 10%

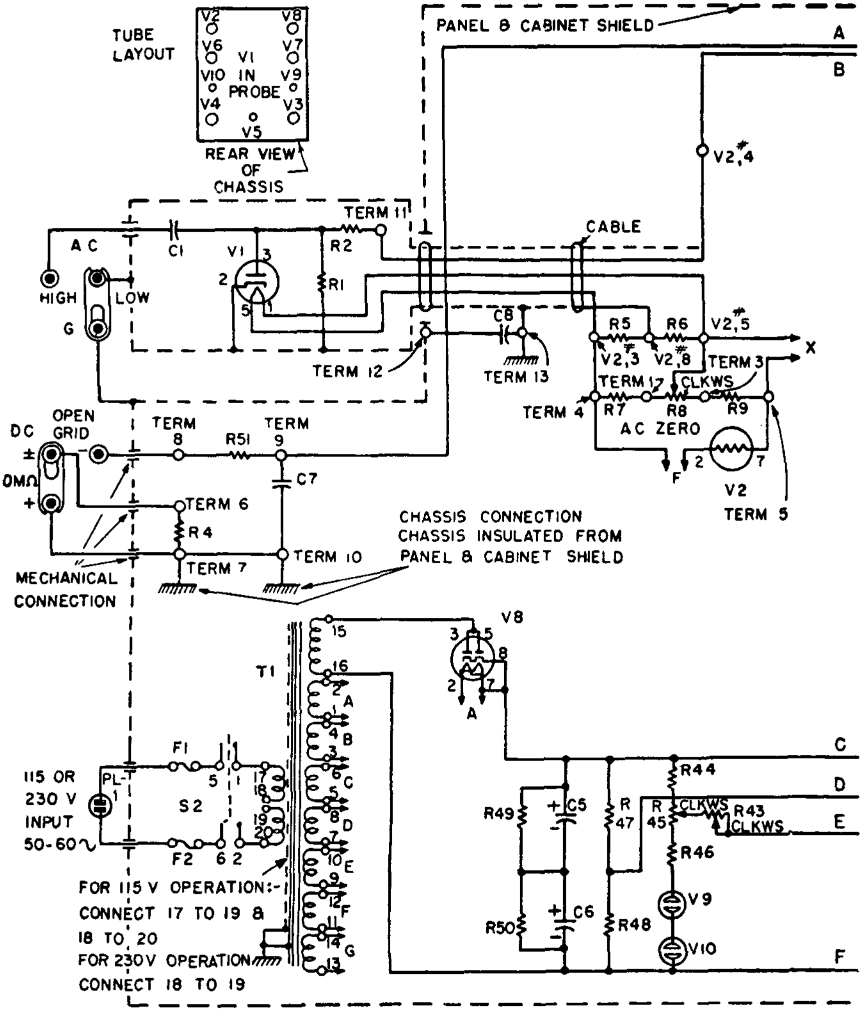
General Electric Co. Type P104.



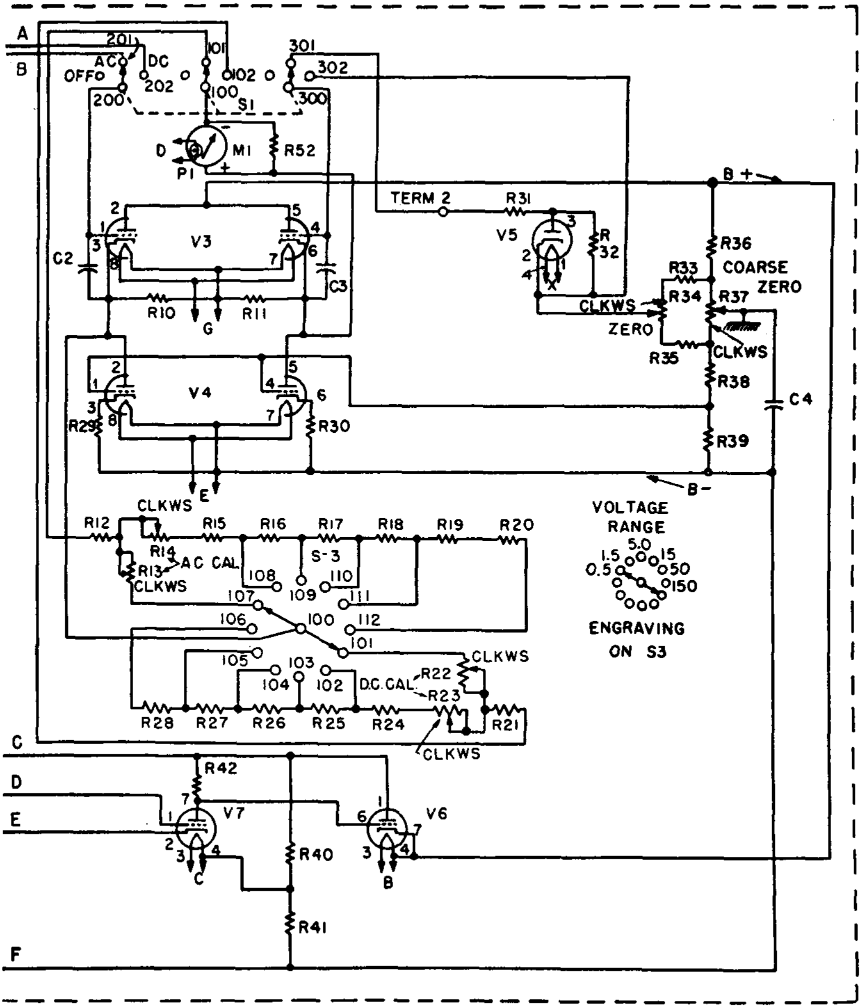
General Radio Co. Model 727A.



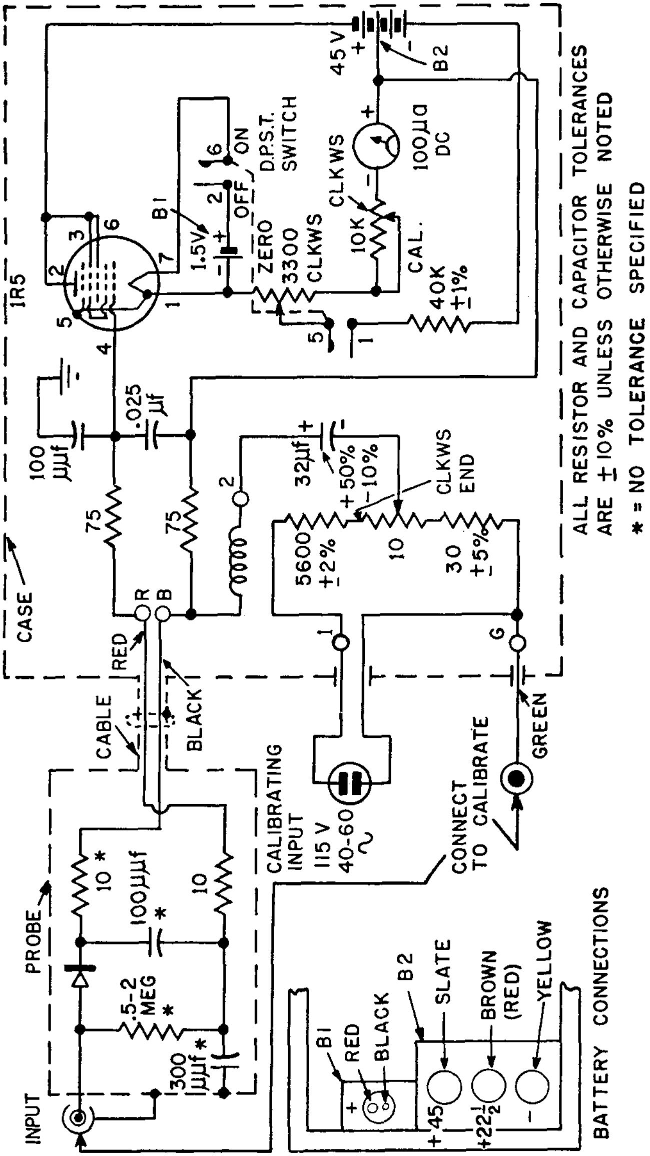
General Radio Co. Type 728A.



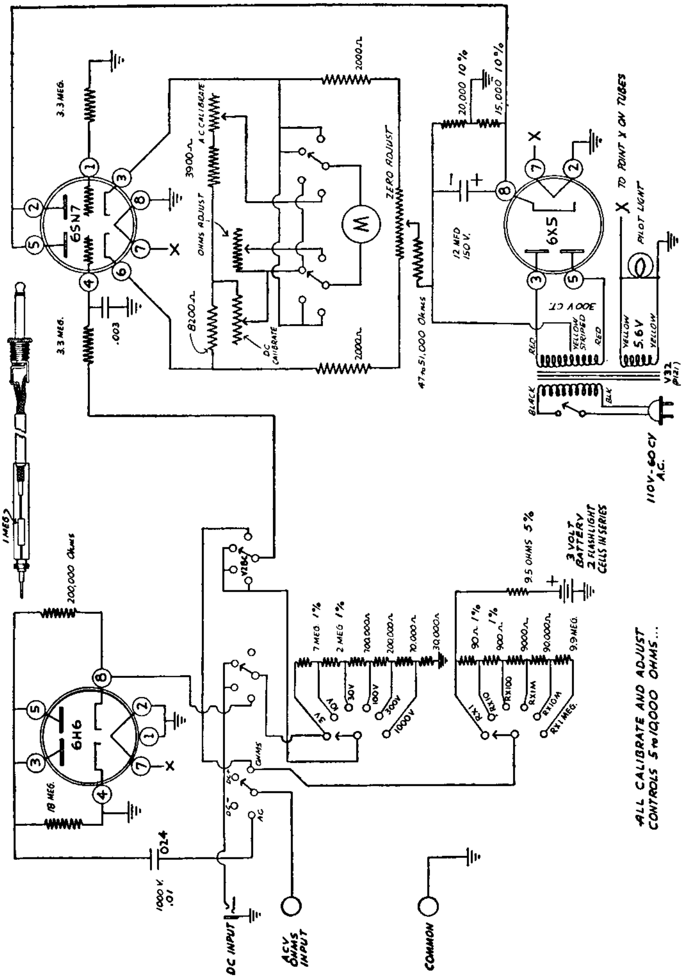
General Radio Co.


A
B
201
AC
DC
OFF
202
200
101
102
100
S1
301
302
300
D
M1
R52
P1
B +
TERM 2
R31
V5
R
32
V3
C2
C3
R10
R11
G
R36
R33
COARSE
ZERO
R34
R37
CLKWS
ZERO
R35
CLKWS
R38
C4
V4
R29
R30
R39
E
B-
CLKWS
R12
R15
R16
R17
R18
R19
R20
R14
AC CAL
R13
CLKWS
S-3
108
109
110
107
111
106
100
112
101
105
103
104
102
CLKWS
R22
D.C. CAL
R23
R28
R27
R26
R25
R24
R21
CLKWS
VOLTAGE
RANGE
5.0
1.5
15
0.5
50
150
ENGRAVING
ON S3
C
D
E
R42
V7
V6
R40
C
B
R41
F

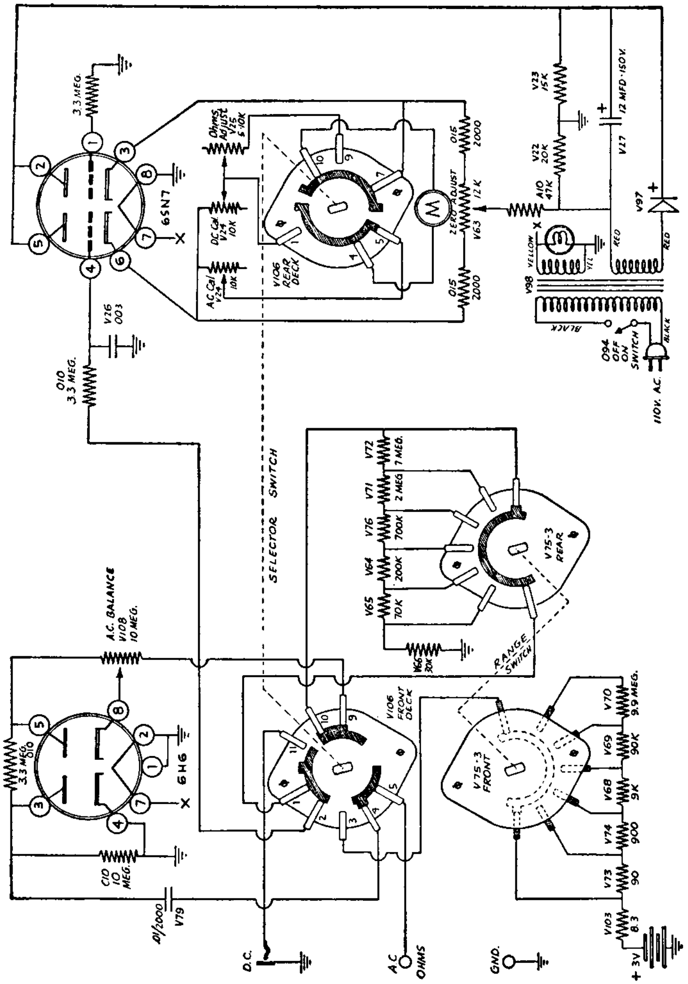
Model 1800A



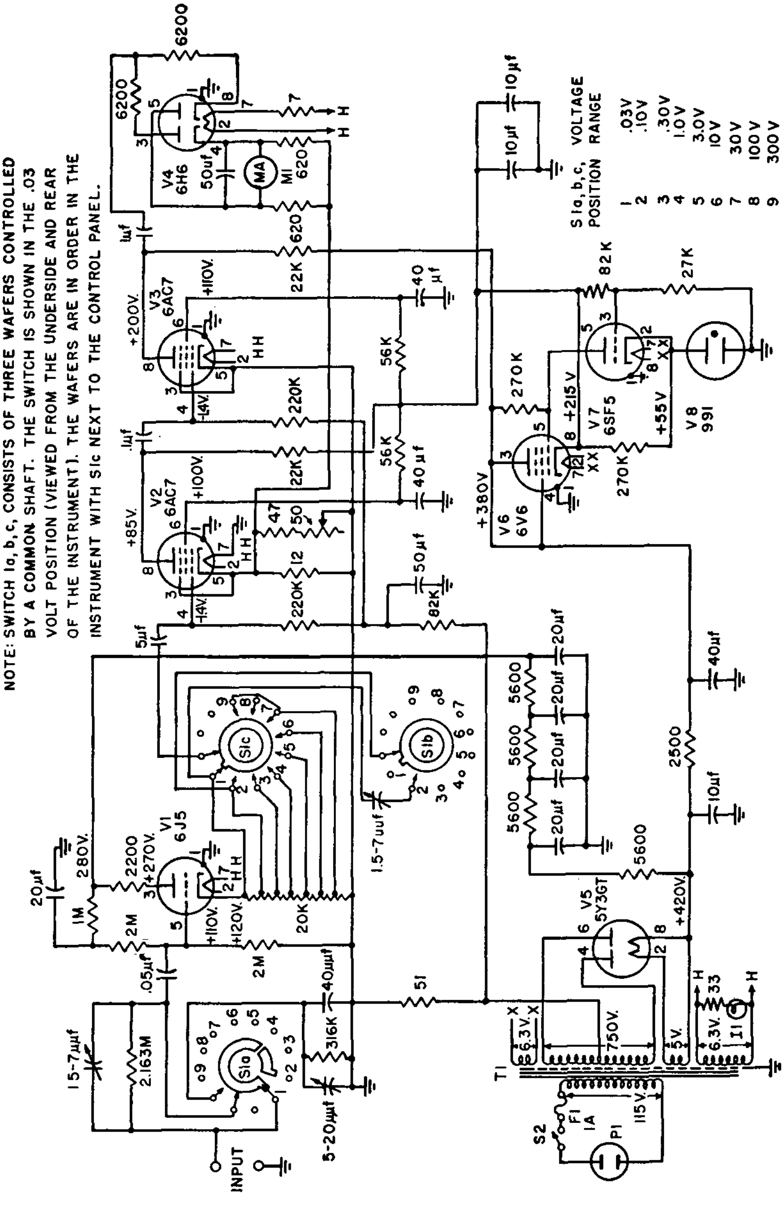
General Radio Co. Type 1802A.



Heath Co. Heathkit Model V-2.



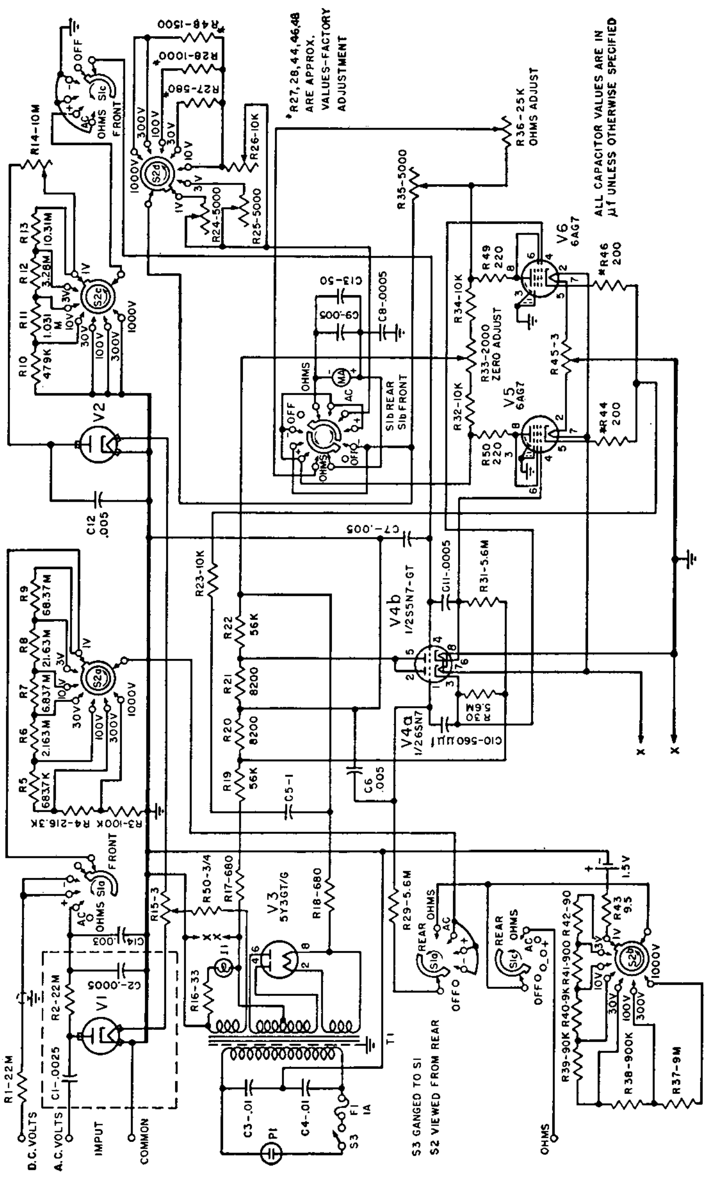
Heath Co. Heathkit Model V-4A.



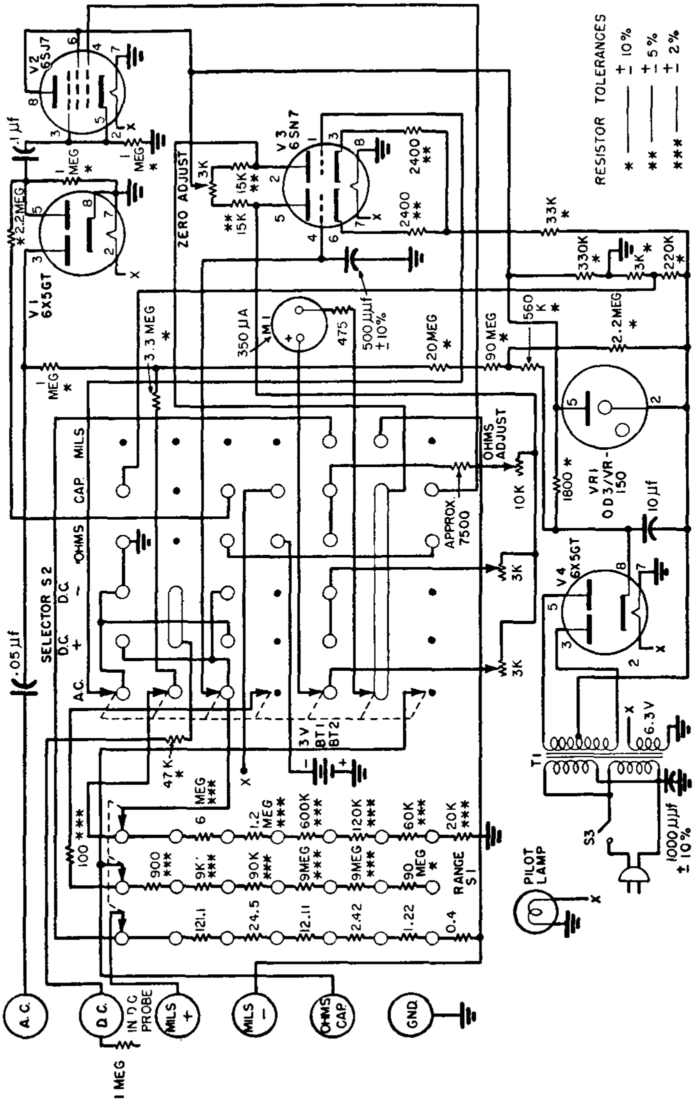
NOTE: SWITCH Ia, b, c, CONSISTS OF THREE WAFERS CONTROLLED BY A COMMON SHAFT. THE SWITCH IS SHOWN IN THE .03 VOLT POSITION (VIEWED FROM THE UNDERSIDE AND REAR OF THE INSTRUMENT). THE WAFERS ARE IN ORDER IN THE INSTRUMENT WITH SIc NEXT TO THE CONTROL PANEL.

S1a, b, c, POSITION	VOLTAGE RANGE
1	.03V
2	.10V
3	.30V
4	1.0V
5	3.0V
6	10V
7	30V
8	100V
9	300V

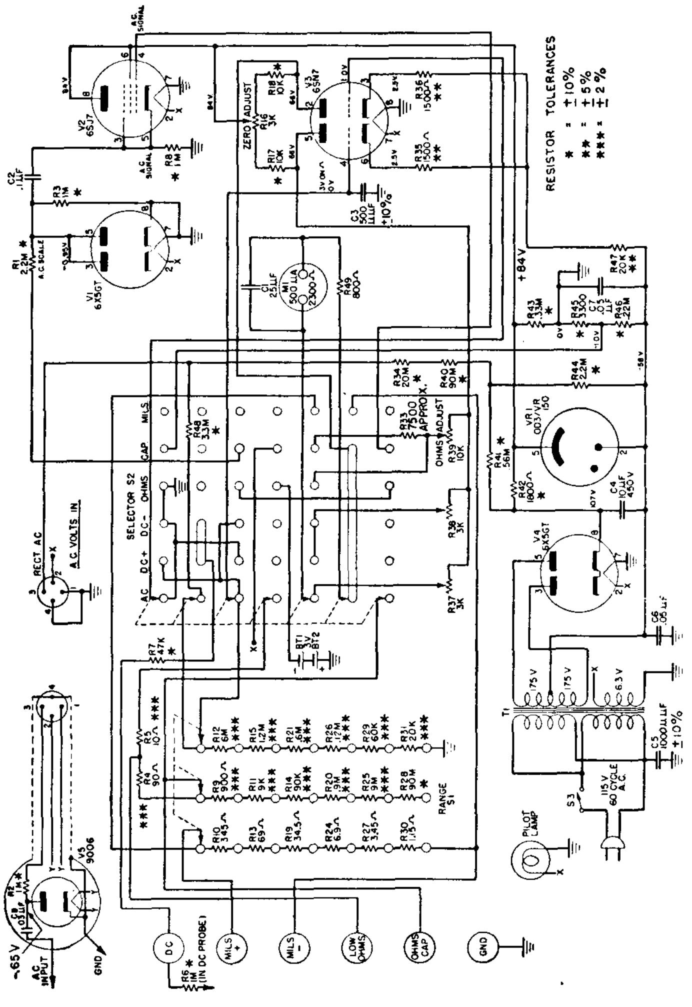
Hewlett-Packard Co. Model 400A.



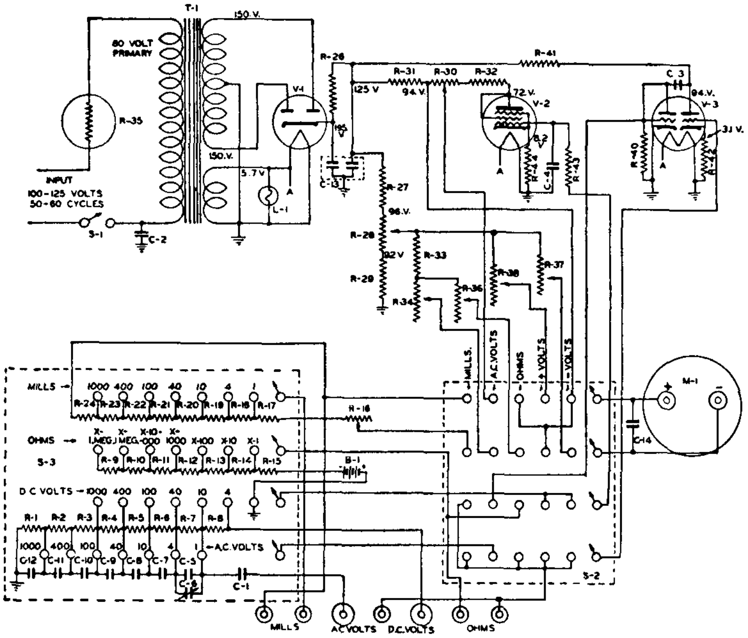
Hewlett-Packard Co. Model 410A.



Hickok Electrical Instrument Co. Model PR203.

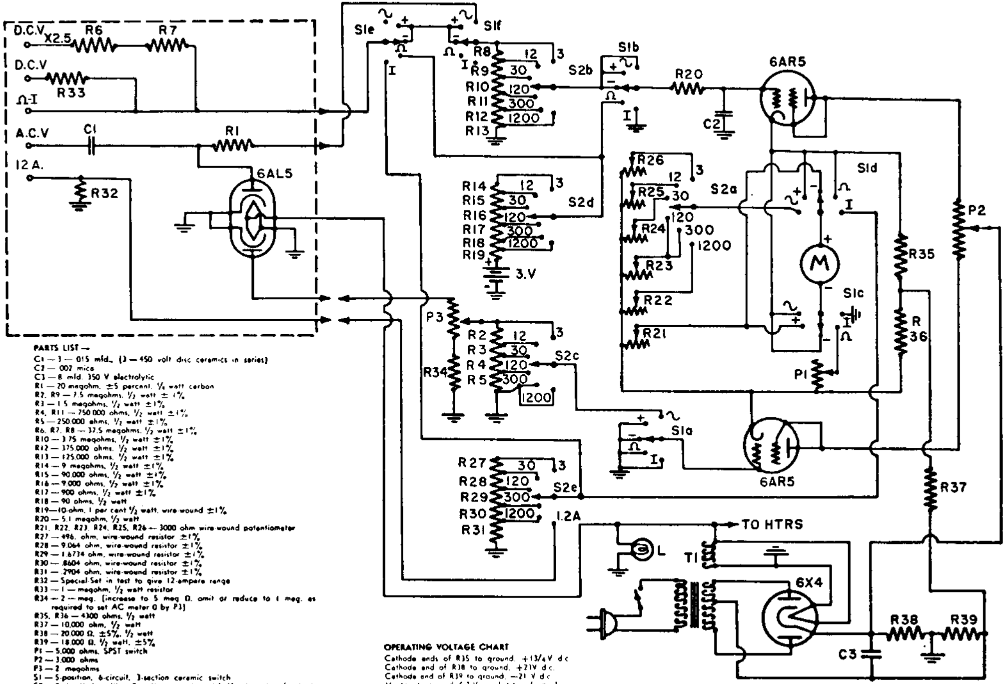


Hickok Electrical Instrument Co. Model 209.



Jackson Electrical Instrument Co. Model 645.

REF. NO.	DESCRIPTION
M-1	Meter Model 1 0-200ua 750 ohms
S-1	S.P.S.T. Toggel Switch
S-2	Rotary Switch 4 Pole 5 Position
S-3	Rotary Switch 4 Pole 7 Position
T-1	Transformer
L-1	Type S-51 Pilot Lamp 7.5 V .2 A.
V-1	Type 6X5GT Tube
V-2	Type 6K6GT Tube
V-3	Type 7N7 Tube
B-1	Type 2370 Battery
R-1	BT½ Series Matched to 4400 ohms 1 %
R-2	" " " " 6600 " " "
R-3	" " " "33000 " " "
R-4	" " " "66000 " " "
R-5	" " " " .33 Meg. ohms 1 %
R-6	" " " " .66 " " " "
R-7	" " " " 3.3 " " " "
R-8	" " " " 6.6 " " " "
R-9	" " " "13.5 " " " "
R-10	" " " " 1.35 " " " "
R-11	" " " " .135 " " " "
R-12	" " " "13500 ohms 1 %
R-13	" Parallel " "1350. " " "
R-14	BW½ " " " 135. " " "
R-15	" " " " 13 " " "
R-16	AD200 200 ohm Adjustable Resistor
R-17	BT½ Single Unit 750 Ohms 10 %
R-18	" Parallel Matched to 300. ohms 1 %
R-19	BW½ " " " 60. " " "
R-20	" " " " 30. " " "
R-21	" " " " 6. " " "
R-22	" " " " 3. " " "
R-23	" " " " .6 " " "
R-24	" " " " .4 " " "
R-25	BTS Single Unit 1. Meg ohms 5 %
R-26	BT 1 Single Unit 8000 ohms 10 %
R-27	BT½ Single Unit 3000 ohms 5 %
R-28	W800 Potentiometer 800 ohms Linear Taper
R-29 R-32	BT½ Single Unit 15000 ohms 10 %
R-30	AD1000 1000 ohm Adjustable Resistor
R-31	BT½ Single Unit 12000 ohms 10 %
R-33	BT½ As Required Approx. 3500 ohms
R-34 R-37	
R-38	#803 8000 ohm Adjustable Resistor
R-35	#3A-20 Regulator Resistor
R-36	W8000 Potentiometer 8000 ohms Linear Taper
R-40 R-43	BT½ Single Unit 3. Meg.ohms 10 %
R-41	BT½ Single Unit 10,000. ohms 10 %
R-42	" " " 1500. " " "
R-44	" " " 5000. " " "
C-1	.1 mf. 600.v Tublar Condenser 10 %
C-2 C-3	.1 mf. 400.v " " " "
C-4 C-10	.005 mf. Mica Condenser 10 %
C-5	30.mmf. " " 10 %
C-6	7 - 30 mmf. Trimmer Condenser
C-7	200 mmf. Mica Condenser 5 %
C-8	490 mmf. " " " "
C-9	.0025 mf. " " 10 %
C-11	.025 mf. 400.v Tublar Condenser 10 %
C-12	.0375 mf. 400.v " " " "
C-13	10-10-mf.300.v Electrolytic Condenser
C-14	25 mf. 25.v " "



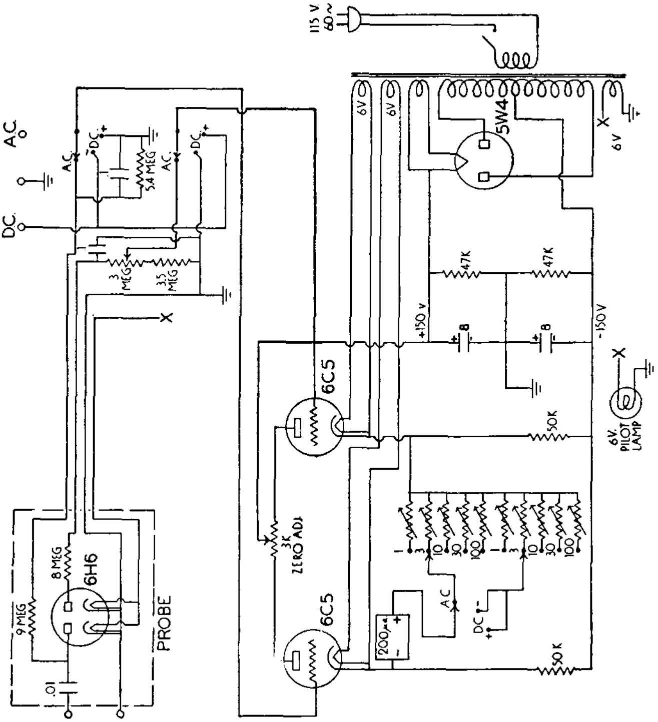
PARTS LIST—

C1 — 3 — .015 mfd., (3 — 450 volt disc ceramics in series)
C2 — .002 mica
C3 — 8 mfd. 350 V electrolytic
R1 — 20 megohm, ±5 percent, 1/4 watt carbon
R2, R9 — 7.5 megohms, 1/2 watt ± 1%
R3 — 1.5 megohms, 1/2 watt ±1%
R4, R11 — 750,000 ohms, 1/2 watt ±1%
R5 — 250,000 ohms, 1/2 watt ±1%
R6, R7, R8 — 37.5 megohms, 1/2 watt ±1%
R10 — 3.75 megohms, 1/2 watt ±1%
R12 — 375,000 ohms, 1/2 watt ±1%
R13 — 125,000 ohms, 1/2 watt ±1%
R14 — 9 megohms, 1/2 watt ±1%
R15 — 90,000 ohms, 1/2 watt ±1%
R16 — 9,000 ohms, 1/2 watt ±1%
R17 — 900 ohms, 1/2 watt ±1%
R18 — 90 ohms, 1/2 watt
R19—10-ohm, 1 per cent 1/2 watt, wire-wound ±1%
R20 — 5.1 megohm, 1/2 watt
R21, R22, R23, R24, R25, R26 — 3000 ohm wire-wound potentiometer
R27 — 496. ohm, wire-wound resistor ±1%
R28 — 9.064 ohm, wire-wound resistor ±1%
R29 — 1.6734 ohm, wire-wound resistor ±1%
R30 — .8604 ohm, wire-wound resistor ±1%
R31 — .2904 ohm, wire-wound resistor ±1%
R32 — Special-Set in test to give 12-ampere range
R33 — 1 — megohm, 1/2 watt resistor
R34 — 2 — meg. (increase to 5 meg Ω, omit or reduce to 1 meg. as required to set AC meter 0 by P3)
R35, R36 — 4300 ohms, 1/2 watt
R37 — 10,000 ohm, 1/2 watt
R38 — 20,000 Ω, ±5%, 1/2 watt
R39 — 18,000 Ω, 1/2 watt, ±5%
P1 — 5,000 ohms, SPST switch
P2 — 3,000 ohms
P3 — 2 megohms
S1 — 5-position, 6-circuit, 3-section ceramic switch
S2 — 5-circuit, 6-position, 5-section ceramic switch (front section shorting)
T — Power Transformer; 115-volt, 50/60 primary; 5.7 volts, 1.8 amp., 72 volts, 20 ma.

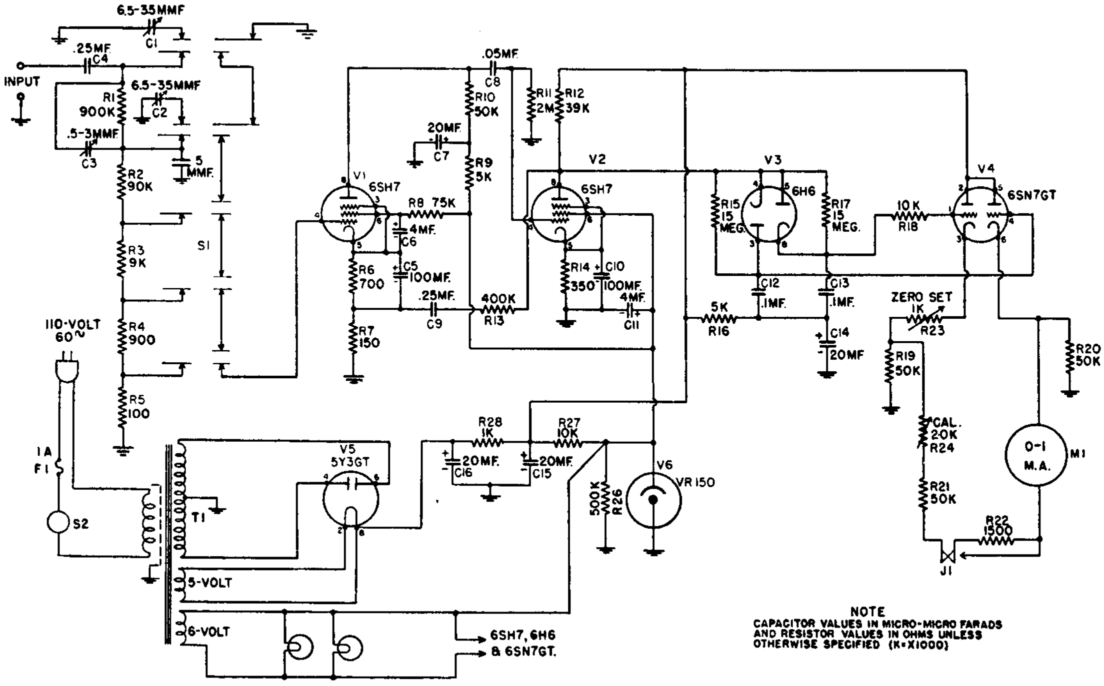
OPERATING VOLTAGE CHART

Cathode ends of R35 to ground, +13/4V d.c.
Cathode end of R38 to ground, +21V d.c.
Cathode end of R39 to ground, −21 V d.c.
Heaters to ground 5.7 V a.c. (at transformer)
Plates of 6X4 to center tap (tube out of socket) 36 volts a.c.

McMurdo Silver Co. Model 900A.

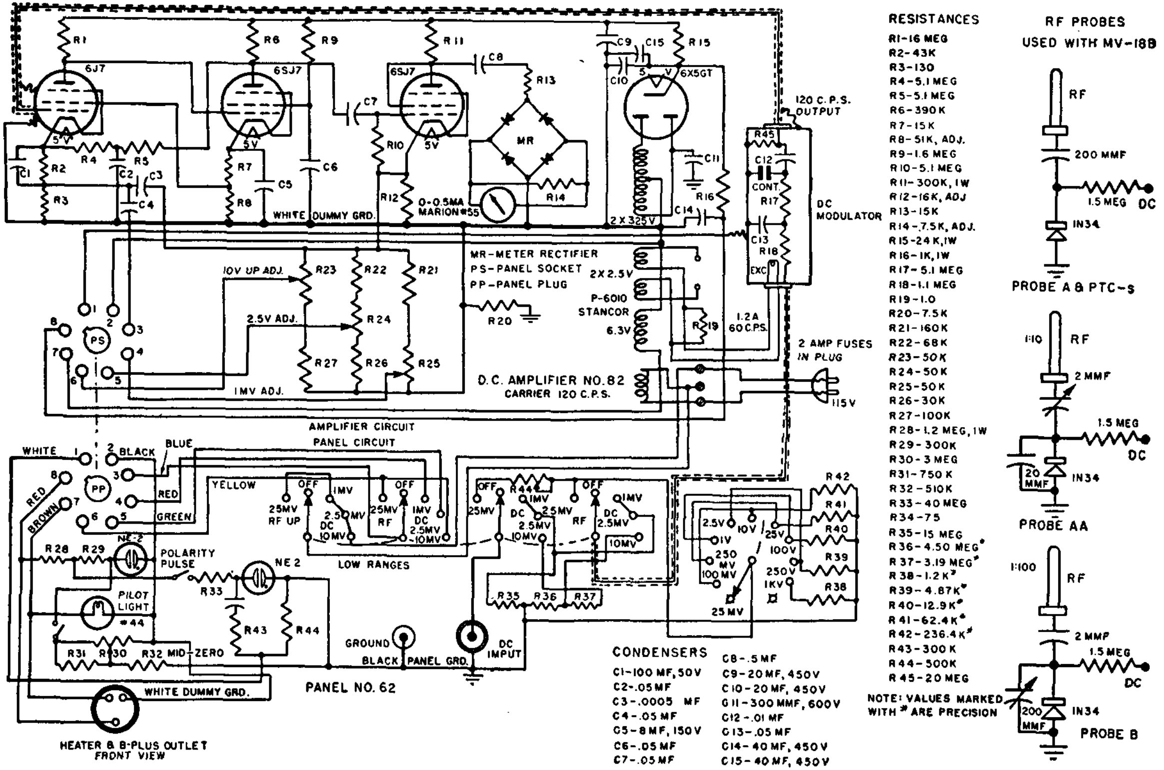


Measurements Corp. Model 62.

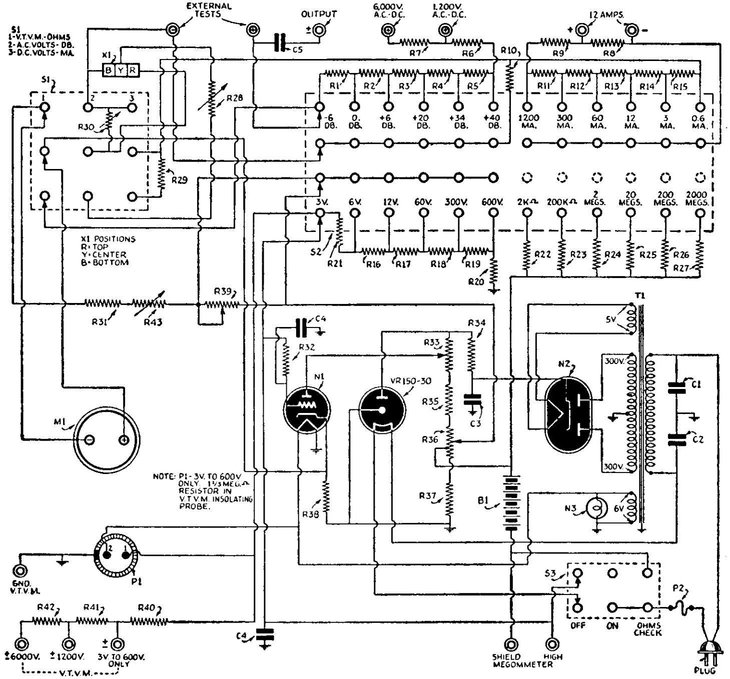


NOTE
CAPACITOR VALUES IN MICRO-MICRO FARADS AND RESISTOR VALUES IN OHMS UNLESS OTHERWISE SPECIFIED (K=X1000)

Measurements Corp. Model 67.

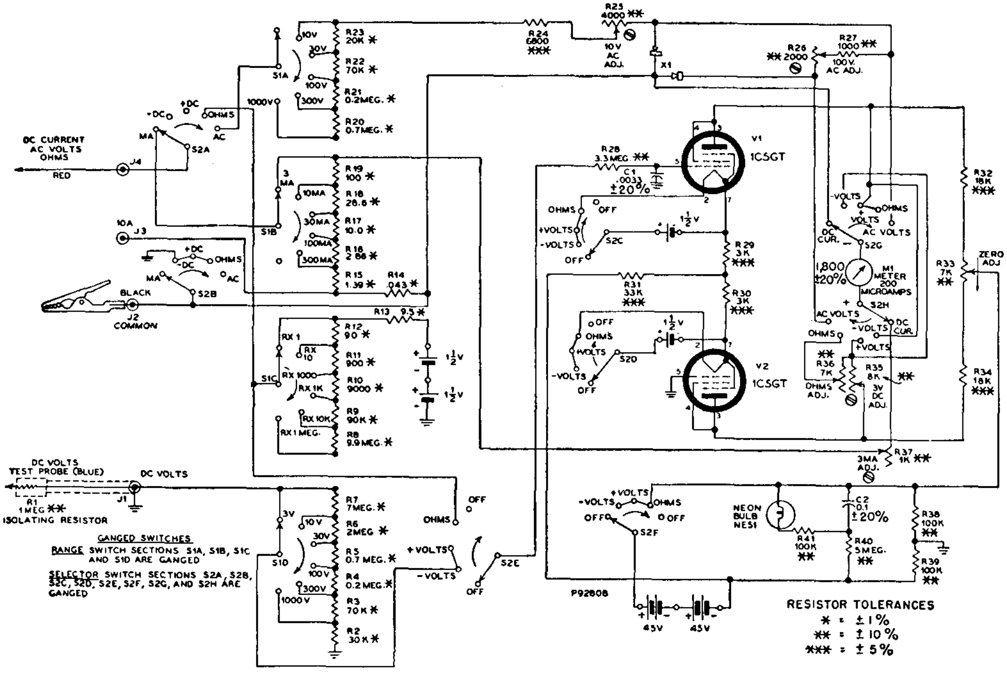


Millivac Instruments Model MV-18B.

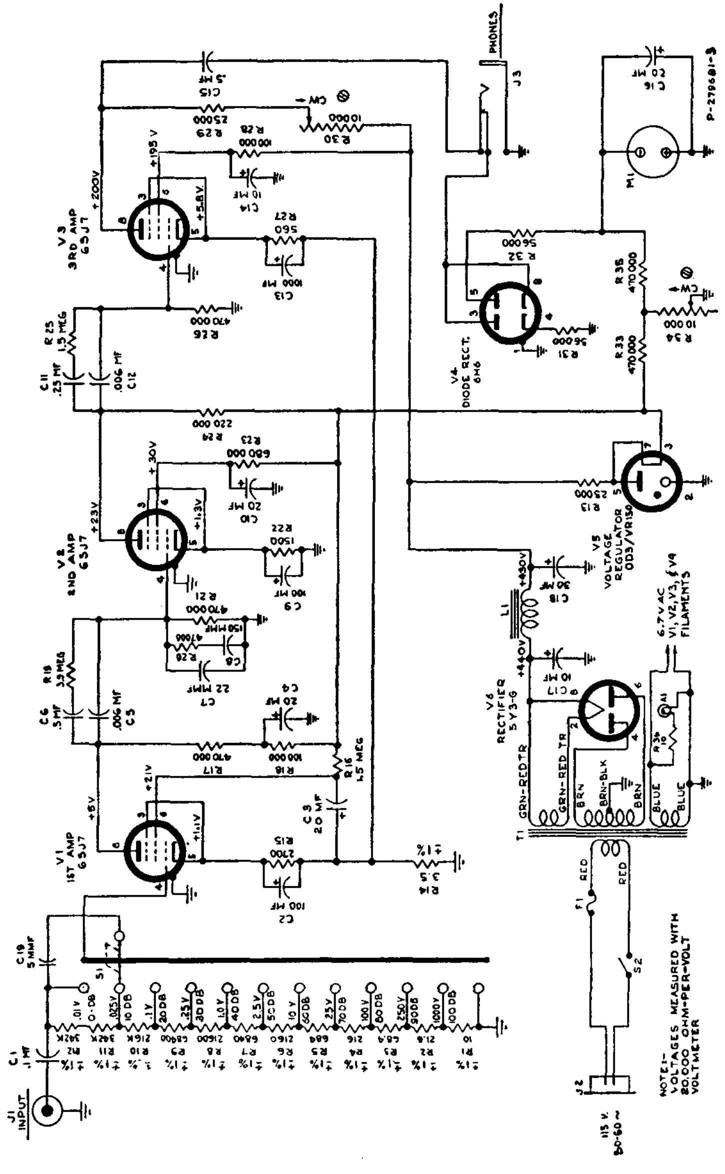


PART NO.	SPECIFICATION
R43	2KΩ SEALED CALIBRATED
R42	106⅔ MEG. Ω
R41	13⅓ MEG. Ω
R40	1⅓ MEG. Ω
R39	4,100Ω OHMS ZERO ADJUST
R38	6KΩ
R37	330Ω
R36	225Ω V.T.V.M. ZERO ADJUST
R35	11,950Ω
R34	4,715Ω - 10 WATTS
R33	3KΩ SEALED CALIBRATED
R32	500KΩ
R31	8,500Ω
R30	12KΩ SEALED CALIBRATED
R29	2,840Ω
R28	3KΩ SEALED CALIBRATED
R27	20 MEG Ω
R26	2 MEG. Ω
R25	200KΩ
R24	20KΩ
R23	2KΩ
R22	20Ω
R21	6 MEG. Ω
R20	60KΩ
R19	60KΩ
R18	480KΩ
R17	2.4 MEG Ω
R16	3 MEG. Ω
R15	640Ω
R14	120Ω
R13	32Ω
R12	6.4Ω
R11	1.2Ω
R10	267Ω CALIBRATED
R9	0.36Ω
R8	0.04Ω
R7	4.8 MEG. Ω
R6	600KΩ
R5	300KΩ
R4	240KΩ
R3	48KΩ
R2	6KΩ
R1	3KΩ
X1	METER RECTIFIER
T1	POWER TRANSFORMER
S3	3-POSITION LINE & OHMS CHECK SW
S2	12-POSITION RANGE SELECTOR
S1	3-POSITION CIRCUIT SELECTOR
P2	1AMP FUSE & EXTRACTOR POST
P1	INSOLATING PROBE CONNECTOR ALSO PROVIDES FOR RF-10 RADIO FREQUENCY PROBING UNIT.
N3	6-8VOLT PILOT LAMP
N2	6X5
N1	6C5
M1	400 μAMPS. - 160 M.V.
C5	0.1 MFD. - 600 W.V
C4	0.002 MFD. - 400 W.V.
C3	16 MFD - 450 W.V
C2	0.01 MFD. - 400 W.V.
C1	0.01 MFD - 400 W.V.
B1	6V. BATTERY EVEREADY #744 OR EQUIVALENT

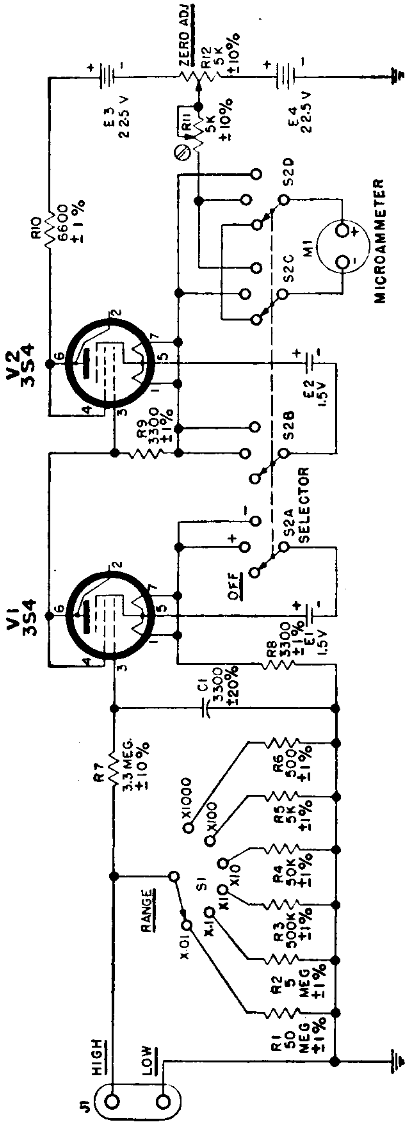
Precision Apparatus Co. Model EV-10.



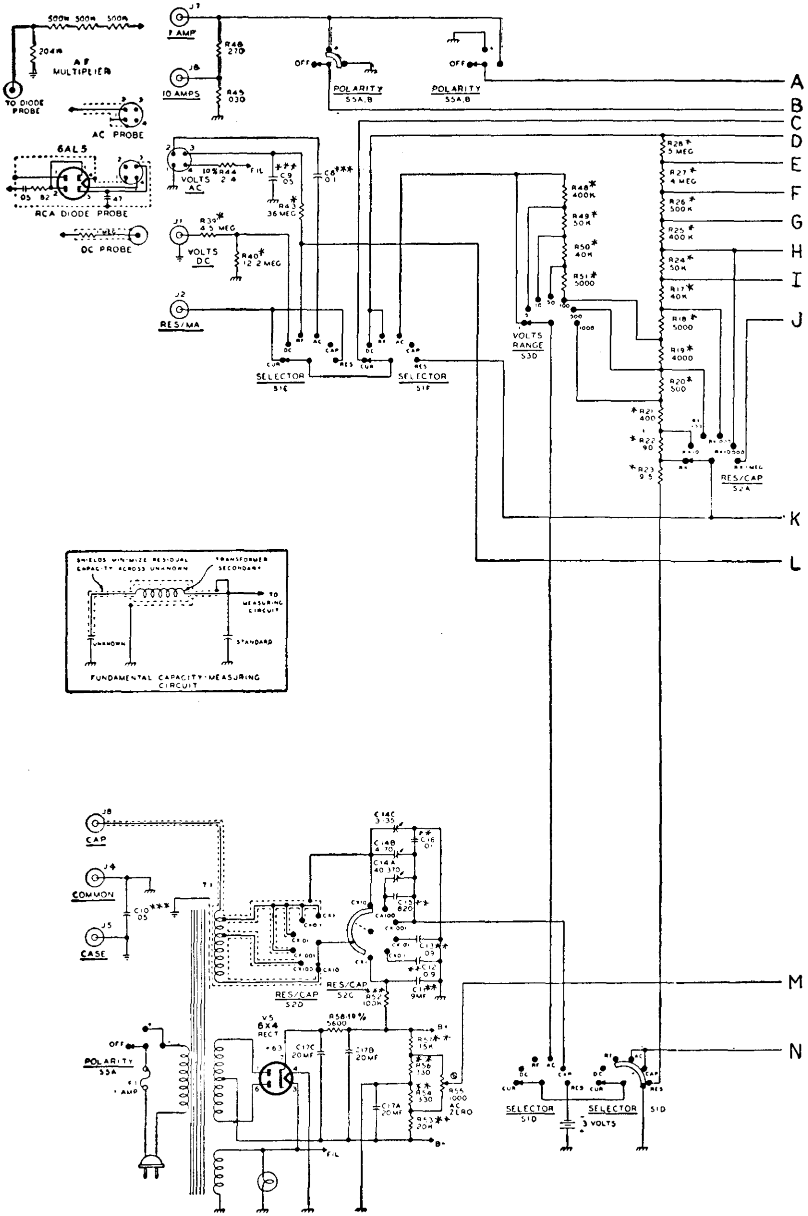
RCA VoltOhmyst WV-65A.



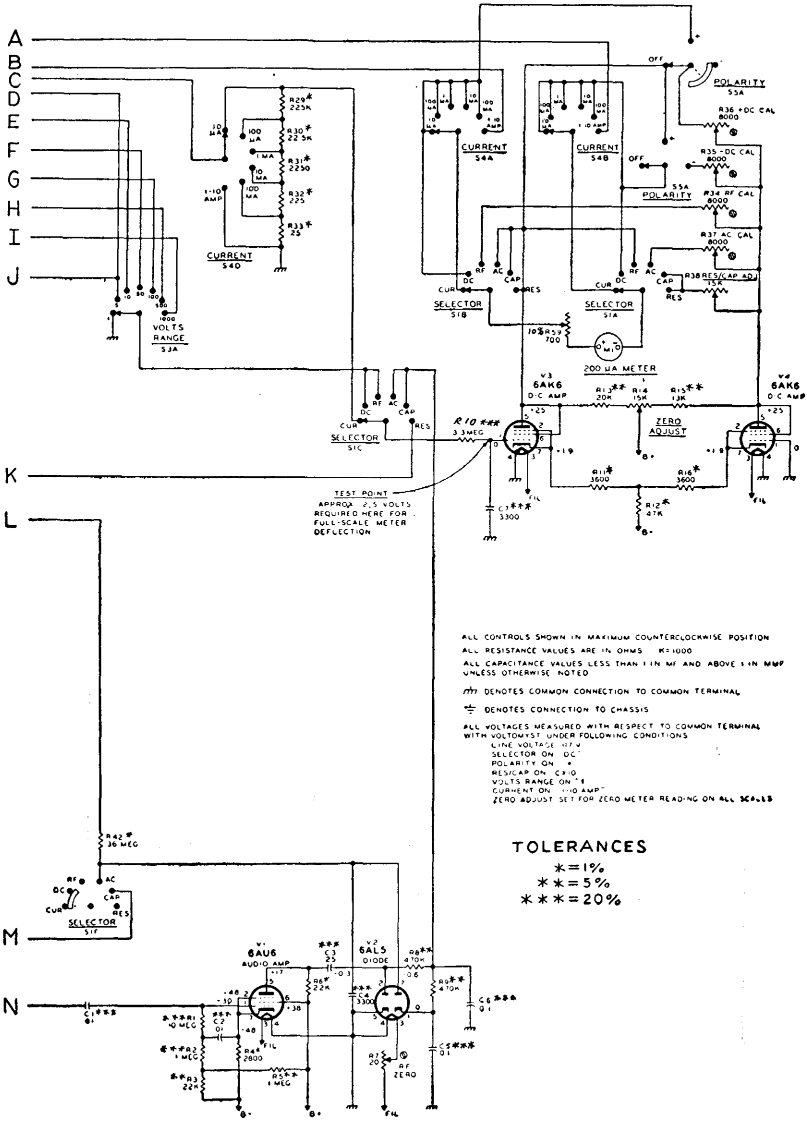
RCA Model WV-73A.



RCA Model WV-84A.


500M 500M 500M
204M
AF MULTIPLIER
TO DIODE PROBE
AC PROBE
6AL5
.05 82
47
RCA DIODE PROBE
DC PROBE
J7
1 AMP
R46 .270
J6
10 AMPS
R45 .030
OFF
POLARITY S5A,B
POLARITY S5A,B
A
B
C
D
E
F
G
H
I
J
K
L
M
N
VOLTS AC
10% R44 2.4
FIL
C9 .05
C8 .01
R43 36 MEG
J1
R39 4.5 MEG
VOLTS DC
R40 12.2 MEG
J2
RES/MA
DC
RF
AC
CAP
CUR
RES
SELECTOR S1E
SELECTOR S1F
R48 400K
R49 50K
R50 40K
R51 5000
VOLTS RANGE S3D
R28 5 MEG
R27 4 MEG
R26 500K
R25 400K
R24 50K
R17 40K
R18 5000
R19 4000
R20 500
R21 400
R22 90
R23 9.5
RES/CAP S2A
SHIELDS MINIMIZE RESIDUAL CAPACITY ACROSS UNKNOWN
TRANSFORMER SECONDARY
TO MEASURING CIRCUIT
UNKNOWN
STANDARD
FUNDAMENTAL CAPACITY-MEASURING CIRCUIT
J8
CAP
J4
COMMON
C10 .05
J5
CASE
T1
C14C 3-35
C16 .01
C14B 4-70
C14A 40-370
C15 820
C13 .09
C12 0.9
C11 9MF
RES/CAP S2D
RES/CAP S2C
R52 100K
V5 6X4 RECT
R58 10% 5600
C17C 20MF
C17B 20MF
C17A 20MF
R57 15K
R56 330
R54 330
R55 1000 AC ZERO
R53 20K
B+
B-
FIL
POLARITY S5A
F1 1 AMP
SELECTOR S1D
3 VOLTS

RCA Type



ALL CONTROLS SHOWN IN MAXIMUM COUNTERCLOCKWISE POSITION

ALL RESISTANCE VALUES ARE IN OHMS K=1000

ALL CAPACITANCE VALUES LESS THAN 1 IN MF AND ABOVE 1 IN MMF UNLESS OTHERWISE NOTED

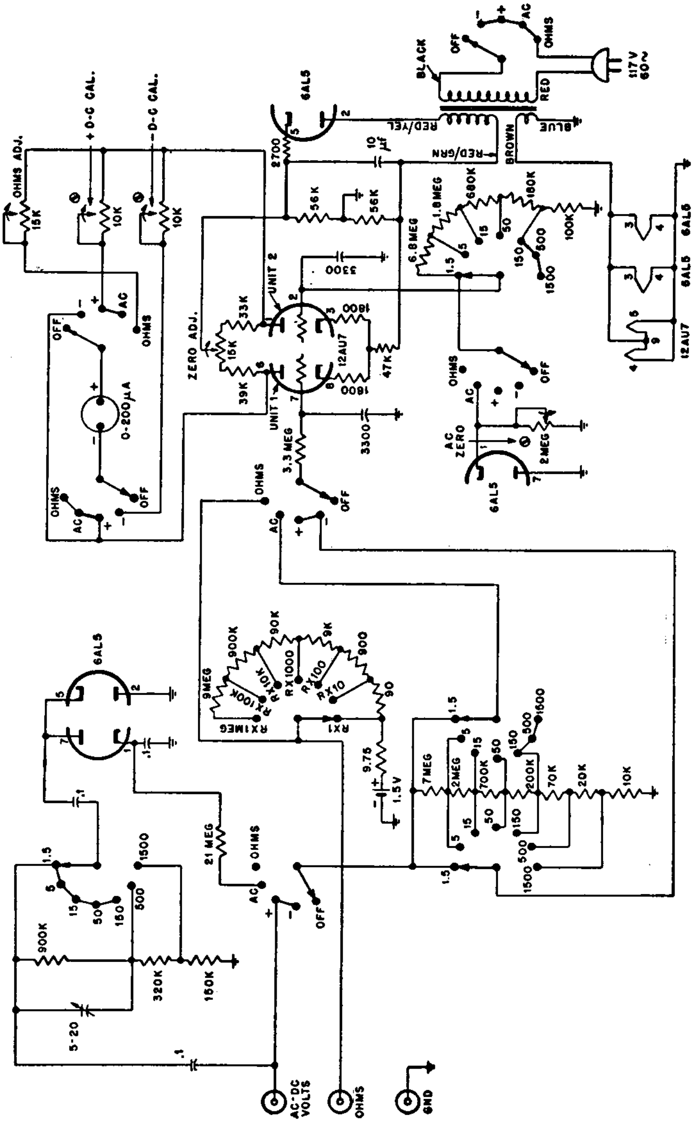
⏚ DENOTES COMMON CONNECTION TO COMMON TERMINAL

⏚ DENOTES CONNECTION TO CHASSIS

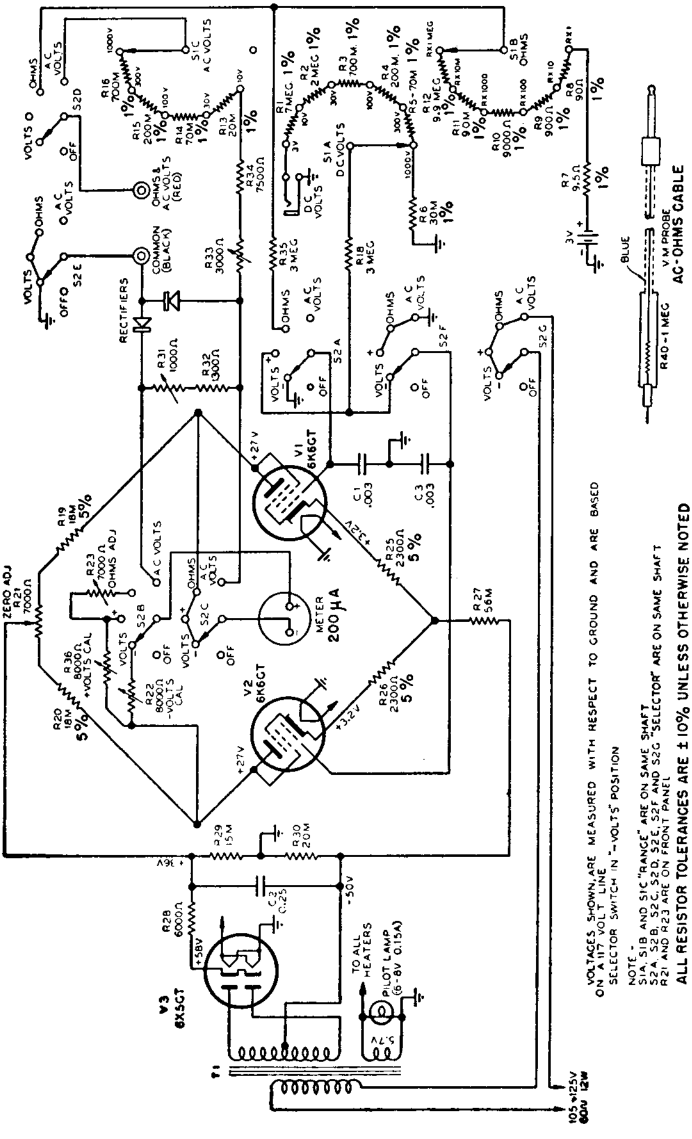
ALL VOLTAGES MEASURED WITH RESPECT TO COMMON TERMINAL WITH VOLTOMYST UNDER FOLLOWING CONDITIONS
LINE VOLTAGE 117 V
SELECTOR ON "DC"
POLARITY ON +
RES/CAP ON C×10
VOLTS RANGE ON "1"
CURRENT ON "1-10 AMP"
ZERO ADJUST SET FOR ZERO METER READING ON ALL SCALES

TOLERANCES
*=1%
**=5%
***=20%

WV-95A.



RCA Senior VoltOhmyst WV-97A.

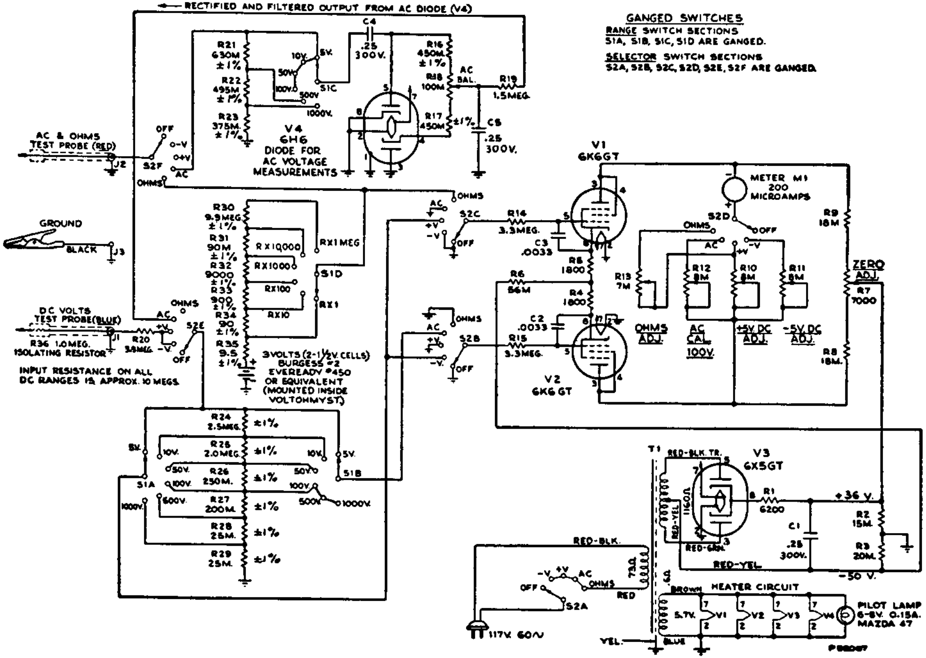


VOLTAGES SHOWN, ARE MEASURED WITH RESPECT TO GROUND AND ARE BASED ON A 117 VOLT LINE
SELECTOR SWITCH IN "-VOLTS" POSITION

NOTE -
S1A, S1B AND S1C "RANGE" ARE ON SAME SHAFT
S2A, S2B, S2C, S2D, S2E, S2F AND S2G "SELECTOR" ARE ON SAME SHAFT
R21 AND R23 ARE ON FRONT PANEL

ALL RESISTOR TOLERANCES ARE ± 10% UNLESS OTHERWISE NOTED

RCA Model 165A.

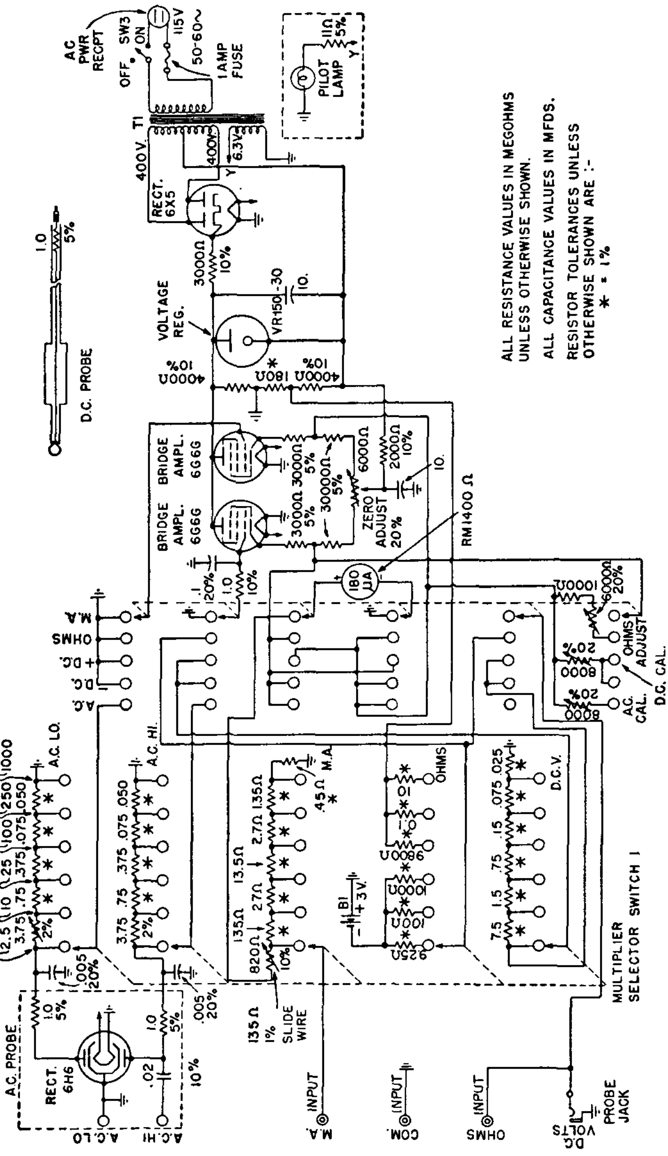


GANGED SWITCHES

RANGE SWITCH SECTIONS
S1A, S1B, S1C, S1D ARE GANGED.

SELECTOR SWITCH SECTIONS
S2A, S2B, S2C, S2D, S2E, S2F ARE GANGED.

RCA VoltOhmyst 195A.

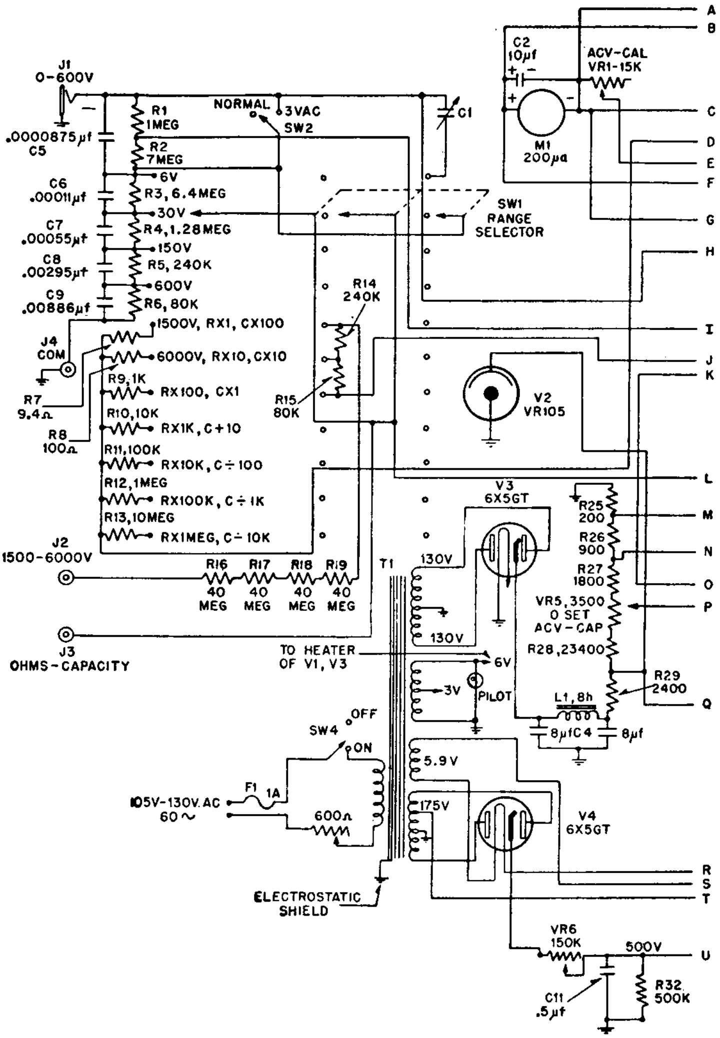


ALL RESISTANCE VALUES IN MEGOHMS UNLESS OTHERWISE SHOWN.

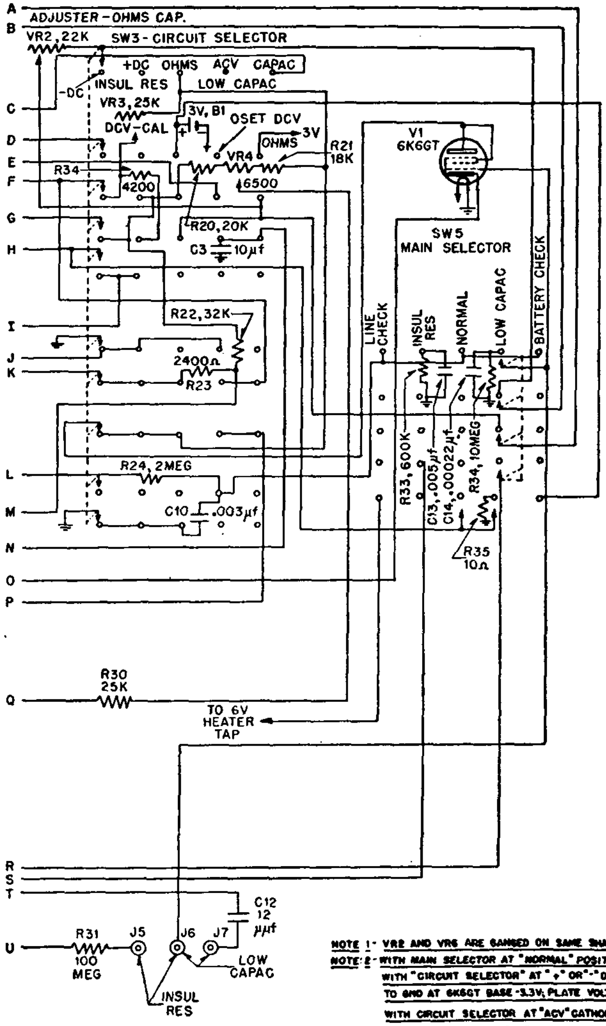
ALL CAPACITANCE VALUES IN MFDS.

RESISTOR TOLERANCES UNLESS OTHERWISE SHOWN ARE :-
* = 1%

Reiner Electronics Co. Model 451.



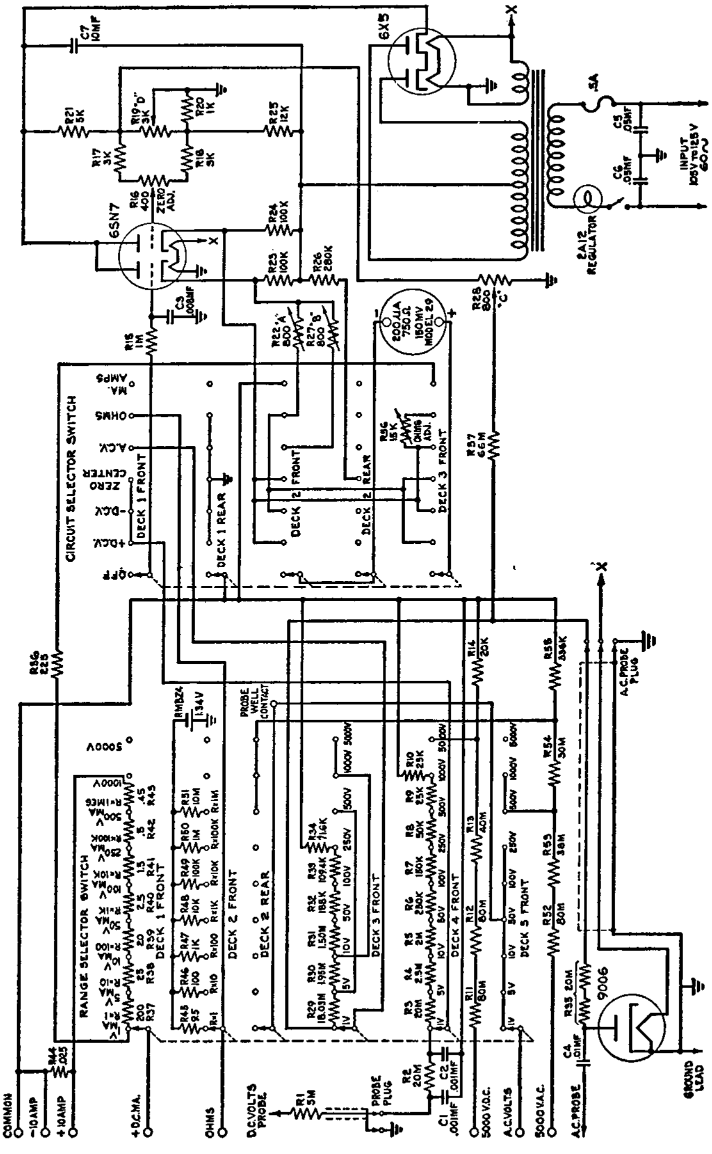
Radio City Products



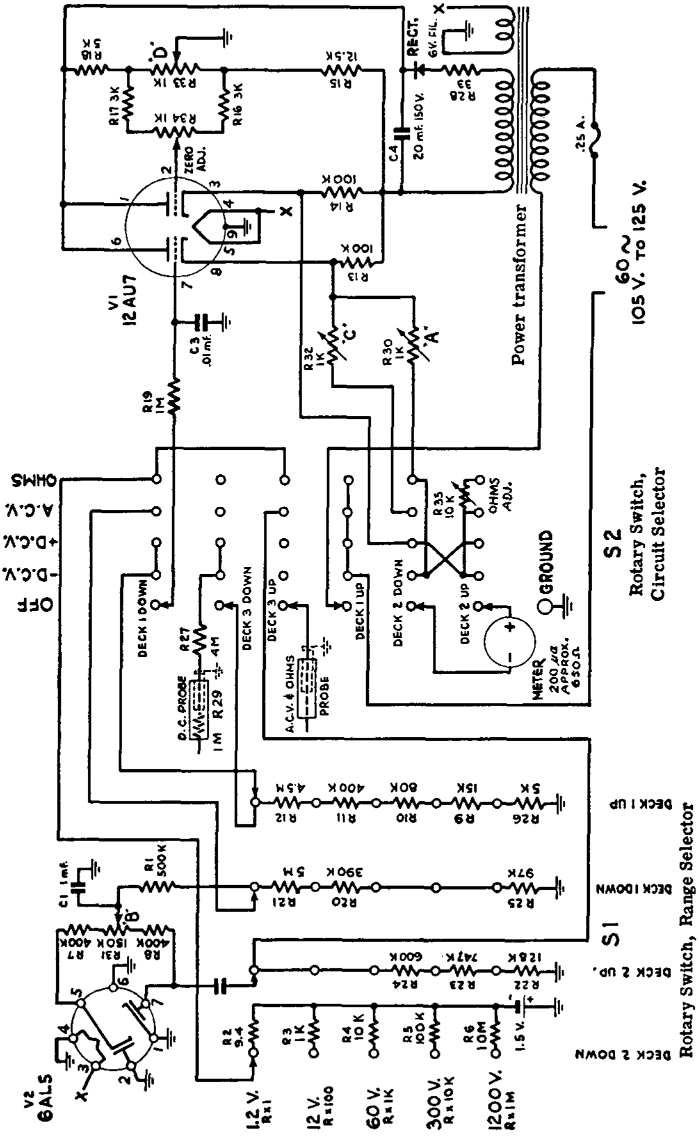
NOTE 1- VR2 AND VR6 ARE GANGED ON SAME SHAFT.

NOTE 2- WITH MAIN SELECTOR AT "NORMAL" POSITION AND WITH "CIRCUIT SELECTOR" AT "+" OR "-" DCV, CATHODE TO GND AT 6K6GT BASE-3.3V; PLATE VOLTAGE TO GND=30V WITH CIRCUIT SELECTOR AT "ACV" CATHODE VOLTS TO GND AT 6K6GT BASE-4.8V; PLATE VOLTAGE TO GND=22V VOLTAGES MEASURED WITH 20,000 OHMS PER VOLT METER OR ANOTHER MODEL 665A

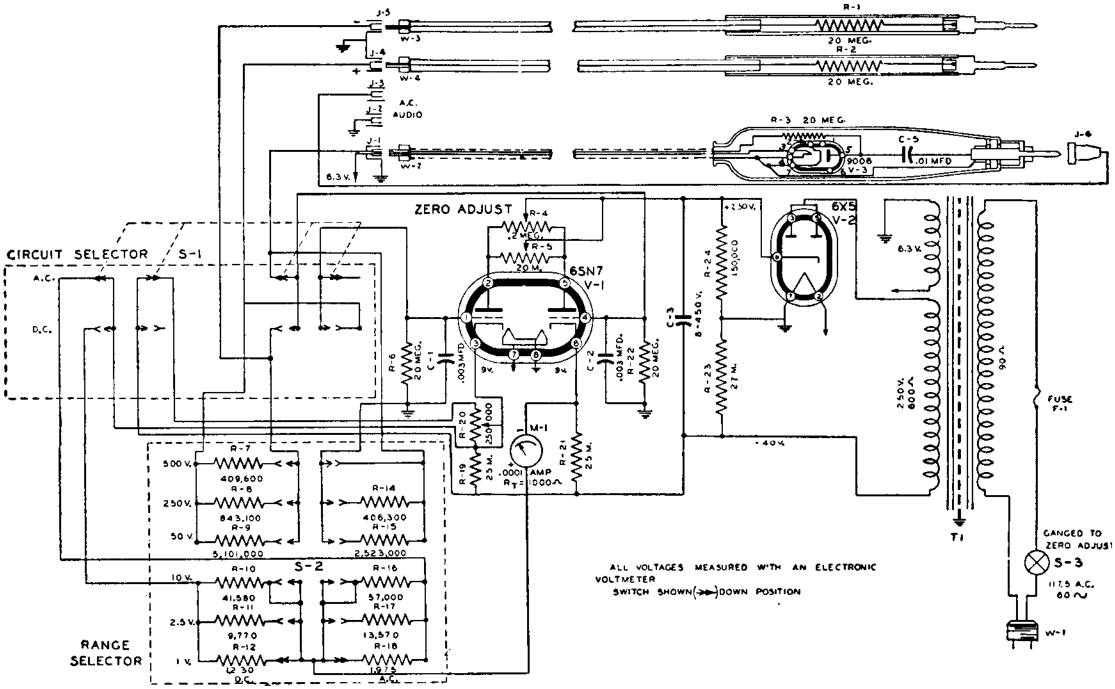
Model 665.



Simpson Electric Co. Model 266.

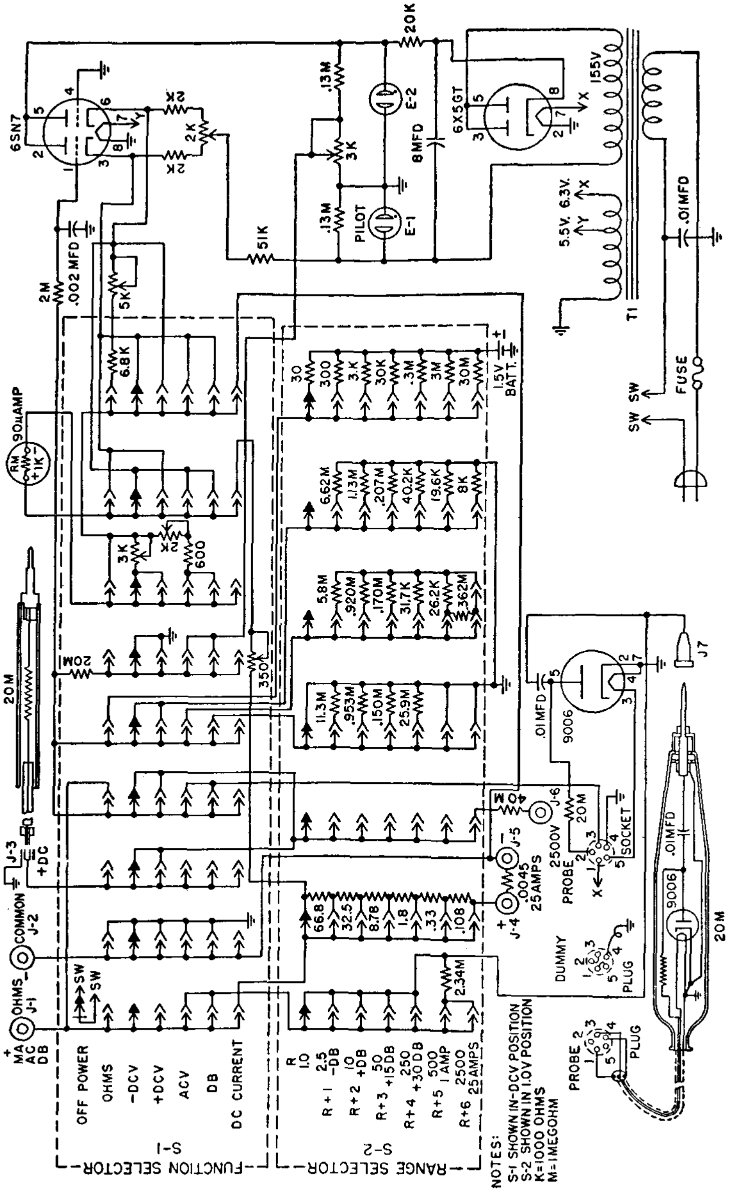


Simpson Electric Co. Model 303.

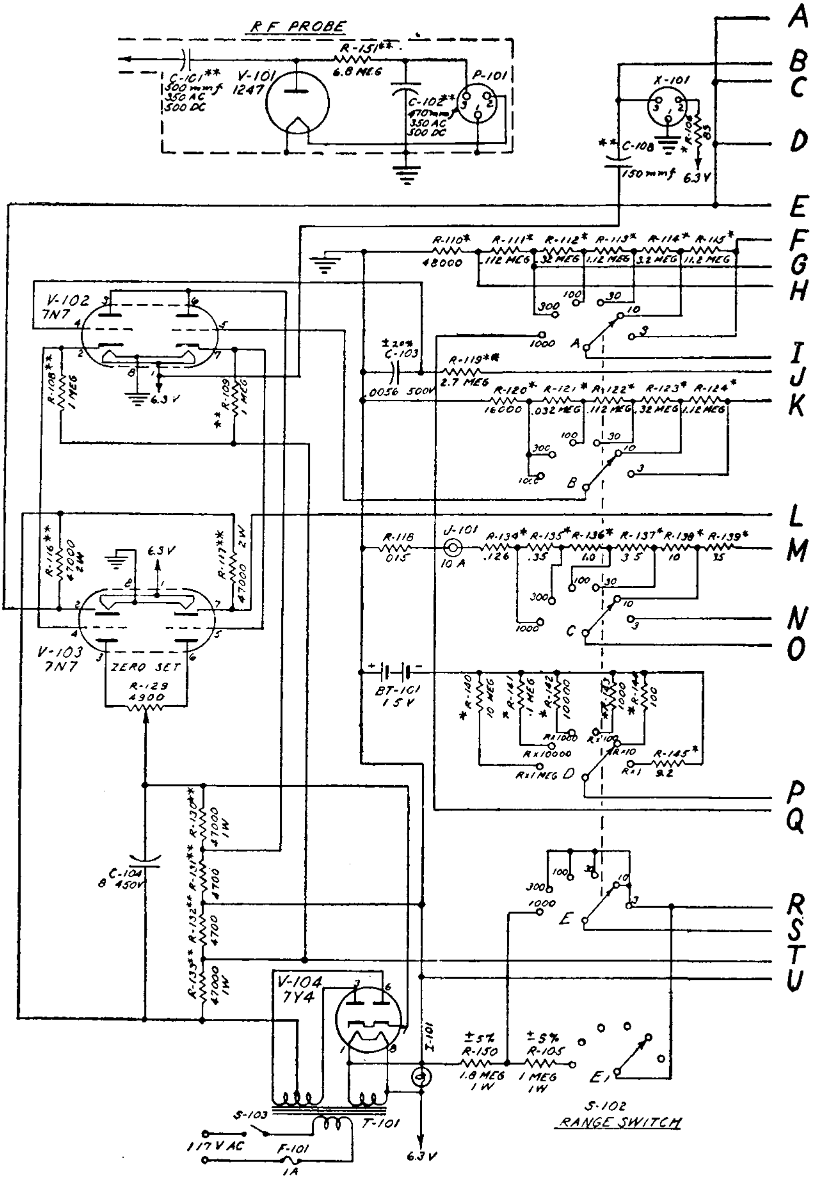


ALL VOLTAGES MEASURED WITH AN ELECTRONIC VOLTMETER
SWITCH SHOWN (→→) DOWN POSITION

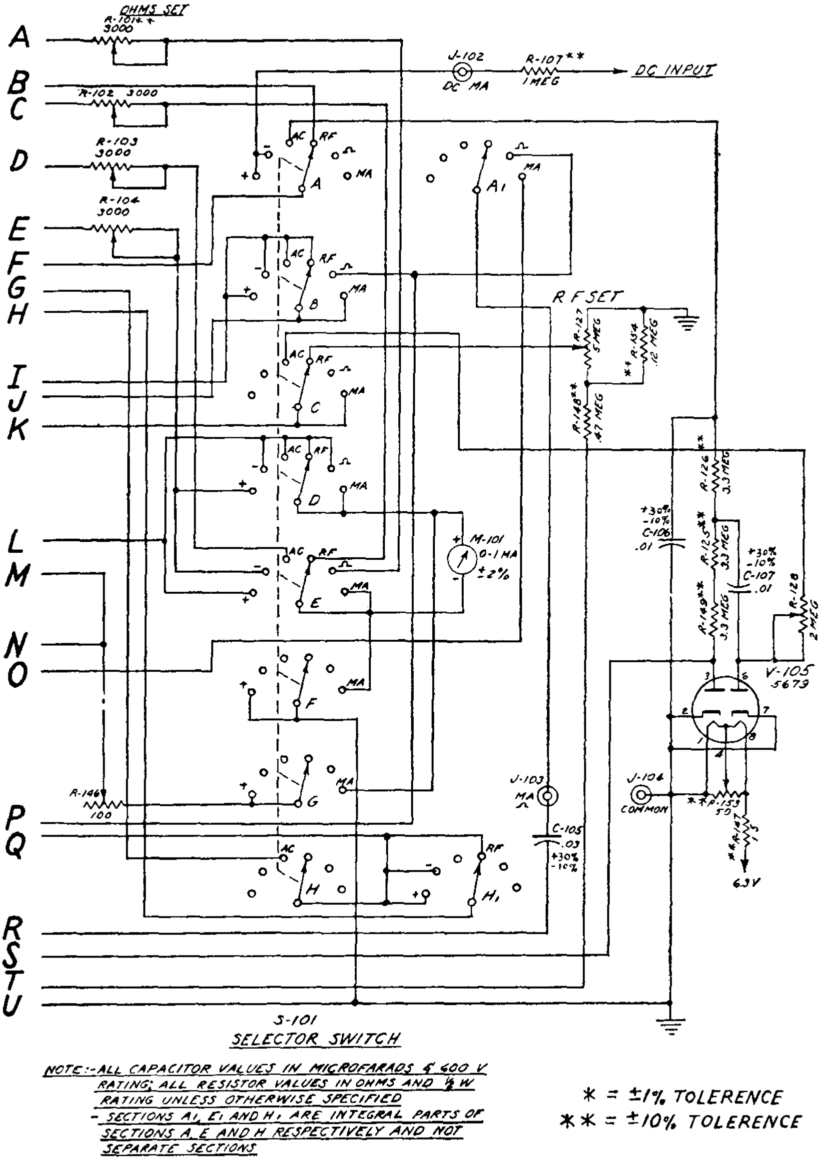
Supreme Instruments Corp. Model 565.



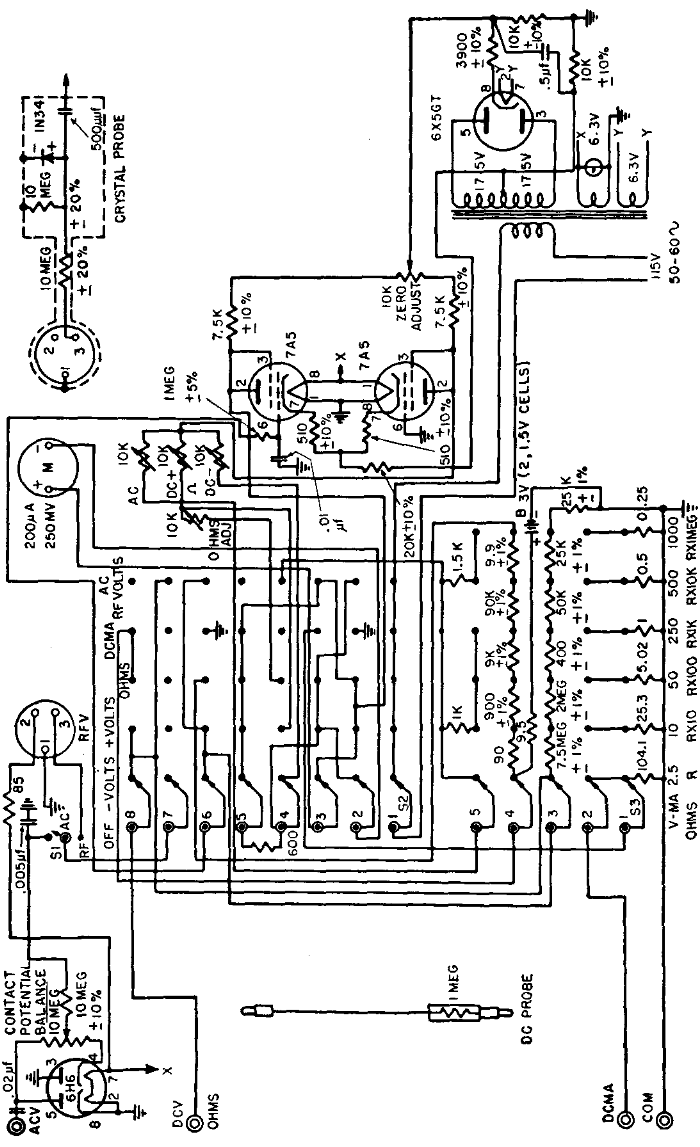
Supreme Instruments Corp. Model 574.



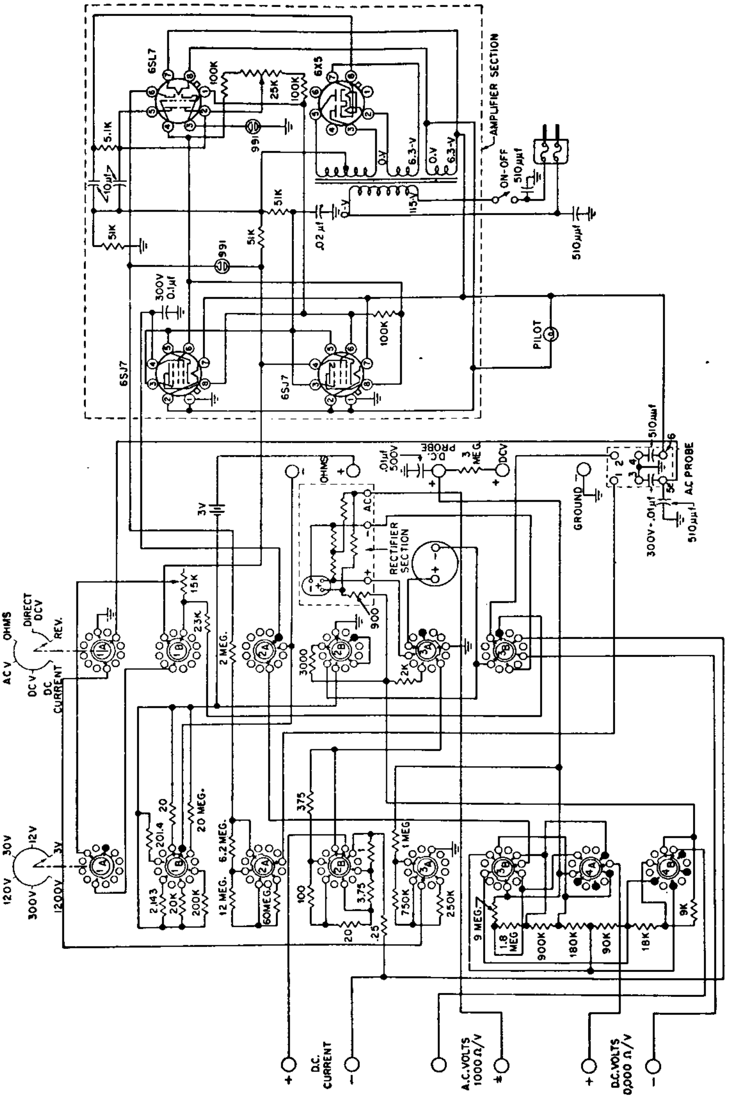
Sylvania Electric Products, Inc.,



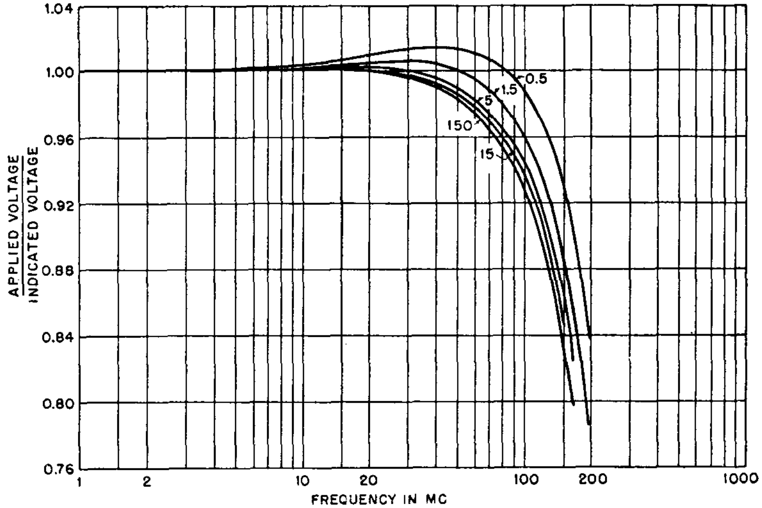
Polymeter Type 221.



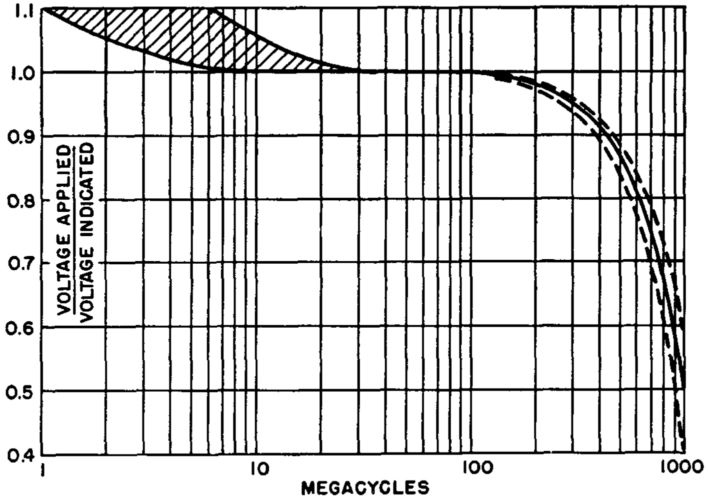
Triplett Electrical Instrument Co. Model 2451.



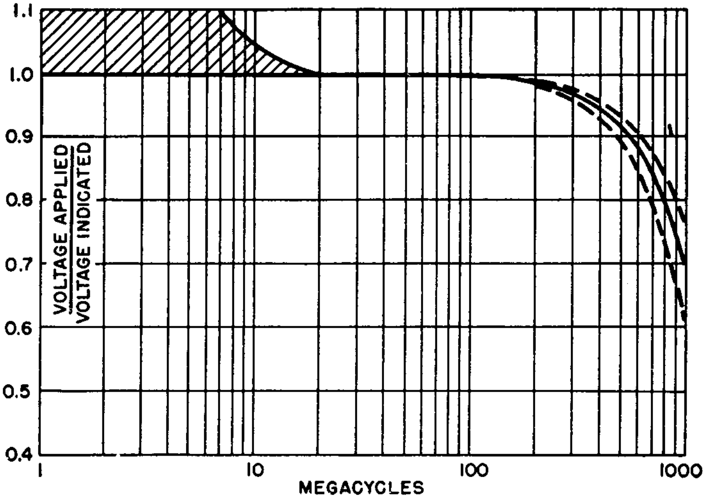
Weston Electrical Instrument Corp. Electronic Analyzer Model 769.



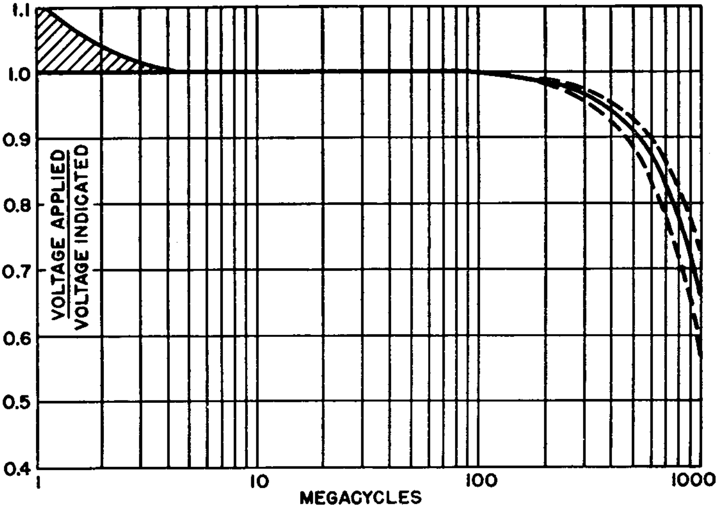
Frequency correction curves for the General Radio Co. model 726-A. To obtain the true input voltage, pick out the curve for the voltage range for which the meter is set, and find the ordinate value on the curve corresponding to the frequency of the input. Multiply the meter reading by the ordinate value to obtain the true input voltage.



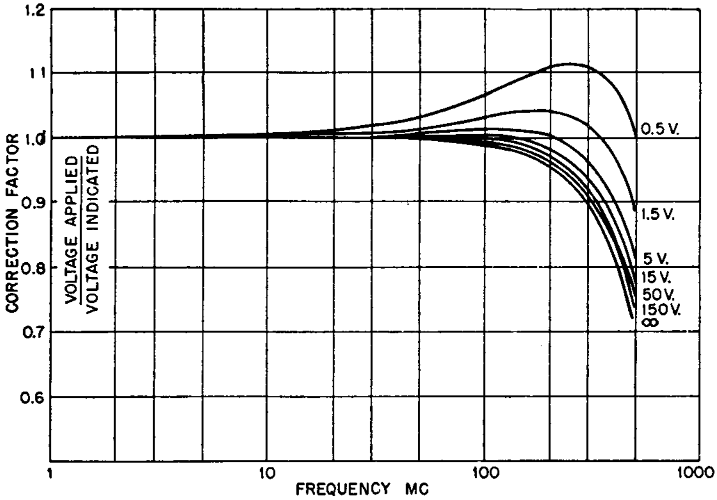
Frequency correction curve for 100-volt range of the General Radio Co. type 1802-A using the 100:1 multiplier in the probe. The possible range of variations for different crystals in the probe is indicated by the shaded area at the low-frequency side, and the dashed lines at the high-frequency side.



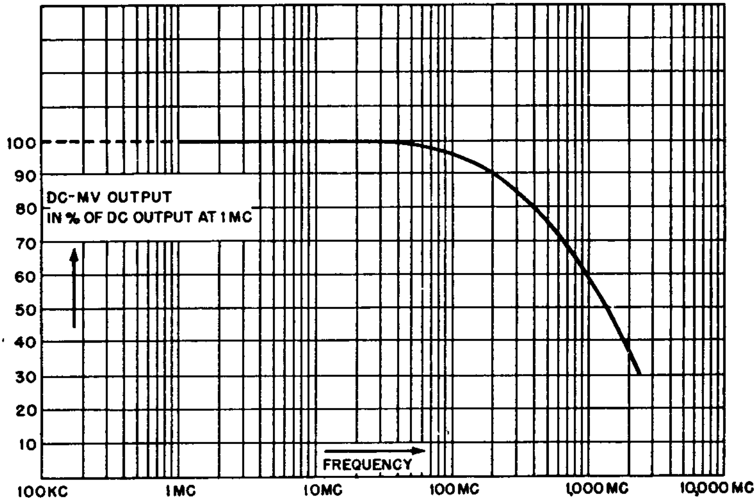
Frequency-correction curve for the 10-volt range of the General Radio Co. type 1802-A using the 10:1 multiplier on the probe.



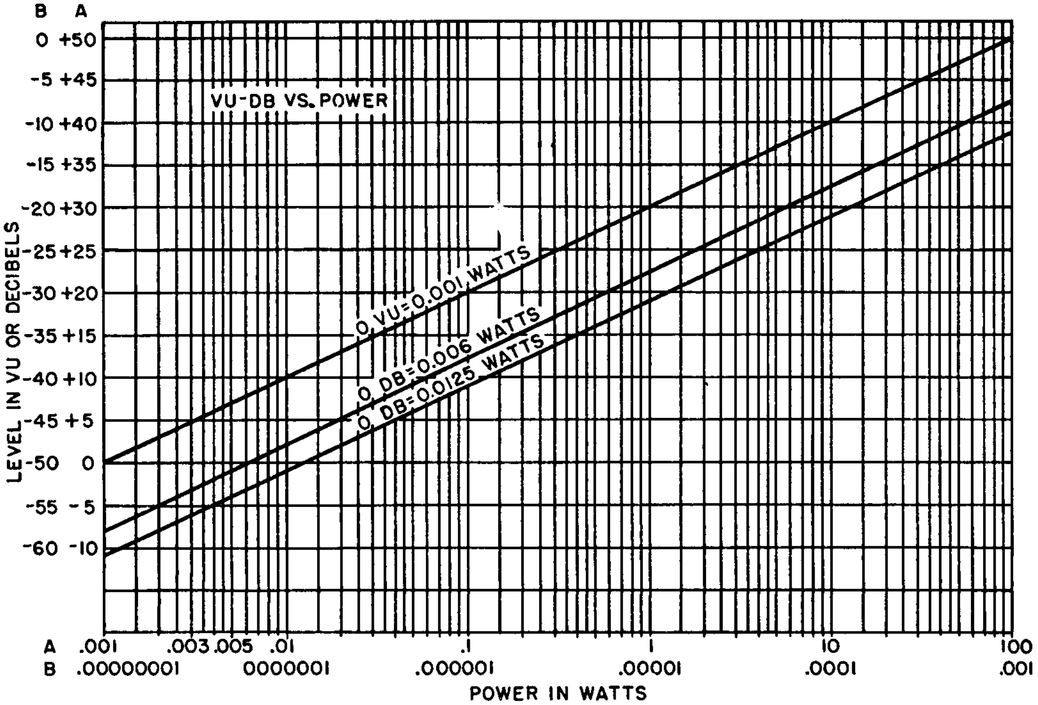
Frequency correction curve for the 1-volt range on the General Radio Co. type 1802-A using the probe without multipliers.



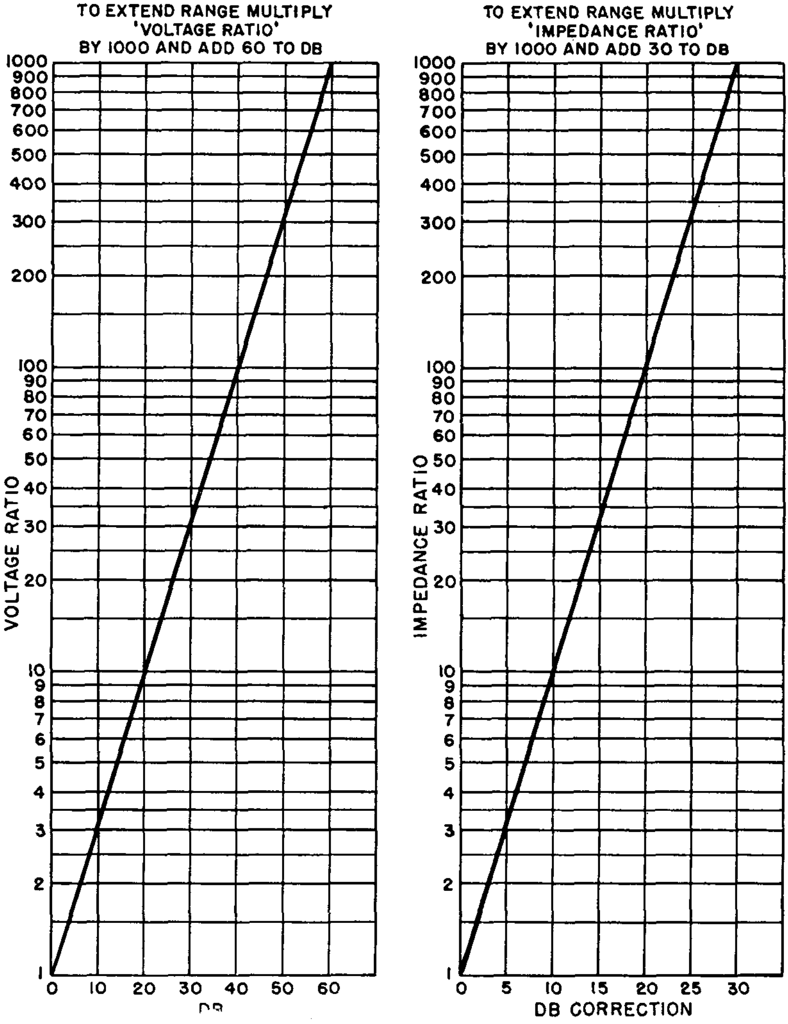
Frequency correction curves for the various ranges of the General Radio Co. model 1800-A. The curve marked ∞ shows the complete resonance effect. These curves were obtained with the cap on the probe.



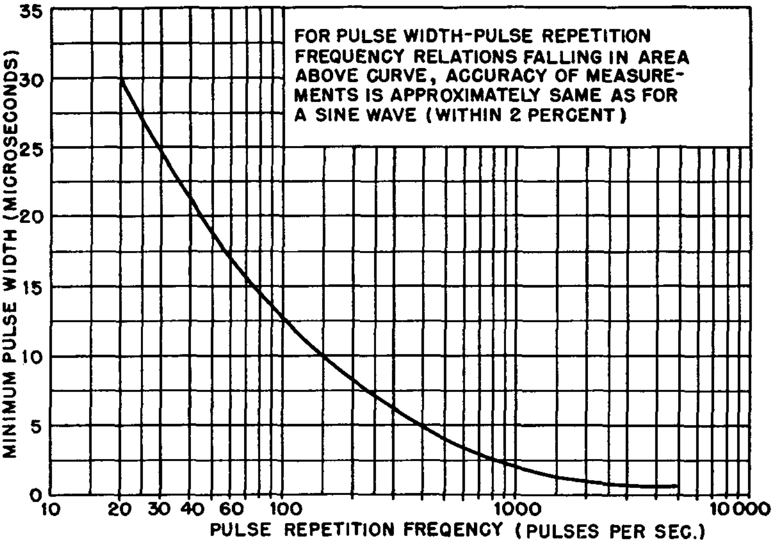
Frequency correction curve for the Millivac Instruments model MV-18B using crystal probes. When using the pseudo-thermocouple probe the d-c voltage must first be converted to r-f voltage and then the correction factor obtained from the above curve for the frequency of the measured voltage is used to multiply the r-f value for the true input.



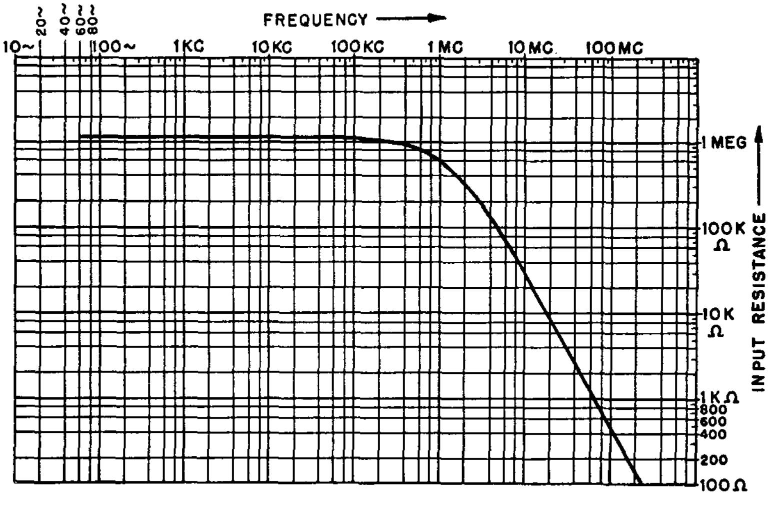
Decibel level versus power level conversion curves for the RCA VoltOhmyst 195-A. The correction curves for the three common power reference levels are included.



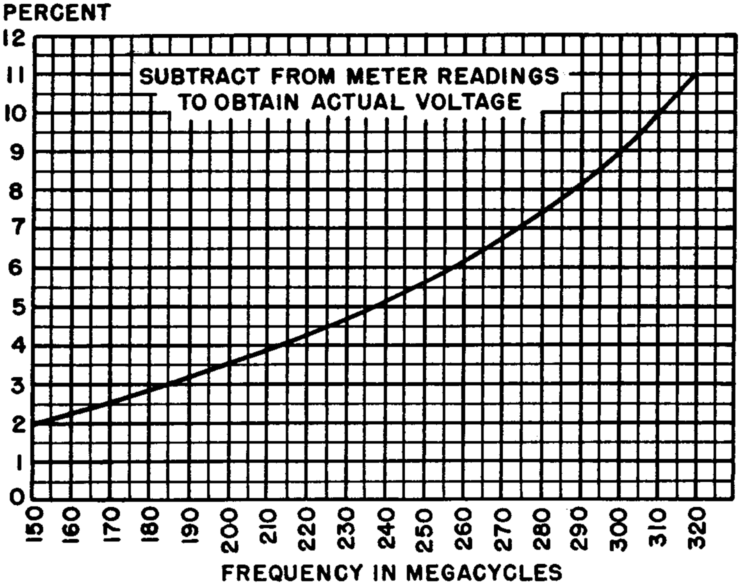
Conversion and correction curves for amplifier gain measurements with the RCA VoltOhmyst 195-A. On the left is the curve used to obtain gain in decibels from a voltage gain ratio. The voltage ratio equals the amplifier output divided by the amplifier input. For correction of different output and input impedances of the amplifier, the curve on the right is used. The impedance ratio equals the input impedance divided by the output impedance.



Curve indicating the limit of pulse-width—pulse-repetition frequency measurement possible with the RCA type WV-75A.



Input resistance versus frequency curve for the RCA type WV-75A.



Frequency correction curve for the Weston Electrical Instrument Corp. model 769. To obtain true input voltage for any frequency, multiply the reading by the percent factor obtained from the curve at the frequency value of the input signal. Then subtract this percent of the reading from the reading for the true voltage.

CHAPTER 14

MAINTENANCE AND REPAIR OF VACUUM-TUBE VOLTMETERS

In the previous chapters of this book will be found a great deal of information on the maintenance of v-t voltmeters in general. In this chapter will be given specific procedures to follow for the correction of particular troubles.

Vacuum-tube voltmeters in use today are in general rugged and well built instruments capable of operation under almost all conditions. Because of this, most meters will operate for long periods without needing any but the most superficial type of adjustments. These include the replacement of faulty components (batteries, tubes, pilot lights, etc.), calibration adjustments, etc. For more complicated servicing, most manufacturers advise that the meter be returned to the factory where more accurate adjustments can be made than at the average workshop. In any case, if the meter requires servicing within the time covered by the guarantee or warranty, it should be returned to the factory. Many manufacturers specify that they will not be responsible for the maintenance of a meter which has been tampered with within the time covered by the guarantee.

The procedures outlined in the first part of this chapter cover the maintenance necessary for most vacuum-tube voltmeters. In addition, in the section following the general procedures, will be found the specific maintenance data for these VTVM's for which the manufacturer has released such information. The data is reproduced exactly as the manufacturer furnished it, so that the procedures given here are actual factory repair procedures. Parts referred to in the maintenance notes may be found on the schematics in Chapter 13. Many manufacturers prefer to have their factories service the instruments they make when they are in need of repair. These manufacturers have not released maintenance data, however, the first part of this chapter on general maintenance procedures will apply to many of these meters. If the general maintenance procedures do not apply, write to the manufacturer describing, in detail, the trouble. He will then either prescribe a method for servicing the meter, or he will send instructions for shipping the meter to the factory for repair.

The calibration curves for many of today's popular commercial meters are furnished at the end of this chapter. They should be referred to when calibration adjustment is to be made on these meters.

General Maintenance Procedures

The procedures included in this section are applicable to the maintenance of most commercial VTVM's.

D-C Calibration

If the calibration of the d-c voltage scales of the VTVM has become inaccurate (due to the aging of tubes and components, etc.), the scales may be recalibrated using the following procedure:

1. Turn the power switch on and allow the instrument to warm up for at least 30 minutes.
2. Check the line voltage to be certain that it is the normal value for the instrument (most VTVM's are based on operation on a line voltage of 117 volts, 60 cycles).
3. Bring the needle to zero by adjusting the zero adjust control.
4. Turn the selector switch to the "+Volts" position, and the range switch to the scale for which a calibration adjustment screw is furnished; for most meters this is the most sensitive range. If no calibration adjustment screw is provided, and if none of the attenuator resistors are adjustable, either the voltage divider resistors will have to be checked, or the meter will have to be returned to the factory for calibration.
5. Connect the ground lead to the negative terminal, and the positive lead (a probe in some meters) to the positive terminal

of a *standard* d-c voltage source whose terminal voltage is equal to the full-scale voltage of the range used in 4 above.

6. Adjust the calibrating resistor for the scale used in 4 above until the needle points to the full-scale value. In most cases this variable resistor is in series with the micro or milliammeter, in some cases it is one of the bridge resistors in bridge amplifier circuits.
7. Turn the selector switch to "−Volts" (or reverse the input terminals), and adjust the calibrating resistor for the minus value of the scale used in 4.
8. Check other d-c ranges by using appropriate standard voltage sources. If any error is noted on these ranges the voltage divider circuit will have to be checked.

If a standard voltage source is not available for these measurements, but if another accurately calibrated VTVM is at hand, the accurate VTVM can be used to furnish readings of the voltage source used and the needle on the other meter should be adjusted to give the same readings.

A-C Calibration

If recalibration of the a-c ranges of the instrument becomes necessary the following procedure should be used (assuming that the proper adjustment controls are present):

1. Follow the procedure outlined under D-C Calibration for the recalibration of the d-c ranges, steps 1 to 3.
2. Turn the selector switch to "A-C Volts" and the range switch to the most sensitive a-c range.
3. Connect the meter to a *standard* source of 60-cycle ac with a value equal to the full-scale voltage of the range selected in 2 above.
4. Adjust the proper calibrating control until the needle reads the voltage of the standard correctly.
5. Using the proper standards, calibrate the higher voltage ranges, as was done in the D-C Calibration procedure.

If an a-c probe is furnished with the meter for use on all a-c ranges, the probe circuit may contribute to the error in calibration, so that the meter should be checked first with the probe attached.

After step 2 above, and with no signal on the a-c probe, the meter should read zero. If the reading is other than zero, the contact potential of the probe diode is not being "bucked" or balanced out correctly. If a balancing control is furnished, it should be adjusted until the needle is returned to zero. If a control is not furnished, the probe diode should be reversed or replaced, and if that doesn't help, the circuit elements should be checked.

Power Supply

If the voltage output of the power supply is lower than normal, or if there is no power supply voltage, the following should be checked:

1. Power supply tubes. Especially check to see whether the regulator tubes are glowing (only one plate if neon tubes are used).
2. Continuity and connections to power supply transformer.
3. Resistors and capacitors in power supply circuit. The d-c voltage across either of the filter capacitors (if there are two) should not exceed the rated output voltage of the power supply. If the d-c voltage across either of the filter capacitors is greater than the rated output voltage of the power supply, the *other* capacitor should be replaced, providing the filter resistors are good.
4. The setting on the power supply adjustment or potentiometer. With the correct value of line voltage, and if there is no other fault in the circuit, the setting should be changed so that the power supply voltage is the correct value.

Batteries

Almost all vacuum-tube voltmeters use batteries for the supply on their ohmmeter ranges (if such ranges are included in the meter). These batteries should be tested frequently if the resistance measurements are to be reliable. To test these batteries without removing them from the meter, set the meter selector switch to "Ohms" and the range switch to the lowest resistance range. Adjust the "Ohms Adjust" so that the pointer reads full scale. Clip the two resistance input leads together for about ten seconds, afterwards, separate them and if the meter needle does not immediately go back to full scale but lingers at a point almost half scale, the batteries should be replaced.

When replacing batteries be certain to clean all contacts thoroughly, and generally, it is a good idea to use the type batteries recommended by the manufacturer. *Batteries should not be left in the meter if they are weak,* chemical leakage may damage the instrument.

For battery-operated v-t voltmeters, in general, the batteries need replacement when the meter can no longer be set to zero by the zero adjust. After replacing these batteries the meter should be recalibrated as described in an earlier section in this chapter. Many battery-operated VTVM's have a neon pilot light which indicates whether the power is on or off. This neon light should "flash" continuously if the battery supply is in good condition. If the neon pilot lamp stops flashing, or slows down in its flashing, the batteries should be checked.

Tube Replacements

Extra care must be taken in the replacement of amplifier tubes for those meters using bridge-type amplifiers. If one tube is defective, both tubes in the bridge must be replaced by a pair of matched tubes. Both tubes should be aged together for the same length of time and under the same conditions.

The same condition holds for the diodes used in the rectifier circuit, if two separate diodes are used.

Generally, the replacement of the probe diode, especially in probes designed for high frequency measurements, is a difficult and sensitive operation. These probes are constructed with a minimum of free space to cut down on losses and for convenience of handling. Consequently, individual manufacturer's instructions must be followed to prevent damaging the probe when a tube is removed. Some typical instructions for probe tube removal follow:

For the a-c probe used with the RCA VoltOhmysts (see Fig. 9-6a) the following instructions should be followed:

1. Unscrew the streamlined cap from the rear end of the probe and push cap, washer, and bakelite cover onto cable.
2. Unscrew the hex nut at rear end of probe, being careful not to turn the bushing with respect to the probe body.

3. After hex nut has been removed, push the bushing into the probe body far enough to disengage locking pin from probe body.
4. Unscrew rear half of probe body from front half, and push back on cable. The 6AL5 (probe tube) will then be exposed, making examination or replacement possible. Should it become necessary to remove the diode socket and capacitor assembly, the disassembly process should continue as follows:
5. Unscrew the threaded bushing which holds the two halves together. This operation can be facilitated by inserting a nail, small screw driver or some other similar tool through the holes in the bushing.
6. After the bushing is removed, heat tip of probe with soldering iron until solder is melted. Then withdraw probe socket and capacitor assembly from rear of probe body.

   Caution—Do not attempt to unscrew the knurled ring at front of probe until step 6 of the above procedure has been completed.

The probe tube should be checked if the meter operates normally on d-c ranges, but not on a-c ranges. Low sensitivity, excessive zero drift, or failure to reach zero with the zero setting control are indications that the a-c ranges are not operating correctly. Another indication that the probe diode is defective is that the meter pointer will deflect sharply to the left when the selector switch is turned to the a-c voltage measuring position.

If a crystal is used in the probe it should be tested with an ohmmeter. Place the ohmmeter across the crystal (center probe tip and input lead from other side of crystal) and measure the front resistance. It should be less than about 1,500 ohms for most crystal probes. Reverse the ohmmeter leads and read the back resistance; this should be about 30,000 ohms or about 30 times as much as the front resistance.

General Precautions

Before removing a voltmeter from its cabinet a few simple checks will often expose the immediate cause of trouble. Be certain to check the following before doing anything else:

1. Check the power line source for proper voltage and frequency.

2. Test the power-supply cord for an open circuit or for poor contact in the power socket.
3. Check the fuses mounted in the meter, and be certain that they are tight in their clips.
4. Excessive heating, erratic operation, smoke or odor from the voltmeter may indicate a shorted filter capacitor or defective power transformer.
5. Failure of the meter to read on voltage ranges above a certain range indicates an open multiplier resistor.

Calibration and Correction Curves

Although many meters claim to be capable of measurements up into the 1,000 megacycle range, the readings on the VTVM scales are not linear to these frequencies. Meters having wideband amplifiers and high frequency probes capable of high-frequency measurement generally furnish calibration or correction curves to be used with the meter reading to find the correct voltage measured. Some of these curves are reproduced in Chapter 13.

Also among these figures are included conversion curves for changing db's and VU's to watts, and a Pulse Width versus Pulse Repetition Rate curve.

MANUFACTURERS' PROCEDURES

The maintenance procedures given in this section were furnished by the manufacturers of commercial VTVM's for use with their meters. They are described alphabetically by manufacturer and model.

Clippard Model 406

To take instrument from cabinet simply remove screws from outer edge of panel, feed A.C. cord thru rear of cabinet and pull panel straight forward. Tubes and battery are now easily accessible and may be replaced when necessary.

In replacing tubes be sure that tubes are good, have practically no gas current, are reasonably balanced between sections and that cathode heater leakage is at a minimum. Otherwise on +D.C. or −D.C. setting you may find that the adjust zero range is insufficient to return meter to zero, or in cases of gas content, variation in zero meter reading on 1 volt D.C. scale will be noted when D.C. probe is grounded and then open-circuited. Many times, inasmuch as production runs of the type SN7 tubes are predominantly unbalanced in the same direction, swapping tubes in the position V2 and V3 will compensate to a great extent and permit ample range of zero meter adjustment.

Replace battery with single large-sized flashlight cell in ohmmeter power supply when unable to adjust full scale deflection of ohmmeter.

To replace 6AL5 tube in standard A.C. probe remove 2 screws in rear of bakelite housing adjacent to cord, slide bakelite cap back along cord and, holding polysterene nose piece in hand, slide back insulated brass tube (sleeve) and remove tube from socket.

Coastwise Electronics Model 730

Tube replacement will become necessary in time. When either 12AU7 is replaced it is necessary to recalibrate the instrument; proceed in the following manner: Allow the unit a warm-up period of 30 minutes, then calibrate +DC and −DC on 3-volt scale. Short the two leads and rotate the ZERO ADJ. until the meter reads zero, then with meter leads across a standard 3-volt dry cell, rotate potentiometer R39 until full scale deflection is read. Repeat the same procedure for −DC and rotate potentiometer R40. If this calibration is made correctly all scales will read accurately.

To recalibrate on AC or audio, rotate selector switch to audio and range switch to 10-volt scale. Short the leads and zero the meter, then with 10-volt AC source adjust potentiometer R42 until the meter reads full scale. All scales should read correctly on AC if the calibration has been made accurately.

For R. F. calibration, set the selector switch to R. F. and the range switch to 1 volt. Then short the R.F. probe to ground and zero the meter. With an accurate 1-volt R.F. source, adjust potentiometer R43 until full scale deflection on special 1-volt scale. Then all R.F. scales should read correctly.

General Electric Type PM-17

If it is necessary to replace any tubes, the following precautions should be observed: Before attempting to make any readjustments, the new tube should be inserted in the PM-17 and allowed to warm up at least one-half hour.

When replacing the 6SN7, set up the PM-17 to measure ohms, checking the pointer at zero and full scale. Rotate the range switch over the ohms ranges with the pointer at full scale and note the position of the pointer at each step. Should the pointer position change more than one division on the DC volt scale, another 6SN7 should be substituted. Excessive movement of the pointer indicates that current is being drawn.

When replacing the 6AL5 tube, set up the PM-16 to measure DC volts and adjust the pointer to zero. With the test prods still shorted, rotate the polarity switch to AC and readjust the pointer to zero by means of the AC zero control located nearest the power transformer on (the chassis deck). When replacing the 6AL5 tube, it is usually unnecessary to recalibrate the AC circuit. Adjustment of the AC calibration control (on the chassis deck) should not be attempted unless reliable standards are available. The AC circuit is calibrated at 30 volts, 400 cycles.

If at any time the zero setting of the pointer should vary more than 10% of the DC scale when the polarity switch is changed from AC to DC +, the AC zero control should be adjusted as described in the previous paragraph.

General Radio Type 1800-A

General—If the voltmeter becomes inoperative, a few simple checks should be made before removing the instrument from its cabinet.

1. Check the power line source for proper voltage and frequency.
2. Test the power-supply cord for an open circuit or for poor contact in the power socket.
3. Check the fuses mounted on the panel for open circuits, and be sure that they are tight in their clips.

Meter Lamps Do Not Light—

1. Test fuses F-1 and F-2 for open circuits.
2. Check lamps P-1 located in meter case.
3. Check contacts and operation of power switch S-2.
4. Check connections to and continuity of transformer T-1.

Meter Does Not Move Upscale and Return to Zero When the Voltmeter is Turned on With VOLTAGE RANGE Switch Set to 0.5—

1. Check tube V-3 and operating voltages.
2. Check operation of switch S-1.
3. Check resistors R-10 and R-11 for open and short circuits.
4. Check condensers C-2 and C-3 for open and short circuits.
5. Defective meter M-1. Nominal sensitivity is 100 microamperes d.c. for full scale deflection.
   If the meter is defective, a replacement should be ordered from the Service Department. The General Radio Company cannot assume responsibility for any local repairs to the meter, although such repairs may be necessary in an emergency.
6. Check tube V-4 and operating voltages.
7. Check resistors R-29, R-30, R-36, R-37, R-38 and R-39 for open and short circuits.
8. Check resistors R-12, R-13, R-21 and R-22 for continuity.
9. Check switch S-3 for continuity and proper operation.

Unable to Set Meter to "0" With ZERO Control, Voltmeter Set to D-C—

1. Check the d-c voltage between B+ and B− to be 450 volts ±5.0 volts.
2. Check resistors R-33, R-34 and R-35 for open and short circuits.
3. Check that tube V-3 has low grid current. This can be done by the following procedure:
   (a) Set the switches for the 0.5-volt d-c range.
   (b) Place the connecting link across the D-C OPEN GRID terminals.
   (c) Adjust the meter to zero with the ZERO control or the COARSE ZERO adjustment.
   (d) Short circuit the D-C 10 MEGΩ terminals. The meter reading should not be more than .015 volt.
   (e) Remove ballast tube V-2 from its socket.
   (f) With the short circuits still across both sets of D-C terminals, adjust the meter to read 0.2 volt using either the ZERO control or the COARSE ZERO adjustment.
   (g) Turn switch S-1 to A-C. The meter should not vary by more than ten scale divisions above or below the 0.2-volt

reading. The reading should stabilize within a few seconds and the meter should show no drift.

(h) If the tube fails to pass any of the above tests it should be rejected in favor of another tube.

Unable to Set to "0" With ZERO Control, Voltmeter Set to A-C—

1. Refer to previous instructions and those given under Power Supply.
2. Check tube V-1 and operating voltages.
3. Check that the cathode of V-1 is grounded to the shell of the probe.
4. Check resistors R-1 and R-2 for open and short circuits.
5. Check tube V-2 for continuity and operating voltages.
6. Check resistors R-5 through R-9.
7. Check tube V-5 and operating voltages.
8. Check resistors R-31 and R-32 for open and short circuits.
9. Check operation of switch S-1.
10. If it is necessary to replace either or both V-1 and V-5, try various tubes until tubes are found which will permit a satisfactory zero adjustment.

Meter Does Not Read With D-C Signal Applied to the 10 MEG-OHM Input Terminals—

1. Be sure that the connecting link is shorting the OPEN GRID terminals.
2. Check resistor R-4 for a short circuit.
3. Check resistor R-51 for an open circuit.
4. Check condenser C-7 for a short circuit.

*Meter Does Not Read With D-C Signal Applied to the OPEN GRID Input Terminals—*Be sure that the connecting link is shorting the 10 MEGΩ terminals.

*Meter Does Not Read With A-C Signal Applied to Input Terminals—*Check condenser C-1 for an open or a short circuit.

Meter Reads Incorrectly on One or More Voltage Ranges—

1. Check meter sensitivity. Full scale sensitivity of the meter, shunted by R-52, is 102 microamperes dc. R-52 is picked in the standardizing laboratory to provide this value of sensitivity.

2. D-C measurements: Check resistors R-21 through R-28 or try changing tube V-3.
3. A-C measurements: Check resistors R-12 through R-20, or try changing tubes V-1, V-3 and V-5.
4. Check calibration of 0.5 and 1.5 volt VOLTAGE RANGE.

Recalibration—

1. Accurately known sources of a-c and d-c voltages should be available before attempting any recalibration of this instrument.
2. Check zero adjustments.
3. Check the d-c voltage between B+ and B−, it should be 450v.
4. D-C Calibration:
   (a) Set VOLTAGE RANGE switch to the 0.5- and 1.5-volt positions and apply the corresponding d-c voltage to the D-C 10 MEGOHM input terminals with the connecting link shorting the OPEN GRID terminals.
   (b) Set the meter to full scale by means of potentiometer R-22 for the 0.5-volt range, potentiometer R-23 for the 1.5-volt range. These are marked D. C. CAL, 0.5 v and 1.5 v, respectively, on the bottom subpanel.
5. A-C Calibration:
   (a) Set VOLTAGE RANGE switch to the 0.5- and 1.5-volt positions and apply the corresponding sine-wave, root-mean-square, a-c voltages to the A-C input terminals.
   (b) Set the meter to full scale by means of potentiometer R-13 for the 0.5-volt range and potentiometer R-14 for the 1.5-volt range. These are marked A.C. CAL, 0.5 v and 1.5 v, respectively, on the bottom subpanel.

Power Supply Inoperative or Has Low Output Voltage—

1. Check tubes V-6, V-7, V-8, V-9 and V-10 and operating voltages. Note that one plate each of V-9 and V-10 glows evenly.
2. Check connections to and continuity of transformer T-1.
3. Check resistors R-40 through R-50 for open and short circuits.
4. Check condensers C-5 and C-6. NOTE. The d-c voltage across either one of these condensers should not exceed 425 volts maximum. If the voltage across either condenser exceeds 425

volts the *other* condenser should be replaced, assuming that R-49 and R-50 are not defective.

5. The output voltage of the power supply, as measured between B+ (slate-red wire) and B− (yellow-green wire) on the terminal strip on the right side of the instrument above the power receptacle, should be set to 450 volts ±5.0 volts, dc, as measured with a 20,000 ohm-per-volt voltmeter.
   - (a) Set the input line voltage to 100 volts, ac.
   - (b) Adjust potentiometer R-45 until B+ voltage reads 450 volts.
   - (c) Increase the line voltage to 130 volts.
   - (d) Adjust potentiometer R-43 until B+ again reads 450 volts.
   - (e) Repeat the above procedure until the B+ voltage remains constant for any input voltage between 105 and 125 volts.

Replacement of Components—Due to the compact design and construction of this instrument and the number of component parts mounted in the available space, a number of mechanical expedients have been used. The following instructions should be followed when replacement of component parts is necessary.

1. Probe
   - (a) Unscrew spring ring at rear of probe.
   - (b) Pull back black phenolic housing.
   - (c) Rotate the rotatable metal shield exposing tube V-1.
   - (d) Remove tube V-1.
   - (e) Unscrew the banana plug probe and the retaining hex nut at the front of the probe.
   - (f) Unscrew and remove the three black-headed screws in the retaining plate.
   - (g) Remove the retaining plate.
   - (h) Remove the snap ring holding the inner assembly in place using a pair of thin, long-nosed pliers to squeeze the ends of the ring together.
   - (i) Unscrew the metal cap at the front of the probe and *pull back* the rotatable metal shield.
   - (j) Unsolder the joint holding the inner suspension to the metal shell.
   - (k) Remove the entire inner assembly by pulling on the cable, being careful not to damage R-1 and R-2 which are now supporting C-1.

CAUTION: *When using a soldering iron to replace components, be careful not to overheat the insulating blocks of polystyrene at the front and rear of the inner assembly as these melt at a relatively low temperature.*

2. Main instrument
   (a) Remove the four screws that hold the subpanel on which the tubes are mounted to the four bakelite mounting posts.
   (b) Unsolder the two black covered wires that run from the socket of V-3 to switch S-1. These points are marked "X" in the photographs.
   (c) The subpanel can now be laid back toward the input terminal end of the front panel to expose most of the component circuit elements.

Vacuum-Tube Data—The table below lists tube socket voltages measured from socket pin to ground, unless otherwise indicated, using a 20,000 ohm-per-volt meter (Weston 772 Analyzer). D-C voltages may vary ±20%.

Sym.	Type	Socket Pin Number								Function
		1	2	3	4	5	6	7	8	
V-1	9005	1 and 5 3.2–3.9v AC		−0.75						Diode Rectifier
V-2	Ampherite 3−4		2 & 7 5.8v AC							Ballast Tube
V-3	6SL7GT		162	1.35		162	1.35	7 & 8 6.3v AC		D-C Amplifier
V-4	6SL7GT	−212	1.35	−215	−212	1.35	−215	7 & 8 6.3v AC		Degeneration Tube
V-5	9005	1 & 4 3.2–3.9v AC	−0.05	−0.25						Balancing Diode
V-6	6C4	300		3 & 4 6.3v AC			132	162		Regulator
V-7	6AT6	0.25	47	3 & 4 6.3v AC				132		Regulator

Sym.	Type	Socket Fin Number								Function
		1	2	3	4	5	6	7	8	
V-8	6X5GT/G		2 & 7 6.3v AC	470v AC		470v AC				Rectifier
V-9	991	62v Dc across terminals								Neon Regulator
V-10	991	65v DC across terminals								Neon Regulator

CONDITIONS: Input—115v – 60 cycles.
Switch S-1 set to DC, D-C input terminals short-circuited.
VOLTAGE RANGE switch set to 0.5.
B+ set for 450 volts, dc.

General Radio Type 1802-A Crystal Galvanometer

General—If the Crystal Galvanometer does not operate properly, a few simple tests should be made before removing the instrument from its cabinet.

1. Test crystal (GR Type 2DEC-5) (RMA Type 1N21-B). The crystal can be measured by connecting an ohmmeter between the chassis binding post to which the black probe lead is connected and the center terminal of the probe. *CAUTION:* Do not use an ohmmeter having a battery with a voltage greater than 1.5 volts.

   The front resistance should be less than 1500 ohms and the back resistance greater than 20,000 ohms. The ratio of the back to the front resistance should be 30:1 or greater. A damaged or defective crystal may be detected by a loss in sensitivity, an increase in forward resistance, and a decrease in back resistance. To replace crystal use method described later in these instructions.
2. Check power line source for proper voltage and frequency.

Meter Will Not Indicate Full Scale and Return To Zero When The Switch is Turned On—

1. Check batteries B-1 (1.5 volts) and B-2 (22.5 volts each section).
2. Check tube V-1 and measure operating voltages.
3. Check operation of Switch S-1.

4. Test ZERO adjustment potentiometer R-4 and CAL adjustment potentiometer R-3 for continuity and resistance.
5. Defective Meter M-1. This should read full scale with 100 microamperes dc applied. If the meter is defective, a replacement should be ordered from the Service Department. The General Radio Company cannot assume responsibility for any local repairs to the meter, although such repairs might be necessary in an emergency.
6. If the meter indicates full scale only or drifts badly, short circuit the red and black leads from the probe at chassis binding posts. If the meter returns to zero, test the probe for open circuits.
7. Resistor R-6 open.

Unable to Set "0" With ZERO Adjustment—

1. Defective ZERO adjustment potentiometer R-4.
2. Resistor R-6 open.
3. Check resistors R-1 and R-2 for continuity.
4. Check probe continuity. With a 4.5-volt ohmmeter connected across the chassis binding posts of the red and black probe leads, a reading of from 0.5 to 2 megohms will indicate proper continuity.

   Check resistors R-21, R-22 and R-23 for continuity and proper values, carefully following directions for disassembling probe. Be sure that the two spring contacts in the probe make positive contact.
5. Erratic zero may be caused by defective batteries.

Meter Does Not Indicate With Signal Applied to Probe—

1. Test capacitors C-1 and C-3 for open or short circuits.
2. Check for short circuits in probe circuit. If measured resistance is noticeably less than 0.5 megohm, test for shorts in probe cable and probe.

   After carefully disassembling probe check capacitors (sleeves in probe), C-21 and C-22, for short circuits.
3. Test crystal.

Cannot Set Meter to Red Line With CAL Adjustment—

1. Adjust the power line voltage to exactly 115 volts, 40 to 60 cycles. This value is necessary in order that the calibration

voltage will be exactly 0.7 volt. The calibration voltage can be measured by connecting a vacuum-tube voltmeter between the probe jack in the top compartment and the binding post on the chassis to which the black lead of the probe is connected. This voltage should be 0.7 volt. If this voltage is not correct, test R-7, R-8 and R-9 for open and short circuits and proper values. Also test capacitor C-2 and choke L-1 for the same points.

CAUTION: *Always disconnect the source of calibrating voltage before attempting to use the probe and galvanometer to measure any voltages; otherwise, serious damage may result to the probe condensers.*

2. Test CAL potentiometer R-3 for continuity.
3. Test crystal as previously outlined.

Disassembly of Probe—

1. Unscrew the cable knurled screw cap. CAUTION: The cable should be held firmly to prevent twisting.
2. Carefully remove the cable and resistor assembly which is mounted at the end of the cable. This should be done very carefully to prevent damage to the assembly, particularly to the two spring contacts.
3. The crystal can be removed by using the crystal key as indicated in the photograph. This key holds the crystal and at the same time permits the crystal mounting to be unscrewed from the shell.
4. In reassembly special care must be exercised so that neither of the contact springs rest on or too close to the slots in the capacitance shells.

Vacuum-Tube Data—Table of tube socket voltages measured from socket pin No. 1 to pins as designated, using a 20,000 ohm-per-volt meter (Weston 772 Analyzer). D-C voltages may vary ±20%.

Symbol	Type	Socket Pin Number 2	4	7
V-1	1R5	21.0	0	1.5

CONDITIONS: Switch ON.
ZERO adjustment set to 0 on meter.
Probe in mounting clip.

Hewlett-Packard Model 400A

General—Tubes—The Model 400A Vacuum Tube Voltmeter requires no maintenance other than occasional replacement of tubes and removal of any accumulated dust and dirt. The design of the circuit is such that changing tubes will have only a slight effect on the calibration of the instrument, especially at frequencies below 100 kc. Tubes which differ widely from the average type characteristics can, however, affect calibration at frequencies above 100 kc, and for this reason it is desirable that the calibration be checked if possible when 6AC7 and 6H6 tubes are replaced.

Calibration Check—Probably the most accurate method which can be used in the field to check the calibration of the Model 400A is a test using a cathode-ray oscilloscope and a freshly calibrated dynamometer type voltmeter.

After the new tube has heated in the Model 400A, apply a low-frequency (50–60 cps) voltage simultaneously to both the Model 400A and the dynamometer type voltmeters. Readings of the two instruments should agree closely. Try another tube if necessary.

Next, calibrate the cathode-ray tube of the oscilloscope by applying a low-frequency sinusoidal voltage simultaneously to the dynamometer voltmeter and to the vertical-deflecting electrodes of the c-r tube. No horizontal sweep voltage should be used. Directions for connecting to the deflecting electrodes of the tube are usually given by the manufacturer of the oscilloscope. By measuring the peak-to-peak deflection of the c-r tube trace with a graph screen and by noting the reading of the voltmeter, the deflection voltage of the c-r tube can be quickly determined. It is important that the voltage used to calibrate the c-r tube be essentially sinusoidal and free from harmonics.

Now connect the Model 400A in parallel with the vertical-deflecting plates of the c-r tube and apply sinusoidal voltages of frequencies up to one megacycle to the combination of the two instruments. The voltage shown by the Model 400A should agree closely with that indicated by the magnitude of deflection of the c-r tube trace. If such is not the case, try another new tube in the Model 400A and repeat the process.

The above procedure will give a reasonable check at all frequencies within the range of the Model 400A, although a check cannot be made of small voltages. Low voltage ranges can be checked by starting with a voltage within one of the ranges checked on the oscilloscope and working downward. For example, if the accuracy and frequency response of the 100-volt range of the Model 400A have been checked on the oscilloscope, apply a 25-volt wave to the Model 400A and note the reading on the 100-volt range. Then switch to the 30-volt range and note that the reading is correct. By extending this procedure, all ranges of the instrument can be checked.

Although the above methods will not give precision results, they will often prove helpful in determining whether or not old tubes have exceeded their service life or new tubes are satisfactory to use.

Now and then, when replacing 6AC7 tubes, a permanent deflection of the meter pointer will be observed with the input terminals shorted and when the new tube has heated. This condition is usually caused by cathode-heater leakage and the tube should be rejected in favor of another.

When replacing 6H6 and/or 6AC7 tubes, it is desirable to check the voltage response of the new tube if the voltmeter is being operated from an unregulated line voltage. This check can be made by applying a constant voltage to the input terminals and varying the line voltage ±10 volts from 115 volts. The voltmeter reading should not change by more than 3% at frequencies below 100 kc nor by more than 5% at frequencies below one megacycle. Try another tube if necessary.

A defective neon regulator lamp will sometimes cause the meter pointer to have a continuous reading well up on the scale with no input. This condition may or may not exist on all ranges. Replace the neon lamp and check d-c voltage at the cathode of the 6V6 tube with a high-impedance instrument. The cathode voltage should be approximately 215 volts. Try another neon lamp if necessary.

Beyond changing tubes and the neon lamp, it is not recommended that repair or recalibration of this instrument be attempted in the field, because of the elaborate equipment required.

Hewlett-Packard Model 404A

Battery Replacement—The batteries in the Model 404A Battery-Operated Vacuum Tube Voltmeter have a life of approximately 60 hours when used at the rate of four hours daily; less or more usage will increase or decrease the battery life. The instrument is designed so that both the plate and filament batteries deteriorate at the same rate and it is therefore necessary to replace both sets of batteries at the same time.

After approximately 60 hours of use, the plate supply deteriorates from 135 volts to approximately 98 volts and from 112½ volts to approximately 75 volts while the filament supply deteriorates from 1.5 volts to approximately 1.1 volts. When the voltages have fallen to these values, it is recommended that the batteries be replaced, although the instrument will continue to operate. The rate of flashing of the neon pilot lamp is a measure of the condition of the plate batteries. As the battery voltages deteriorate, the rate of flashing of this lamp will decrease.

Access to the five filament supply batteries is obtained by removing the instrument from its case. The three plate supply batteries are held in the large compartment at the rear of the instrument chassis. Access to them can be obtained by removing the back covering.

Special care should be taken to replace the batteries with proper polarity as the voltmeter will not operate if polarity is reversed.

Tube Replacement—The Model 404A Vacuum Tube Voltmeter is designed so that changing tubes will have as little effect as possible on the calibration accuracy of the instrument when average tubes are used. Tubes which differ widely from the average type characteristics, as is often the case with battery tubes, may, however, affect calibration and for this reason it is desirable that the following be checked when any or all of the tubes are changed.

If V1 or V2 is replaced, the screen voltage on V1 should be reset by means of R9. When this variable screen dropping resistor is properly set, the accuracy of the instrument becomes practically independent of plate battery voltage decrease over the normal life of the batteries. It is necessary to recheck R9 when any of the 1U4 tubes are changed because the optimum value of screen voltage on V1 may vary considerably with different tubes.

The procedure is as follows: After a new tube has been installed allow the instrument to warm up, with case removed, for a short time. Next, introduce a voltage of approximately 1.0 volt RMS amplitude and approximately 100 cps frequency into the input of the instrument when it is operating as a voltmeter. Note and record the meter reading.

After removing the back cover to allow access to the plate supply batteries, move the 135 volt (red) positive battery lead to the 112½ volt (center) positive terminal of the battery. Also move the 112½ volt (orange) battery lead to the 90 volt or negative terminal of the battery (BT6 on the schematic diagram). Again note and record the meter reading, keeping a constant input voltage to the instrument.

If the readings on the meter are not the same in both cases, adjust R9 (a 200,000 ohm potentiometer) by means of a screw driver from the top of the instrument until the second reading corresponds with the first. (This is the only screw driver adjustment accessible from the top of the instrument.)

After reconnecting the battery as it was originally, check the meter reading again, being sure that the input voltage has not changed. Repeat the above procedure until it is certain that both readings are the same. Try another tube if necessary.

When this setting has been properly made the normal deterioration in battery voltage with age will have negligible effect on the voltmeter accuracy.

Because of the fact that a change in screen voltage on V1 also changes the gain of the voltmeter amplifier and a new tube may affect calibration at high frequencies, it becomes necessary to check the calibration of the instrument.

Probably the most practical method for checking the calibration of the Model 404A is to compare its calibration with that of another voltmeter such as the Hewlett-Packard Model 400A, 400C, or 410A: Apply a low-frequency (50–60 cps) voltage simultaneously to both of the voltmeters. If it is found necessary to correct the calibration of the Model 404A, adjust R30 which is located beneath the chassis on the right side. This potentiometer controls the gain of the voltmeter amplifier and therefore compensates for the change in gain produced by adjusting R9 as described above. If the gain can not be set properly with R30, select another replacement tube and repeat the entire procedure.

This procedure should be used to reset the calibration only at low frequencies. The calibration at higher frequencies is a function of the tubes and, if the high-frequency calibration is found to be out of limits, another replacement tube should be selected and the entire calibration procedure repeated.

Although the above methods will not give precision results, they will often prove helpful in determining whether or not old tubes have exceeded their service life or new tubes are satisfactory to use.

Amplifier Gain Check—When a tube is changed in the Model 404A and voltage compensating and calibration adjustments become necessary, it should be kept in mind that these adjustments will affect the instrument when operating as an amplifier as well. It is therefore necessary to check the gain of the amplifier after the other circuit adjustments have been made. This may be done as follows: Set the right hand toggle switch on the panel to AMPLIFIER position. Now apply Sinusoidal voltage of 3.0 volts RMS at a frequency of approximately 100 cps to the input of the instrument. Check the accuracy of this voltage with a Hewlett-Packard Model 400A, 400C, or 410A VTVM.

With the range switch set to the 3.0 volt scale, check the output voltage of the amplifier. If this voltage is not also very nearly 3.0 volts, set it to exactly 3.0 volts by adjusting R33 (next to R30 beneath the chassis of the instrument).

When this adjustment has been properly made the amplifier has been set for a gain of 60 db. When using the amplifier, the range switch should be on the 0.003 volt range to provide a full 60 db gain. The maximum input to the amplifier for negligible distortion and maximum gain is 0.015 volt RMS.

Internal Adjustments—The Model 404A Vacuum Tube Voltmeter is provided with seven internal adjustments including four variable capacitors and three variable resistors.

The capacitors, C3, C5, C12, and C14, appear in the attenuator circuits of V1 and V3 and are adjusted for constant attenuation over the frequency range of the instrument for each voltage range selected. These capacitors should not require further adjustment for the life of the instrument.

The three variable resistors include R9, R30, and R33. The necessary adjustments of these components are discussed above in the section on tube replacement.

Beyond that necessary when changing tubes and batteries, it is not recommended that repair or recalibration of this instrument be attempted in the field, because of the elaborate equipment required.

Hickok Model 209

Vacuum Tubes—All vacuum tubes are operated at, or below, their normal rating to insure long life and uniform service. To check the tubes, remove the chassis from the case by removing the eight cap nuts around the edge of the panel and lifting the panel from the case.

Dry Cells—Two dry cells are operated in series as a source of d-c in making ohmmeter measurements. If it is impossible to bring the meter to full scale deflection on any scale it is probable that one or both of the dry cells are low. To replace these, remove the chassis from the case and remove the dry cells. It will be necessary to remove the clamp holding the cells in place first before removing the cells from their clip holders. NOTE: *If the meter pointer moves violently to the left with the selector switch in ohms position, remove the model 209 from its case and check the electrical contacts of batteries BT1 and BT2.*

Jackson Model 645

The schematic circuit diagram of the Jackson Model 645 Electronic Volt-Ohmmeter includes the operating voltages at 115 volts input. Another instrument of this type should be used for checking these voltages if failures should develop.

D-C Voltage Calibration Adjustment—The Jackson Model 645 is provided with a calibration adjustment on both + and − volts. These adjustments are on the left side of the chassis and have reference No. R37 and R38 shown on schematic diagrams. These adjustments are set at the factory and should not require changing except when tubes are replaced. If readjustment is necessary, use the following procedure:

1. Set zero adjustment on the meter until pointer is exactly zero.
2. Turn toggle switch to "*on*" position. Set selector switch to 4 volts position, allowing the instrument to warm-up for several minutes. Turn Zero Adj. until meter reads exactly zero. A good method for checking for ample warm-up time is to shift selector from − volts to + volts readjusting Zero Adj. after each time shifted. When no readjustment is necessary and pointer stays on zero, the instrument is ready to calibrate.
3. Connect a negative 4 volt D.C. source to the D.C. voltage probe. This voltage should be exactly 4 volts as the accuracy of the D.C. voltage depends on this adjustment.
4. Adjust R-38 or adjustment marked "Volts," until the meter reads exactly 4 volts.

This completes the adjustment for −volts. To calibrate +volts repeat the above procedure only set selector on +volts position and adjust R-37 Adjustment marked +volts. The voltage source will have to be reversed to get an up scale reading.

A-C Volts Calibration Adjustment—There are two internal adjustments for calibrating A.C. volts R-34 and R-30. These are set at the factory and should not require changing unless tubes are replaced. If readjustment is necessary, use the following procedure:

1. Set zero adjustment on the meter until pointer is exactly zero.
2. Turn toggle switch to *on* position. Set selector switch to −volts and range switch to 1V. A.C. position. Allow the instrument to warm up for several minutes, turn Zero Adj. until meter reads exactly zero. If no movement of the pointer is detected when selector is shifted from −volts to +volts or vice versa, without changing Zero Adj. set selector in A.C. volts position, adjust R-30 which is mounted under the chassis in back of selector switch until meter again reads exactly zero. When these adjustments are properly made, the meter will read exactly zero on − and + volts and A.C. volts. Set selector switch on A.C. volts position and range switch to 4V. position without turning the Zero Adj. knob. The instrument is ready to calibrate for A.C. volts.
3. Connect a 4 volt 50 or 60 cycle a-c source to the a-c voltage

probe. This voltage should be exactly 4 volts as the accuracy of the a-c voltage section depends on this adjustment.

4. Adjust R-34 or adjustment marked A.C. volts until meter reads exactly 4 volts on the meter.

To calibrate the a-c ranges for high audio frequencies a small trimmer condenser C-6 is used. This adjustment is made at the factory and should not require changing unless the wiring of the unit is tampered with or one or more of the compensating condensers on the range switch are changed. A 10,000 cycle 4 volt source is required for this adjustment. Set the control as required to measure 4 volts ac as explained above. Connect 4 volt 10,000 cycle source to input of A.C. volts lead. Adjust C-6 until meter reads full scale. Here again, the accuracy of this section depends on the accuracy of the voltage source used.

D-C Milliamperes Calibration—An adjustment R-16 is incorporated in the d-c milliampere section to compensate for difference in meter resistance. This adjustment is also set at the factory and should not be changed unless the meter or one or more of the shunts require changing. If readjustment is necessary the following procedure should be used:

1. Set zero adjustment on the meter until meter reads zero.
2. Set selector switch to mills position and range switch to 1 mill position. The instrument need not be plugged into the power outlet for mills measurements.
3. Connect the instrument using the Jacks marked *mills* into a circuit where exactly 1 mill is flowing. Here again, the accuracy of this section depends on the accuracy of the source used.
4. Adjust R-15 mounted under the chassis just back of the *Off On* switch until meter reads exactly full scale.

Tubes—The Jackson Model 645 employs three tubes. One, the 6X5GT, is used as a full wave rectifier supplying the dc for the instrument. One 6K6GT is used as the d-c voltmeter tube. It is also used in the ohmmeter and a-c voltmeter. One 7N7 is a twin triode. One section is used as a diode rectifier for a-c section, and the other section as an amplifier for the a-c section. Because of the low operating voltages of this instrument the tube life should be unusually long.

Replacement of Battery—When full scale adjustment is no longer possible on the ohms ranges, a new battery can be installed by removing the eight sheet metal screws holding the front panel to the case. This will allow removal of the panel and complete chassis of the instrument. A bracket is supplied to hold the battery on the right side of the chassis. By loosening the two top screws on this bracket, the battery can be slid into place from the back of the instrument. Care should be taken to see that the terminals are toward the front panel and the positive terminal on top. The red wire should be connected to the top or positive terminal of the battery, and the green wire to the bottom or negative terminal. The battery used should be Burgess #2370 or equal, or Signal Corps Type #BA 27.

McMurdo Silver Model 900-A

Humidity—Because of the extraordinarily high input resistance of "VOMAX" in both a.c. and d.c. voltage measurements, "VOMAX" is sensitive to moisture accumulation within its cabinet. Should meter fail to zero, or should 0 shift up or down over 1 division, as RANGE knob is rotated, check 6AR5 tubes by replacing one or both with known-good tubes. If condition persists withdraw "VOMAX" halfway from its cabinet, turn power ON and leave in a dry room overnight. This will evaporate any moisture condensation. If no dry room is available (as in periods or localities of continuing high humidity), do as above but place a large carton over "VOMAX". Prop carton top-flaps slightly open to allow egress of moisture during drying-out period.

"Flip-Flop"—If meter cannot be zeroed, FUNCTION at DC+, RANGE at 3V, and if meter reads off-scale in one direction, off-scale opposite for FUNCTION DC−, check P2 for open circuit and replace.

Ohmmeter Batteries—Ohmmeter batteries should be replaced when they measure less than 2.2 volts total as measured by +DC FUNCTION, 3V RANGE of "VOMAX" itself or when OHMMETER readings become unstable. Connections to batteries should be unsoldered, old batteries removed, new ones inserted and connections thereto resoldered.

Vacuum Tubes—6AR5 tubes should be replaced when SET V-ZERO knob will not bring meter pointer to zero, or when zero appears unstable after 10 to 15 minutes warm-up time. Known-good tubes may be directly substituted for original tubes. The same applies to the 6AL5 probe. It should be replaced when no adjustment of P3 only will make AC zero coincident with DC zero. If the first replacement 6AL5 tried will not permit establishing AC zero coincident with DC zero through adjustment of P3 alone, a second tube should be tried. If no second tube is available, required coincidence of AC and DC zeros brought about through adjustment of P3 only may be obtained by omitting, raising or lowering of the value of R34. In extreme cases, reverse connections to 6AL5 socket lugs 2 and 7.

Calibration—Recalibration should practically never be necessary unless the instrument is abused, damaged or its internal range set resistor adjustments are tampered with. DC calibration may be effected by applying 2 or 3 volts of precisely known d.c. voltage (measured by an external precision laboratory standard meter) to the 3V, +DC range of "VOMAX" and then carefully adjusting R21 for identical readings between the external standard meter and "VOMAX." Higher voltage ranges when tested will be in step.

AC calibration requires laboratory standard meters having ranges of 2/3, 8/12, 20/30 and 80/120 volts, together with an a.c. voltage source within these limits. Having zeroed "VOMAX", calibration consists of applying a definitely known 50 or 60 cycle a.c. voltage to "VOMAX" and adjustment of a.c. range set resistors identicalism of meter readings upon the different a.c. voltages on the four meter ranges. Using an external voltage which will give a meter reading somewhere upon the upper ⅓ of "VOMAX" scale for each of the 3, 12, 30 and 120/300 (and about mid-scale on the 1200 volt) ranges, adjust the appropriate RANGE SET resistors. Adjustment of R23 will bring 120 and 300 volt AC ranges into proper step.

Testing "VOMAX"—The chart appended gives voltages correct to ±10% which should be observed when the DC prod-tip is contacted to the d.c. voltage points listed. Internal a.c. voltages may be similarly measured upon appropriate ranges of "VOMAX" using AC prod-tip to measure mains input voltage, volt heater circuits, and high voltage power transformer secondaries.

Operating Voltage Chart—
Cathode ends of R35 to ground, +13.75 V d.c.
Cathode end of R38 to ground, +23 V d.c.
Cathode end of R39 to ground, −21 V d.c.
Heaters to ground, 5.7 V a. c. (at transformer)
Plates of 6X4 to center-tap (tube out of socket) 36 volts a.c.

Radio City Products Model 665

General—There are two factory sealed controls mounted on the chassis in back of the meter. The 15,000 ohm control located directly between the 2-6X5GT tubes is used for calibrating the a-c voltage ranges in order to compensate for variations in meter sensitivity and tube characteristics. The 25,000 ohm control which is located between the 6K6GT and the VR105 tubes is used for calibrating the d-c voltage ranges. If for any reason it is desired to recalibrate this instrument (there should be no occasion for this except when changing the 6K6GT tube) the following procedure should be followed for d-c volts:

1. Check the mechanical zero of the meter.
2. Remove the instrument from the case.
3. Set "Main Selector" to LINE CHECK. Make sure that the meter pointer rests at zero on DC scale (black).
4. Plug line cord into 105–130 volt, 60 cycle outlet and turn power switch to "ON" position.
5. Allow a few minutes for instrument to warm up.
6. Rotate the "Line Adjust" control clockwise until the meter reads full scale on the 6V AC scale. This adjustment standardizes all voltages in the instrument, compensating for different line voltages.
7. Return "MAIN SELECTOR" to "NORMAL" position. Set the "CIRCUIT SELECTOR" to "+DCV" position and turn the "ZERO SET—DCV—OHMS" adjust until the meter pointer reads zero. Sufficient time should be allowed for the tubes to heat so that there will be no movement of the pointer when the "CIRCUIT SELECTOR" switch is turned from "+DCV" to "−DCV" position.
8. Insert the tip end of the black high voltage test lead into the

jack marked "COMMON" and the shielded lead having the *black* phone plug at one end into the 0–600V phone jack.

9. Set the "RANGE SELECTOR" switch to 30V position.
10. Use a known voltage source of exactly 30 volts and connect the test probes of the instrument across this voltage. The black high voltage lead is connected to the grounded side.
11. Adjust the 25,000 ohm control that is located directly between the 6K6GT and VR105 tubes until the meter reads full scale with exactly 30 volts applied. This completes adjustment.

To calibrate a-c volts:

1. Remove the instrument from the case.
2. Set "Main Selector" to LINE CHECK. Make sure that the meter pointer rests at zero on DC scale (black).
3. Plug line cord into 105–130 volts, 60 cycle outlet and turn power switch to "ON" position.
4. Allow a few minutes for instrument to heat up.
5. Rotate the "Line Adjust" control clockwise until the meter reads full scale on the 6VAC scale. This adjustment standardizes all voltages in the instrument, compensating for different line voltages.
6. Set the circuit selector to ACV position.
7. Return "MAIN SELECTOR" to "NORMAL" position. Insert the tip end of the black high voltage lead into the jack marked "COMMON" and the black test lead having a red phone plug at one end and a *red* prod handle at the other end into the 0–600V phone jack.
8. Set the "RANGE SELECTOR" switch to 30V position.
9. Use a known sine wave voltage source of exactly 30 volts R.M.S. value and connect the test probes of the instrument across this voltage. The black high voltage lead is connected to the grounded side.
10. Adjust the 15,000 ohm control that is located directly between the 2-6X5GT tubes until the meter reads full scale with 30 volts effective value applied. This completes the adjustment.

Tubes—This instrument employs one 6K6GT, two 6X5GT and one VR105 tube. Since the tubes have low operating voltage, their life will be unusually long. If it ever becomes necessary to replace either the 6X5GT tube or the VR105, no other adjustment will be necessary. However, if the 6K6GT tube is replaced, the instrument will have to be recalibrated according to the procedure outlined previously. In replacing the 6K6GT tube, it is advisable to check for grid current as occasionally a gassy tube will be found. The presence of gas is indicated by an appreciable shifting of the zero position when changing ranges with the free ends of the test probes shorted.

Battery—This instrument contains one 3 volt battery which is used for all resistance measurements. Its condition should be checked periodically as outlined under RESISTANCE MEASUREMENTS and if found unsatisfactory should be replaced with a new 3 volt Burgess type F2BP or equivalent.

RCA Type WV-65A

D-C Calibration Adjustment—The Battery VoltOhmyst is provided with a calibration adjustment R-35 which is originally set at the factory to compensate for variations in meter sensitivity and tube characteristics. This adjustment ordinarily does not require changing except when tubes are replaced. If readjustment is necessary, use a known source of d-c voltage of exactly 3 volts and proceed as follows:

1. Check the mechanical zero of the meter.
2. Turn on the power, allow the instrument to warm up for about one minute. Set the SELECTOR switch to position marked "+ VOLTS," turn the RANGE switch to position marked "3V DC," and turn the ZERO ADJ until the meter reads exactly zero.
3. Connect the Battery VoltOhmyst across the source of exactly 3 volts. The accuracy of the calibration of the instrument depends on the accuracy of the standard-3-volt source, which should be carefully checked with a voltmeter known to be accurate. Alternatively the voltage drop across an accurate 1,000 ohm resistor with exactly 3 ma flowing through it may be used.
4. Adjust R-35 so that the meter reads exactly 3 volts.
5. After the adjustment is completed, the two 1C5GT tubes

should not be interchanged since this may have a slight effect on the accuracy of calibration.

A-C Calibration Adjustment—Two internal adjustments, R-25 and R-26 which are set at the factory, are provided to compensate for variation in both rectifier and meter characteristics, and to insure the greatest possible accuracy of the a-c ranges. These adjustments should not be changed unless one or more of the components in the a-c voltmeter section of the circuit is replaced. If necessary to readjust, proceed as follows:

1. Check the mechanical zero of the meter.
2. Set the SELECTOR switch to position marked "AC VOLTS" and the RANGE switch to position marked "100 V." Apply an a-c voltage of exactly 100 volts to the test leads. This voltage should be of good waveform and should be measured by an instrument which is known to be accurate. The 60-cycle power line is a convenient source of such voltage.
3. Adjust R-26 so that the meter reads exactly full scale (100 volts).
4. Remove the 100 volts and apply a know voltage of 10 volts to the test leads. Set the Range switch to 10 volts.
5. Adjust R-25 so that the meter reads exactly full scale (10 volts).
6. The procedure for adjusting R-25 and R-26 should be repeated until no further change is required. Usually it will not be necessary to go over these adjustments more than two times.

Direct Current Calibration Adjustment—The Battery VoltOhmyst is provided with one internal adjustment, R-37 to compensate for variations in meter resistance. This adjustment is set at the factory and should not be changed unless one or more of the resistors in the direct-current section of the circuit is changed. When readjustment is necessary, proceed as follows:

1. Check the mechanical zero of the meter.
2. Set the SELECTOR switch to the "DC CUR" position and the RANGE switch to the position marked "3V DC."
3. Connect the VoltOhmyst in series with a standard direct-current meter capable of indicating 3 milliamperes.
4. Connect both meters (series-connected) in series with a circuit through which the current can be adjusted to exactly 3 milliamperes as read on the standard meter.

5. Adjust R-37 so that the meter in the VoltOhmyst reads exactly full scale (3 MA).

Tubes—The Battery VoltOhmyst employs two type 1C5GT tubes. Because of the low operating voltages the tube life will be unusually long. However, when replacement becomes necessary, care should be taken to see that the two type 1C5GT tubes are approximately balanced. If they are unbalanced, it will be impossible to bring the pointer to zero by means of the ZERO ADJ control. If this should happen, the tubes should be interchanged and the adjustment tried again. If it is still impossible to bring the pointer to zero, the tubes have different characteristics and each one should be matched with another tube in order to obtain a balanced pair. When the tubes are matched, it will be possible to bring the pointer to zero with the ZERO ADJ control. The unique circuit design of the Battery VoltOhmyst is such that grid current is reduced to a negligible value. However, when replacing tubes, it is advisable to check for grid current as occasionally a gassy tube will be found. The presence of gas is indicated by an appreciable change in the pointer position when the RANGE switch is changed from the 3 volt position while the SELECTOR switch is in the "+ VOLTS" position.

Meter Needle Off Scale—If the meter needle drives violently off scale when no test is being made, the cause may be due to the meter circuit being grounded. Check circuit for grounds, being sure that the grounded covers of the potentiometers (R-33, R-35, R-36) are not making contact with any part of the circuit both inside and out.

If it becomes necessary to insulate the inside of a potentiometer cover, be careful not to disturb the adjustment of R-35 or recalibration with a voltage standard will be necessary.

Meter Needle Sticking—The plastic meter case in the VoltOhmyst has been treated with a special anti-static solution and no difficulty should be experienced with the operation of the meter. However, it is possible that, with continued use over a long period under severe climatic conditions, the effect of the anti-static solution may diminish. If such difficulty should be encountered, corrective information may be obtained from the Test and Measuring Equipment Sales Division of the Radio Corporation of America. Correspondence should include the code and model numbers of the VoltOhmyst.

This condition may also be caused by wiping the anti-static compound off the inside of the meter case. Caution should therefore be exercised if it should be necessary to clean the inside of the meter-case. A very light dusting with cotton is recommended for cleaning this portion of the instrument.

Batteries—To replace batteries, remove the instrument from its case by first removing the six front-panel screws. The filament batteries and those for the ohmmeter circuit are mounted on the rear wall of the case. Remove the nut holding the retaining strip. The batteries may now be removed from their mounting clamps.

To replace the 45-volt "B" batteries, loosen the two screws securing the clamp which holds them in position. Remove the batteries and release the snap-on connectors.

Make certain battery contacts are bright and clean so that there will be no resistance at the connections. This is particularly important for the filament and Ohmmeter batteries.

Batteries should be checked occasionally to insure satisfactory operation. Weak filament batteries are generally indicated by inability to attain full scale deflection with the SELECTOR switch in the "OHMS" position, although weak batteries in the Ohmmeter circuit will produce similar results. To test the batteries in the Ohmmeter circuit, proceed as follows:

> Set the RANGE switch for "Rx1" and adjust OHMS ADJ until the pointer reads full scale (or as near to full scale as possible). Short circuit the test leads (red and black) for about 10 seconds. Relieve the short circuit and immediately observe the scale reading. If the batteries are in a weakened condition the scale reading will be substantially below that obtained before the leads were short circuited.

Battery replacement for the Ohmmeter circuit is generally necessary when the Ohmmeter readings become unstable, especially on the "Rx1" scale.

Exhausted filament batteries may cause the meter needle to drive violently off scale when the SELECTOR switch is in the "−VOLTS," "+VOLTS," or "OHMS" position and no test is being made.

The neon lamp mounted in the front panel indicates the general condition of the two 45-volt "B" batteries. If these batteries are in good condition, the lamp will flash on and off whenever the SELECTOR switch is in the "−VOLTS," "+VOLTS", or "OHMS" position. As the battery deteriorates, the terminal voltage will decrease and finally the tube will stop flashing. Although reliable readings may be obtained as long as it is possible to balance the tubes by means of the ZERO ADJ control, it is advisable to replace the "B" batteries when the tube ceases to flash.

CAUTION: *Batteries should not be allowed to remain in test equipment after they have become exhausted or in equipment that is to remain idle for a long period of time, as they deteriorate and may damage the instrument.*

RCA Type WV-73A

Tube Replacement—With proper care, the instrument should require little servicing other than possible replacement of tubes after long periods of service. All tubes can be made accessible for replacement by removing four screws on the front panel and two screws under the case, then withdrawing the panel and chassis assembly from the case.

Replacing Fuses—One side of the power line to the Audio Voltmeter is fused with a two-ampere fuse (F-1). The fuse block is mounted on the side apron beneath the chassis, and is accessible when the panel and chassis assembly is removed from the case. Always replace the fuse with one of equal rating.

Meter Calibration—Two screwdriver adjustments (R-30, R-34) are provided for calibration of the panel meter. When tubes or other critical elements of the amplifier or of the rectifier circuits are replaced, some readjustment may be necessary to insure normal accuracy. Before adjustment is attempted, however, be certain that the WV-73A actually is in error, since its stability and accuracy is often better than that of conventional reference standards. The meter-calibration adjustment can be made as follows by using a one volt, 1000 cycle-per-second sinusoidal signal from an accurately calibrated source.

Withdraw the panel and chassis assembly from the case to allow access to the potentiometers, which can be adjusted from the top side of the chassis. With the instrument turned on and the range switch set to "1," apply the one-volt standard signal to the input jack (J-1). The meter pointer should read full-scale ("10"). If it does not, adjust the potentiometer (R-30) located near the center of the chassis until the exact full-scale reading is obtained. Then turn the range switch to "10" and adjust the other potentiometer (R-34) until the meter reads "1." These adjustments should be repeated.

If it is possible to supply calibrated voltages of different values to the input of the voltmeter, points between the ends of the scale may be checked. In this case, the two potentiometers can be alternately adjusted for each input voltage until the panel meter readings most nearly agree with the input voltages over the entire scale.

RCA Type WV-75A

Meter Pointer Zero Adjustment—The meter pointer should be at "0" on the volt and ohm scales when the power is off. If it is not, the following check should be made:

Vigorously wipe the meter case window with a clean, soft, dry cloth. If the pointer moves away from "0" and remains in deflected position for several minutes, the anti-static coating on window is not effective. The only remedy is to renew coating on inside of window.

If pointer did not respond to static test, the following procedure should be used for adjusting mechanical position of the pointer:

1. Unscrew the moisture-proof meter adjustment plug.
2. Insert a scriber or similar tool to engage the meter zero adjustment pawls and move them sideways until the meter pointer reads exactly zero.
3. Replace moisture-proof meter adjustment plug.

CAUTION—*Extreme care must be taken to prevent insertion of the tool to a depth where it will injure the pointer spring. The guarantee does not cover damage resulting from this adjustment on the meter.*

D-C Calibration—

1. Check mechanical zero of pointer and if necessary, adjust as described in section under "Meter Pointer Zero Adjustment."

2. Turn the SELECTOR switch to + VOLTS position and allow instrument to warm up for at least 30 minutes.
3. Check line voltage to be sure that it is normal before proceeding with calibration. (The specifications for this instrument are based on operation on a line voltage of 117 volts, 60 cycles.)
4. Bring the pointer to zero by adjusting the ZERO ADJ. control. This control should not be disturbed during remainder of calibration.
5. Turn RANGE switch to 3 VOLT position.
6. Connect the ground lead to negative and probe (blue cable) to positive terminal of a *standard* 3 volt D-C source.
7. Adjust the + 3 V. D-C, calibrating control (R31) until the meter reads exactly 3 volts.
8. Reverse connections to the standard voltage source.
9. Turn SELECTOR switch to − VOLTS.
10. Adjust the −3 V. D-C calibrating control (R22) until the meter indicates exactly 3 volts.
11. Check all other D-C ranges by applying proper values of voltage from standard source to give full scale deflection. If any error is noted on the higher ranges, the voltage divider circuit, comprising R1 to R6, should be checked.

NOTE—If (R31) and (R32) both have insufficient range to permit adjusting pointer to correct position, reverse position of shorting link (S3), that is, if open, close; if closed, open; and recheck range of calibration adjustments. It should be noted that shifting the link position affects A-C as well as D-C calibration.

A-C Calibration—If A-C calibration is not preceded by D-C calibration, perform first four operations of procedure for D-C calibration. Then proceed as follows:

1. Turn SELECTOR switch to A-C VOLTS.
2. Turn RANGE switch to 3 volts.
3. With no signal on the A-C probe, the meter should read zero. If the reading is other than zero, the initial emission of the diode (V5) in the probe is not properly balanced with initial emission of the bucking diode (V-4). Adjust the A-C BAL. control (R38) until the meter reads zero. It should be noted that there is considerable time delay between movement of

the control and response of the meter pointer. This is due to the thermal inertia of the diode cathode. It is, therefore, necessary to move the control in slight increments allowing sufficient time between movements to permit the cathode temperature to stabilize. If the meter pointer cannot be moved to zero position with the A-C BAL. control, the 6AL5 tubes (V4 and V5) should be reversed and above repeated, then check and replace if necessary. (See below on Tube Replacements.)

4. Recheck position of pointer for +VOLTS position of SELECTOR switch. If pointer does not read "0," readjust ZERO ADJ. and repeat "3."
5. Connect the A-C probe to a standard source of 3 volts r.m.s., 60 cycles.
6. Adjust the 3 V. A-C calibrating control (R39) until the pointer reads exactly 3 volts on the red A-C scale. If R39 has insufficient range, see note under D-C calibration.
7. Using suitable voltage values from standard A-C source, check the 10-volt point on the 10 V. A-C (red) scale, the 30 volt point on the 30 V. A-C (black) scale, and the 75 volt point on the 100 V. A-C (black) scale. If any error is noted on higher scales, check the voltage divider circuit R-13 to R-16.

Tube Replacements—All tubes (except the diode in the probe) are located on the chassis and are accessible for replacement after the panel and chassis assembly is removed from the case.

When it becomes necessary to replace tubes, care should be taken to see that the two 6K6GT/G tubes are approximately balanced. If sufficient unbalance exists, it will be impossible to zero the pointer at the left end of the scale with the ZERO ADJ. control. If this condition is noted after a single 6K6GT/G has been replaced, the 6K6GT/G tubes should be interchanged and range of adjustment rechecked. If still unsatisfactory, additional tubes will have to be tried until a matched pair can be found.

Care should be taken to avoid installing gassy tubes which will permit excessive grid current to flow in the voltmeter circuit. The presence of gas is indicated by appreciable deviation of pointer from "0" position when the RANGE switch is changed from the 3 VOLT to the 30 VOLT range, while the SELECTOR switch is in the + VOLTS or −VOLTS position.

Replacing Diode in A-C Probe—Failure of the 6AL5 diode in the probe will normally cause the meter pointer to deflect sharply to the left when the SELECTOR switch is thrown to A-C VOLTS, just as if the A-C lead were disconnected from the VoltOhmyst. An open filament can usually be detected by feeling the probe since the heater of the diode warms the body of the probe slightly.

To gain access to the diode in the probe for examination or replacement proceed as follows:

CAUTION—DO NOT ATTEMPT TO UNSCREW THE KNURLED RING AT FRONT OF PROBE UNTIL STEP 6 OF PROCEDURE LISTED BELOW HAS BEEN COMPLETED.

1. Unscrew the streamlined cap from the rear end of the probe and push cap, washer, and bakelite cover onto cable.
2. Unscrew the hex nut at rear end of probe, being careful not to turn the bushing with respect to the probe body.
3. After hex nut has been removed, push the bushing into the probe body far enough to disengage locking pin from probe body.
4. Unscrew rear half of probe body from front half, and push back on cable. The 6AL5 tube will then be exposed, making examination or replacement possible. Should it become necessary to remove the diode socket and capacitor assembly, the disassembly procedure should be continued as follows:
5. Unscrew the threaded bushing which holds the two halves of the probe together. This operation can be facilitated by inserting a nail, small screw driver or some similar tool through the holes in the bushing.
6. After the bushing is removed, heat tip of probe with soldering iron until solder is melted. Then withdraw diode socket and capacitor assembly from rear of probe body.

Battery Replacement—CAUTION—*Do not allow exhausted batteries to remain in the VoltOhmyst. Chemicals leaking from deteriorated batteries may damage interior of instrument.*

To insure maximum accuracy of resistance measurements, the batteries should be tested frequently. The following procedure is recommended:

1. Set SELECTOR switch to OHMS.

2. Set RANGE switch to the RX1 scale.
3. Adjust OHMS ADJ. control so that pointer reads full scale.
4. Short-circuit red and black tests leads for about ten seconds.
5. Relieve short-circuit and immediately observe meter deflection. A substantial deviation from full scale reading indicates that batteries are in weakened condition and should be replaced.

To replace batteries, proceed as follows:

1. Remove the six panel screws from the front and two chassis screws from rear of VoltOhmyst, and withdraw panel and chassis assembly from case.
2. Remove the plug-button on side of case and loosen screw inside.
3. Remove retaining-plate screw, the retaining plate and then the battery terminal connectors.
4. Replace batteries with two RCA No. VS036 1½ volt cells (or equivalent). Be sure all contacts are clean and tight so that contact resistance can be kept to a minimum. Watch lead dress while replacing instrument in case.

RCA Type WV-95A

Meter-Pointer Zero Adjustment—The meter pointer should be aligned with the zero marks on the meter scales when the power is off. If it is not, the following check should be made:

Vigorously wipe the meter case window with a clean, soft, dry cloth. If the pointer moves away from zero and remains in a deflected position for several minutes, then the anti-static coating on the inside of the window is ineffective. In this case, the only remedy is to renew the coating. Additional details about this coating material may be obtained by writing to the Test and Measuring Equipment Section, Building 60, RCA, Camden, New Jersey.

If the meter pointer did not respond to the static test, the following procedure should be used to adjust the mechanical position of the pointer:

1. Unscrew the meter adjustment plug.
2. Insert a scriber or similar tool to engage the meter-pointer adjusting pawls. Move the pawls sideways until the pointer reads exactly zero.

3. Replace the meter adjustment plug.

CAUTION—*Extreme care must be taken to prevent insertion of the tool to a depth where it will injure the pointer spring. The guarantee does not cover damage resulting from this adjustment.*

Tube Replacement—All tubes are located on the chassis and are accessible for replacement after the rear panel is removed from the case. To remove the rear panel, unscrew the four screws on the rear of the case. To remove the instrument from the case, unscrew the four screws in the corners of the front panel, and the two screws underneath the case, then withdraw the panel-and-chassis assembly.

If it becomes necessary to replace tubes, care should be taken to see that the two RCA-6AK6 tubes are approximately balanced. If they are unbalanced, it will be impossible, when the POLARITY switch is on "+," to bring the pointer to the zeros at the left end of the scale and in the center by means of the ZERO ADJ control. If this should happen, the tubes should be interchanged and the adjustment tried again. If it is still impossible to bring the pointer to zero at both the center and left-hand edge of the meter scale, the tubes have different characteristics and each one should be tried with another tube in order to obtain a matched pair. When the tubes are matched, it will be possible to bring the pointer to zero both at the center of the scale and at the left-hand end of the scale with the ZERO ADJ control. This can be done only when the POLARITY switch is on "+." When this switch is on "−," then it should be impossible to set the pointer to the center-scale zero.

NOTE—Before replacing an RCA-6AK6, age the replacement tube by applying 6.3 volts to its filament for 12 hours.

The circuit design of the Master VoltOhmyst is such that grid current is reduced to a negligible value. However, when replacing tubes, it is advisable to check for grid current as occasionally a gassy tube will be found. The presence of gas is indicated by an appreciable change in the pointer position when the VOLTS switch is changed from "5" to "50" while the SELECTOR switch is in the "DC" position and while no voltage is being measured.

Vibration of Pointer on A-C Ranges—Vibration of the pointer on a-c ranges may be caused by a defective 6AU6 or 6AL5. Replace with known good tubes. Pointer vibration can also be caused by mechanical resonance of the pointer assembly. This condition should be remedied at the factory because the pointer assembly is very delicate. Please communicate with Test and Measuring Equipment Section, Building 60, RCA, Camden, New Jersey, for a return tag.

Battery Replacement—Do not allow exhausted batteries to remain in the Master VoltOhmyst. Chemicals leaking from the deteriorated batteries may damage the interior of the instrument. Steel-clad batteries such as the RCA VS-036 are recommended because of their long life and small chance of chemical leakage.

Battery replacement is generally necessary when the ohmmeter readings become unstable, especially on the "RX1" position of the RES/CAP switch. To insure accuracy of the ohmmeter readings, it is suggested that the batteries be checked occasionally as follows:

1. Set the SELECTOR switch to "RES."
2. Set the RES/CAP switch to "RX1," and adjust the RES/CAP ADJ control until the pointer reads full scale.
3. Short circuit the RES/MA and COMMON terminals for about ten seconds.
4. Open the short circuit and immediately observe the meter deflection. A substantial deviation from a full-scale reading indicates that the batteries are weak and should be replaced.

To replace the batteries, remove the rear panel as described under "Tube Replacement," and replace the batteries with two RCA VS-036 1.5-volt cells or the equivalent. Be sure all contacts are clean and tight so that contact resistance will be kept to a minimum.

Meter Pointer Off Scale—If the meter pointer drives violently off scale when no test is being made, the cause may be due to the meter circuit being grounded. Check circuit for grounds, being sure the grounded covers of the potentiometers (R-14, 34, 35, 36, 37, 38) are not making contact with any part of the circuit both inside and out.

If it becomes necessary to insulate the inside of a potentiometer cover, be careful not to disturb the adjustments of R-34, 35, 36, 37, 38 or recalibration with a voltage standard will be necessary.

Calibration—Before adjustments of the calibration controls are made, see that the pointer is mechanically set on zero, and allow the instrument to warm up for 30 minutes. All of the calibration adjustments are located on the rear and left-side aprons of the chassis, and are clearly marked. All calibration adjustments are cemented in place at the factory; the cement can be softened with acetone thinner.

The following procedures are recommended for calibrating the Master VoltOhmyst:

DC + CAL:

1. Set the VOLTS switch on "5," and the POLARITY switch on "+."
2. Set the SELECTOR switch on "DC," and rotate the ZERO ADJ control until the pointer reads zero.
3. Insert the black lead into the COMMON terminal, and the blue probe lead into the VOLTS DC terminal.
4. Connect a standard d-c voltage of four volts between the two test leads. This voltage should be metered with a high-quality, accurate, d-c voltmeter in parallel with the Master VoltOhmyst.
5. Adjust the DC + CAL control until the pointer reads exactly 4 on the scale.
6. Check the accuracy of the instrument on all settings of the VOLTS switch by employing standard voltages of different value on each range. If the accuracy of the meter is not better than ±3% of the full-scale indication on all ranges, then check the multiplier resistors (R17 to 28 incl., R39, 40 and the 1 meg. resistor in the probe) with a reliable bridge.

DC − CAL:

Follow the same procedure given under DC + CAL with the POLARITY switch set on "−," and with the polarity of the standard voltage source reversed. If the various settings of the VOLTS switch checked correctly under the previous DC + CAL test, it will not be necessary to repeat step 6.

AC ZERO; AC CAL:

1. Set the POLARITY switch on "+" or "−," the VOLTS switch on "1," and the SELECTOR switch on "DC."
2. Zero the meter pointer with the ZERO ADJ control.
3. Set the SELECTOR switch on "AC."
4. Plug the a-c probe into the VOLTS AC socket and short-circuit this probe to the COMMON lead.

5. Set the AC AERO control so that the pointer is aligned with the small red zero on the a-c volts scale.
6. Connect a 60-cycle sine wave of exactly 0.8 volt rms between the a-c probe and the COMMON lead. Adjust the AC CAL control until the meter reads exactly 0.8 volt on the center scale.
7. Check all settings of the VOLTS switch by applying appropriate voltages to the instrument for each setting. If the accuracy is not better than ±3% of the full-scale indication on all ranges, then check the multiplier resistors (R19 to 23 incl., R48 to 51 incl.) with a reliable bridge.

RF ZERO; RF CAL:

1. Set the POLARITY switch on "+" or "−," the VOLTS switch on "5," and the SELECTOR switch on "DC."
2. Zero the meter pointer with the ZERO ADJ control.
3. Set the SELECTOR switch on "RF."
4. Plug the RCA Diode Probe Cable into the VOLTS AC socket and short circuit the probe center-pin to the grounding ring.
5. Set the RF ZERO control so that the meter pointer reads zero. Allow the reading to stabilize, as response to this adjustment is slow.
6. Set the VOLTS switch on "50."
7. Apply a 60-cycle sine wave of exactly 40 volts rms to the probe.
8. Adjust the RF CAL control until the pointer reads exactly 40.
9. Check all settings of the VOLTS switch by applying appropriate voltages to the probe for each setting. Since the multipliers used with the diode probe are the same as those used for d-c voltage measurements, any fault in these multipliers should have been discovered during the DC + CAL test previously described.

CX10 ADJ MAX; CX10 ADJ C.S.; CX100 ADJ MAX:

1. Set the SELECTOR switch on CAP and adjust the ZERO ADJ control for zero pointer reading (small red zero on capacity scale).
2. Set the RES/CAP switch on "CX0.1."
3. Short-circuit the CAP and COMMON terminals, then rotate the RES/CAP ADJ control until the pointer is aligned with the last line on the right-hand side of the top scale.

4. Set the RES/CAP switch to "CX.01," then to "CX.001." The meter should still read full scale.
5. Set the RES/CAP switch to "CX1.0 mf." The meter reading should be within −1.5 divisions of full scale on the center scale.
6. Set the RES/CAP switch to "CX10 mmf," then set the CX10 ADJ MAX trimmer until the meter reads exactly full scale.
7. Remove the short circuit from the CAP and COMMON jacks, and in its place connect a 100-mmf. standard capacitor.
8. Set the CX10 ADJ C.S. trimmer for a meter reading of exactly ten on the capacity scale. If this adjustment cannot be made, the capacity-measuring winding on the power transformer probably has excess distributed capacity.
9. Remove the capacitor. The meter should indicate less than two mmf. (less than 0.2 on the capacity scale). If the reading is greater than this, the power transformer probably has a defective shield.
10. Set the RES/CAP switch to "CX100 mmf." and short-circuit the CAP and COMMON terminals.
11. Set the CX100 ADJ MAX trimmer for a full-scale meter reading.
12. Remove the short circuit and in its place connect a 1000-mmf. standard capacitor. The meter reading should not differ from the capacitor value by more than ±10%.
13. Remove the capacitor. The meter should read less than one scale division.

Replacing Diode in Diode Probe—Failure of the RCA 6AL5 diode in the Diode Probe will normally cause the meter to deflect sharply to the left when the SELECTOR switch is on "RF." An open filament can usually be detected by feeling the probe since the diode heater warms the probe body slightly. RF calibration should be checked whenever the diode is replaced.

To gain access to the RCA-6AL5 in the probe for examination or replacement proceeds as follows:

CAUTION—*Do not attempt to unscrew the knurled ring on the probe front until step 6 of the following procedure has been completed.*

1. Unscrew the streamlined cap from the rear of the probe and push cap, washer, and bakelite cover back over the cable.
2. Unscrew the hex nut at the rear of the probe, being careful not to turn the bushing with respect to the metal probe body.
3. Push the bushing into the probe body far enough to disengage the locking pin.
4. Unscrew the rear half of the probe body from the front half, and push the rear half back over the cable. The 6AL5 will then be exposed, making examination or replacement possible.
5. If it is necessary to remove the diode socket and capacitor assembly, unscrew the threaded bushing which holds the two halves of the probe together. This operation is facilitated by inserting a nail or some similar instrument through the holes in the bushing.
6. Heat the probe tip with a soldering iron until the solder is melted, then withdraw the diode socket and capacitor assembly from the rear of the front half of the probe body.

RCA Type 195-A

Meter Pointer Zero Adjustment—The meter pointer should be aligned with the zero marks on the meter scales when the power is off. If it is not, the following check should be made:

Vigorously wipe the outside of the meter case window with a clean, soft, dry cloth. If the pointer moves away from zero and remains in a deflected position for several minutes, then the anti-static coating on the inside of the window is ineffective. In this case the coating should be renewed. Additional details about this coating material may be obtained by writing to the Test and Measuring Equipment Section, RCA, Camden, New Jersey.

If the meter pointer did not respond to the static test, the following procedure should be used to adjust the mechanical position of the pointer:

1. Unscrew the meter adjustment plug.
2. Insert a scriber or similar tool to engage the meter-pointer adjusting pawls. Move the pawls sideways until the pointer reads exactly zero.
3. Replace the meter adjustment plug.

CAUTION:—*Extreme care must be taken to prevent insertion of the tool to a depth where it will injure the pointer spring. The guarantee does not cover damage resulting from adjustment.*

Calibration—Before attempting to recalibrate the VoltOhmyst, the following precautions should be observed:

1. Be sure the contemplated adjustment is understood and is necessary.
2. Check the mechanical zero of the meter with power off.
3. Check line voltage. Line voltage should be 117 volts, 60 cycles.
4. The instrument should be allowed to "heat up" to its ambient heat stability (30 to 60 minutes).

D-C Voltage Calibration—

1. Check and only if necessary, set mechanical zero with power off. Tap meter, to be sure that it remains at zero after a deflection.
2. Turn SELECTOR to + VOLTS position and allow instrument to warm up for about 20 minutes to one-half hour. Adjust electrical zero with ZERO ADJ. control. Turn RANGE to 5 volts.
3. Connect ground lead and blue cable to a standard source of D-C voltage applying 4 volts of accurately measured D-C to the input through the D-C probe.
   Adjust R-10, the D-C positive voltage calibrating control, until the meter reads exactly 4 volts on 5 Volt Scale.
4. Reverse cable connections at the standard voltage source and set SELECTOR switch to −volts. Adjust R-11, D-C negative voltage calibrating control, until meter reads exactly 4 volts.
5. Check other ranges by applying 8 volts on 10 volt range, 40 volts on 50 volt range and etc.

A-C Voltage Calibrations—D-C calibration must precede that of A-C.

1. Disconnect instrument from A-C power supply.
2. Before the A-C section of the meter can be calibrated, it will be necessary to connect a .25 mfd. capacitor between the cathode (pin 4) of the 6H6 tube and the junction of the range switch

(S1-C) arm and capacitor C-4. Capacitor C-4 is the middle capacitor of the three located on the rear of the selector switch.

3. Set SELECTOR to A-C VOLTS.
    a. Reconnect instrument to power supply.
    b. Set SELECTOR to + VOLTS.
    c. Adjust ZERO ADJUST (R7) until meter reads zero.
4. Set RANGE to 100 and apply approximately 100 volts, 60 cycles through the A-C (red) and GND (black) leads.
5. Adjust the A-C-BAL (R-18) balancing control until the meter reads zero.
6. Remove the 100 volts A-C and the .25 mfd. capacitor and note zero meter setting. After slightly tapping the meter, this should be within plus or minus one scale division of the zero mark on the 5 volt range.
7. Set RANGE to 5 volts and apply exactly 4 volts r.m.s., 60 cycles, as measured by a standard.
8. Adjust the A-C-CAL (R-12) control on under side of chassis to give a reading of exactly 4 volts on the meter.
9. Other ranges up to 100 can be checked but this is not necessary if the D-C range test was found satisfactory, since this portion of the A-C range test is made with the same multipliers.

The high voltage ranges can be checked with 400 volts on the 500 range and 800 volts on the 1000 range if standards for such are available.

Tubes—The VoltOhmyst employs two type 6K6-GT, one type 6H6 and one type 6X5-GT RCA preferred type tubes. Because of the low operating voltages the tube life will be unusually long. However, when replacement becomes necessary, care should be taken to see that the two type 6K6-GT tubes are approximately balanced. If they are unbalanced, it will be impossible to bring the pointer to zero at the left end of the scale and in the center by means of the "ZERO ADJ." control. If this should happen, the tubes should be interchanged and the adjustment tried again. If it is still impossible to bring the pointer to zero, the tubes have different characteristics and each one should be matched with another tube in order to obtain a balanced pair. When the tubes are matched, it will be possible to bring the pointer both to the normal zero at the left end of the scale and to the zero in the center of the scale with the "ZERO ADJ." control. The unique circuit design of the VoltOhmyst is such that grid current is reduced to a negligible value. However, when replacing tubes, it is advisable to check for grid current as occasionally a gassy tube will be found. The presence of gas is indicated by an appreciable change in the pointer position when the "RANGE" switch is changed from the 5 volt position to the 50 volt position while the "SELECTOR" switch is in the "+ VOLTS" position.

Meter—METER POINTER OFF SCALE: If the meter pointer drives violently off scale when no test is being made, the cause may be due to the meter circuit being grounded. Check circuit for grounds, being sure the grounded covers of the potentiometers (R-7, R-10, R-11, R-12 or R-13) are not making contact with any part of the circuit both inside and out.

If it becomes necessary to insulate the inside of a potentiometer cover, be careful not to disturb the adjustments of R-10, R-11 or R-12 or recalibration with a voltage standard will be necessary.

Battery—BATTERY REPLACEMENT: To replace batteries, remove the instrument from its case by first removing the six front-panel screws. Remove plug button on side of case and loosen screw inside. Remove retaining plate and then the battery terminal connectors.

Be certain battery contacts are clean and tight so that there will be no possibility of resistance at the connections. Use two RCA No. VS 001, or two Burgess No. 2, or two Eveready No. 950 Flashlight Cells, or equivalent. When replacing instrument in case, be careful not to pinch the battery leads.

Battery replacement is generally necessary, when the ohmmeter readings become unstable, especially on the "R x 1" scale.

Reiner Electronics Model 451

Calibration—There are two factory sealed controls mounted on the top of the chassis inside the instrument case. The control marked "VR2" is used for calibrating the DC voltage ranges in order to compensate for variations in meter sensitivity and tube characteristics. The control marked "VR1" is used for calibrating the AC voltage ranges. Calibration is usually unnecessary except when changing the 6G6G tubes, when the following procedure should be followed.

a. DC VOLTS

(1) Remove the instrument from its case by removing the panel screws and the two screws on the bottom of the case near the back.
(2) Check the mechanical zero position of the meter pointer with the instrument turned off and all test leads removed. If the meter needle is not exactly on "Zero," turn the zero adjustment screw located on the front of the meter case until the needle returns to zero.
(3) Set the Function Selector to the "Neg DCV" position and the Range Selector to the "250 Volt" position.
(4) Plug the power supply cable into 105–130 volt 60 cycle single phase outlet and turn the power switch to "ON" position.
(5) Allow a few minutes for the instrument to heat up.
(6) Set the Function Selector to the "Neg DCV" position and rotate the Zero Adjust control knob until the meter pointer reads zero. Sufficient time should be allowed so that there will be no movement of the pointer when the Function Selector switch is turned from "Neg DCV" to "Pos DCV" position.
(7) Insert the tip end of the black test lead into the binding post marked "Common" and the DC test probe having the black phone plug at one end into the "DC Volts" jack.
(8) Set the Range Selector switch to the "25 Volt" position.
(9) Use a known voltage source of exactly 25 volts and connect the DC test probe to the negative side of the voltage source and the clip end of the "Common" test lead to the positive side of the voltage source.
(10) With a screw driver, adjust the control VR2 until the meter reads full scale with exactly 25 volts applied to the instrument completing the adjustment.

b. AC VOLTS

(1) Remove the instrument from its case.

Service Troubles and Remedies

Trouble	Probable Cause	Remedy
PILOT LIGHT DOES NOT LIGHT WHEN OPERATING SWITCH IS TURNED "ON" WITH INSTRUMENT CONNECTED TO PROPER OPERATING SOURCE. NO MOVEMENT OF METER NEEDLE.	Fuse on Panel Blown.	Replace with proper fuse.
	Fuse missing.	Replace with proper fuse.
	Fuses making poor contact in holder.	Replace fuse holder. Clean fuse clips and burnish ends of fuse.
	Open connection *in power supply* cable.	Repair or replace power supply cable.
	Defective line cord plug.	Replace plug.
	Defective operating switch.	Replace switch.
	Open transformer primary.	Replace transformer.
	Grounded high side of transformer filament secondary.	Locate and clear grounded condition.
PILOT LIGHT DOES NOT LIGHT BUT METER INDICATIONS NORMAL.	Pilot light burned out.	Replace pilot light.
	Poor contact in socket.	Clean socket terminals.
PILOT LIGHT GIVES NORMAL INDICATION BUT IN INITIAL ZERO ADJUST CANNOT BE OBTAINED.	Burned out or low emission tube.	Replace 6X5 tube.
	Burned out or low emission vacuum tube voltmeter tubes.	Replace 6G6G tubes.
	Grounded high voltage secondary circuit.	Locate and clear ground or replace transformer.
	Shorted filter condenser.	Replace condenser.
	Open resistor in rectifier output voltage divider.	Locate open resistor and replace.
	Open filter resistor, R42	Replace R42.
	Shorted meter by-pass condenser, C5.	Replace condenser C5.
	Open meter coil.	Replace meter. NOTE: Replace only with the proper meter compensated for use on a steel panel—180 microamperes in panel.
	Defective circuit selector switch.	Replace switch.
	Poor contact at circuit selector switch.	Clean switch contact by brushing with carbon tetrachloride and drying with air.

Service Troubles and Remedies (cont'd)

Trouble	Probable Cause	Remedy
INITIAL ZERO ADJUST NORMAL BUT NO AC OR DC VOLTAGE READINGS.	Poor contact between test lead tips or plugs and voltage jacks.	Burnish tips or plugs and binding post contacts with carbon tetrachloride.
	Defective range selector switch.	Replace switch.
	Poor contact at range selector switch.	Clean switch contacts by brushing with carbon tetrachloride and drying with air.
	Open multiplier resistor.	Locate and replace resistor.
	DC voltage jack ground.	Replace jack insulating washers.
	Open dc test lead.	Repair or replace lead.
	Low emission or burned out 6H6.	Replace 6H6 tube.
INITIAL ZERO ADJUST NORMAL BUT FULL SCALE READING CANNOT BE OBTAINED ON LOW OHMMETER RANGES.	Run down internal battery.	Replace battery.
BENT METER NEEDLE.	Meter overload.	Remove meter from instrument, disassemble and straighten needle or replace meter.
BROKEN METER GLASS.	Mechanical injury.	Remove meter from instrument, disassemble and replace glass or replace meter.
METER NEEDLE MOVEMENT SLUGGISH OR DOES NOT RETURN TO INITIAL READING.	Defective bearings or pivot points.	Replace meter.
	Open quadrant springs.	Replace meter.
MEASUREMENTS NOT WITHIN SPECIFIED ACCURACY AFTER PROPER CALIBRATING ADJUSTMENTS HAVE BEEN MADE.	Change of multiplier resistor values.	Check and replace faulty resistors.
	Change in meter sensitivity due to weakening of permanent magnet.	Replace meter.

(2) Check and adjust the mechanical zero position of the meter pointer with the power supply switch at "OFF."

(3) Set the Function Selector to "AC Volts" position and the Range Selector to the 25 volt range.

(4) Plug the power supply cable into the 105–130 volt 60 cycle single phase outlet and turn the power switch to "ON" position.

(5) Allow a few minutes for the instrument to heat up.

(6) Rotate the "Zero Adjust" control knob until the meter reads zero on the scale.

(7) Obtain a known sine wave voltage source of exactly 25 volts RMS value whose frequency is from 60 to 1,000 cycles per second.

(8) Connect the AC test probe to this known 25 volts source. Be sure that the "AC Lo" banana plug is connected to the grounded side of this calibrating voltage source.

(9) With a screw driver, adjust the control VR1 until the meter reads exactly full scale, completing the adjustment.

(10) Seal the screw drived slot in control VR2 and VR1 with some sort of colloidal non-corrosive cement or sealing wax.

(11) Reinstall the instrument in its case.

c. DC CURRENT

(1) Remove the instrument from its case.

(2) Check and adjust the mechanical zero position of the meter pointer.

(3) Set the "Function Selector" switch to the "MILS" position and the "Range Selector" switch to the "2.5MA" position.

(4) Connect the "Common" and "DC-MA" posts in series with a meter of known accuracy and a source of DC current adjusted to 2.5MA.

(5) With a screw driver, adjust R14 located on the top of the chassis just back of the meter until the meter reads full scale.

d. 1000 VOLT AC MULTIPLIER

(1) Obtain a 25 volt sine wave voltage source whose frequency is from 60 to 1,000,000 cps—500 ohm impedance or less.

(2) Connect the 1000 volt AC multiplier to the AC probe.

Connect the 1000 volt AC multiplier to the 25 volt AC source.

(3) Set the "Function Selector" switch to "AC VOLTS" and the "Range Selector" switch to "25 VOLTS" position.
(4) Remove the hole plug from the side of the 1000 volt AC multiplier.
(5) Set the frequency of the voltage source to 60 cycles. Note reading on meter (25 volts).
(6) Set the frequency of the voltage source to 1 megacycle (amplitude 25 volts) and adjust the variable capacitor with an insulated shaft screw driver to same reading obtained on 60 cycles.

Simpson Model 266

Replacement of Battery—The RMBZ4 battery as a current source for the ohmmeter section has an extremely long shelf life. It will give long service in the 266 but when replacement is necessary, a new battery can be slipped into the clamp holding the battery in place. It will be necessary to remove the 266 from its case which can be done by removing the four panel screws and the two in the bottom of the case. When inserting the battery, be certain that the polarity is correct. The case of this type battery is positive and the battery should be inserted so that the terminal fastened to the clamp makes contact with the case of the battery.

Calibration—The Model 266 is carefully calibrated at the factory and no further changes should be necessary. However, in case recalibration is required at any time, the following instructions should be observed.

1. Allow the 266 to warm up for approximately 1 hour. Plug the DC probe into the "COMMON" jack. Connect the AC probe and plug it into the probe well. Place the range selector switch in the 1V position.
2. Place the circuit selector switch in the "−DC" position. Turn the "ZERO ADJ" knob to the extreme right and note the reading on any scale. Turn the circuit selector switch to the "+DC" position and turn the "ZERO ADJ" knob to the extreme left. Note reading. Adjust potentiometer "D" (located

on chassis inside of tester) until these two readings are approximately equal.

3. Place the circuit selector switch in either the "+DC" position. Adjust the "ZERO ADJ" knob so that the meter indicates zero. Place the circuit selector in the "ACV" position and adjust potentiometer "C" (located on chassis) until the meter indicates zero.
4. Place the circuit selector switch in either the "+DC" or "−DC" position and set the range selector switch to any convenient range. Apply a known DC voltage to the DC probe of corresponding polarity and within the limits of the range selected. Adjust potentiometer "A" (located on chassis) until the meter indication corresponds to the known calibrating voltage. For calibration at the factory a voltage is selected approximately equal to 0.8 of full scale.
5. Place the circuit selector switch in the "ACV" position and apply a known AC voltage to the AC probe. Adjust potentiometer "B" (located on chassis) until the meter indication corresponds to the known voltage.

Replacement of Tubes—To replace the 9006 tube in the AC probe, remove the three small screws holding the front section to the cylindrical housing. Carefully separate the two sections, holding the 9006 tube socket while the housing is slipped up on the cable until the tube is exposed. Lift the terminal board away from the top of the tube and remove the 9006 tube while holding the socket in position. Clip off terminals 2, 5, and 6 of the new 9006 tube (to reduce capacitance) and insert tube in socket. Replace terminal board over the top of the tube. Re-assemble the probe housing, being certain that the clip attached to the ground terminal of the 9006 socket engages the eyelet to which the grounding clip is fastened. It may be necessary to bend the ears of this clip slightly to make certain of good connection. When assembling, turn the cable until the cable anchor slips into the notches inside of the housing. After replacement of the 9006 tube, recalibration of the AC ranges may be necessary. The calibration may also change after the tube has aged unless the tube has been aged before using.

The 6X5 tube can be replaced when necessary without affecting calibration.

When replacing the 6SN7 tube, it is advisable to use a tube which has been aged for 48 hours (connected in a circuit with a small amount of plate current flowing). A tube should be selected that will provide the best calibration for all ranges. This can be checked in the following manner. Place the circuit selector switch in the "−DC" position. Place the DC probe in the "COMMON" jack. Turn the range selector switch to the 1V position and set zero by means of the "ZERO ADJ" knob. Turn the range selector switch through all positions, noting any variation in the meter indication. This should not vary more than 2.5 divisions.

Simpson Model 303

Replacement of Battery—The 1.5V battery used as a current source for the ohmmeter will give a long service in the 303 but when replacement is necessary, a new battery can be slipped into the clamp holding the battery in place. It will be necessary to remove the 303 from its case which can be done by removing the four screws in the bottom of the case. When inserting the battery, be certain that the polarity is correct.

Calibration—The Model 303 is carefully calibrated at the factory and no further changes should be necessary. However, in case recalibration is required at any time, the following instructions should be observed:

1. Allow the 303 to warm up for approximately 1 hour. Place the range selector switch in the 1.2V position.
2. Place the circuit selector switch in the "−DC" position. Turn the "ZERO ADJ" knob to the extreme right and note the reading on any scale. Turn the circuit selector switch to the "+DC" position and turn the "ZERO ADJ" knob to the extreme left. Note reading. Adjust potentiometer "D" (located on chassis inside of tester) until these two readings are approximately equal.
3. Place the circuit selector switch in the "−DC" position. Adjust the "ZERO ADJ" knob so that the meter indicates zero. Place the circuit selector in the "ACV" position and adjust potentiometer "B" (located on chassis) until the meter indicates zero.
4. Place the circuit selector switch in the "−DC" position and set the range selector switch to the 1.2 V range. Apply a known

DC voltage to the DC probe of corresponding polarity and within the limits of the range selected. Adjust potentiometer "A" (located on chassis) until the meter indication corresponds to the known calibrating voltage. For calibration at the factory a voltage is selected approximately equal to ⅔ of full scale.

Sylvania Type 221

Removal From Cabinet—The unit is removed from the cabinet by removing the screws from the edge of the panel and lifting out the assembly.

Components—

1. Should replacement of any components become necessary, parts equivalent in all ways to those listed in the parts should be used.
2. The type 7N7 tubes should be replaced when the DC range cannot be properly set to zero even after reasonable warm up time (10 min.). These tubes may be replaced without adjustment.
3. The aging of the type 5679 tube may change the zero setting on the AC range. If an appreciable change in zero setting occurs when the SELECTOR switch is changed from DC to AC, the potentiometers marked AC ZERO SET should be adjusted to eliminate the error.
4. The 1.5 volt cells should be replaced when the OHMS SET control does not permit adjustment of meter pointer to full scale with an open circuit between ohmmeter prods. To prolong life of these cells, do not unnecessarily short the test leads in Ohmmeter use, especially on the lower resistance ranges. To change the battery cells, remove the Polymeter from its cabinet, remove the Phillips head screws holding battery bracket, then remove the bracket holding the cells by raising slightly and sliding toward the rear. Place new cells in position in series, soldering the ground lead to the positive pole of one battery and the lead from the range switch to the negative pole of the other battery. Reassemble the entire unit, noting that the *positive terminal of the battery is grounded.*

Calibration—

1. Recalibration is seldom necessary even when the tubes are replaced, but if it should become necessary proceed as follows: NOTE: All potentiometers should be resealed with radio cement or lacquer after resetting.
2. DC Calibration—Zero the meter mechanically with the unit turned OFF. Turn the Polymeter ON and allow approximately fifteen minutes as warm-up time. Set the SELECTOR switch on plus (+) VOLTS and the RANGE switch in the 10 v. position, zero the meter with ZERO SET, apply exactly 10 v. DC and adjust the potentiometer on the chassis marked DC SET until the meter reads 10 v. This calibrates all DC ranges.
3. AC Calibration—Adjust ZERO SET as described under DC Calibration, above. Set the SELECTOR switch on AC VOLTS and the RANGE switch in the 3 v. position. Connect the AC VOLTS and COMMON test prods to each other for adjustment of the AC ZERO SET. Rotate FINE AC ZERO SET until the meter indicator rests on zero. If this is not possible, turn FINE AC ZERO SET to its complete clockwise position, and adjust the COARSE AC ZERO SET until the meter indicates 0.4 to 0.5 on the 10 v. scale. (Caution—the COARSE AC ZERO SET is in the filament circuit of the Type 5679 tube. Allow sufficient time for the meter reading to stabilize after each adjustment to allow for slow changes in heater temperature.) Rotate FINE AC ZERO SET until the meter reads zero. If this procedure fails, replace the type 5679 tube and repeat the procedure. Set the RANGE switch on the 10 volt scale, apply a harmonic-free voltage of exactly 10 volts rms and about 60 cycles frequency to the Polymeter, and adjust the potentiometer marked AC SET until the meter reads 10 volts. This calibrates all AC ranges.
4. RF Calibration—Adjust ZERO SET as described under DC Calibration. Set the SELECTOR switch on RF VOLTS, and the RANGE switch in the 3 v. position. Short the point of the probe to the probe case and adjust the front panel RF SET control until the meter pointer indicates zero volts. Set the RANGE switch on the 10 v. scale, apply a harmonic-free

signal of exactly 10 volts rms and a frequency of about 20 kc. to the Polymeter through the RF probe, and adjust the RF SET located on the rear of the chassis until the meter reads 10 v. This calibrates all RF ranges.

Triplett Model 2451

General—Model 2451 is designed to require little or no maintenance. In the event of rough handling the unit may be checked quickly by referring to the voltages read at the pins of the tubes as taken with a 1000 ohm per volt meter from the pin to ground.

Tube	Pin Number							
	1	2	3	4	5	6	7	8
6H6		0					H	
6X5GT		*	110 AC		110 AC		*	†110 DC
7A5 (grounded grid)	H	†39 DC	†39 DC	NC	NC	0	†5.2 DC	0
7A5 (ungrounded)	H	†39 DC	†39 DC	NC	NC	†	†5.2DC	0

* Ungrounded 6.3 volt AC filament supply H-6.3 volt AC filament voltage.

† These voltages read with SELECTOR switch in "+ volts" position and DC leads shorted. NC—No Connection.

Battery Replacement—As the batteries age or are subjected to frequent use the "ZERO ADJ" knob will have to be turned further clockwise to adjust the meter pointer to full scale. When this adjustment can no longer be made the batteries should be replaced.

To replace the batteries it is only necessary to remove the chassis assembly from the case. This assembly is fixed to the front panel and sub panel. This is accomplished by removing the four corner screws and separating the case from the chassis front panel assembly. The AC line cord must be free to follow the chassis as the case is removed. Care should be used so that components or the meter are not injured.

Tubes and Calibration—All components and tubes are operated at very conservative ratings. However, at times certain parts may have to be replaced. The tubes, some resistors, and condensers are standard. Precision and calibrating resistors are labeled on the wiring diagram. Bridge tube replacement should be made with some care. These tubes should be reasonably balanced, otherwise difficulty will be encountered with drift or when attempting to zero.

DC Voltage Calibration—If you find it necessary to recalibrate this tester yourself turn the SELECTOR switch to "+volt" and adjust the meter pointer to zero with the "ZERO ADJ" knob and the DC test leads shorted. The RANGE switch should be on the 2.5 volt setting. A standard source of 2 volts DC must be used and the instrument adjusted accurately to this point by the screwdriver type potentiometer R29 located on the top of the chassis. R29 is the left potentiometer of the three located beneath the meter when viewed from the rear.

After this adjustment has been made reverse the polarity of the connections to the standard voltage source and move the SELECTOR switch to the "−volts" position. Adjust the 2 volt scale point accurately by means of R28 which is the potentiometer located to the right when the chassis is viewed from the rear.

No further adjustment need be made on higher ranges for either +volts or −volts since the calibration is fixed by the above controls.

AC Voltage Calibration—It is necessary that the 2451 be functioning properly on DC voltage range before it can be calibrated on AC.

With the AC test leads shorted, the SELECTOR switch in the "AC-RF VOLTS" position and the RANGE switch in the "2.5 volts" position, adjust the meter pointer to zero with the "ZERO ADJ" control. Next connect the test leads to a source of 2 volt AC and adjust the AC calibrating potentiometer R30 which is the center one of three located on the chassis.

All of these calibrations should be performed with the greatest amount of accuracy possible.

No electronic calibration is required for the Ohm and DCMA ranges after the previously mentioned ones have been made since the former depends upon the DC voltage ranges and the latter is not electronic.

Weston Model 769

Batteries—Two internal 1½ volt flashlight type batteries are used for operating the ohmmeter ranges. They are the standard #2 size. When it is impossible to bring the instrument pointer to the zero resistance or full scale reading with the test leads shorted on the low ohmmeter or "R" range, these batteries should be replaced.

The batteries are held in clamps in the bottom of the case.

1. Remove the four corner panel screws and lift the complete panel assembly out of the case.
2. Place the thumb over the positive end of the clamp pressing towards the battery.
3. Pull up the ring clamp.
4. Pull the battery up and out of the clamps.
5. Replace the battery, fasten the open end of the ring clamp over the projections at the negative end.
6. Snap the ring down over the thumb clamp at the positive end.

Fuses—The Model 769 is insulated from the power line, and both line cord conductors are fused. The two fuses are mounted in the line cord plug. If the device will not operate and the pilot lamp does not glow when the switch is turned on, check the A-C line potential using the 300 volt 1000 ohms per volt A-C range. If the line is energized, check the fuses in the plug using the "R" or "R x 10" range. This may be done without removing the fuses from the plug. Also check between line terminals with the power switch on, to be sure the fuses are making contact. Replace the fuses with an automobile fuse type 3AG, with a 1 ampere rating.

Pilot Lamps—The pilot light used is a brown bead 6.3 volt miniature bayonet base lamp. To replace: remove the plastic cap and insert a new lamp.

Tubes—The amplifier section includes 4 tubes and 2 neon regulator lamps. Since all of the tubes are operated at relatively low potentials, long operating life may be expected. The amplifier, however, is self-balancing to the extent that tube changes will not affect the operation of the device.

If any time it is necessary to replace any of the tubes, remove the 4 corner panel screws and lift the panel assembly out of the case. The tube type numbers are marked on the chassis next to the sockets. The tube complement consists of:

2 type 6SJ7 Tubes
1 type 6SL7 Tube
1 type 6X5 Rectifier
2 type 991 Neon Glow Lamps

If the device appears to be defective on all electronic functions the tubes should be examined and replaced as required. After replacement it may be advisable to check the Model 769 for excessive grid current in the input 6SJ7 tube. This is the tube furthest from the panel.

Probe Tube Replacement—The subminiature diode tube in the AC or RF probe is operated under very conservative conditions and should render long service without any need for replacement. The very short tube leads are soldered in place in the tip, and are not accessible without small tools and a very small soldering iron.

The polystyrene head may be damaged in attempting to replace the tube with the wrong tools.

Test for Excessive Grid Current in the Input 6SJ7 Tube—

1. Operate the device on the 3 volt D-C electronic range.
2. Warm up the equipment for three to five minutes.
3. Short circuit the three volt input by connecting the +DC VOLTS ELECTRONIC jack to the GROUND jack.
4. Using the ELECTRONIC ZERO ADJUSTMENT, set the instrument pointer to zero.
5. Open the circuit by removing the shorting lead from both jacks.
6. If the pointer moves more than one division on the D-C scale, the input 6SJ7 should be replaced by a new tube if first interchanging the two 6SJ7 tubes does not correct the fault.

Glow Lamps—The two type 991 glow lamps will very seldom require replacement. However, if this is necessary, unsolder the two short flexible leads connected to the base terminals of the lamp and remove the lamp from the clip. Replace as required and solder the leads in position.

Care of Accessories—When not in use, the RF probe, Test Leads and other Accessories should be carefully stored in the accessory compartment. To assure long service of the accessories handle them with reasonable care and check the test leads periodically for continuity.

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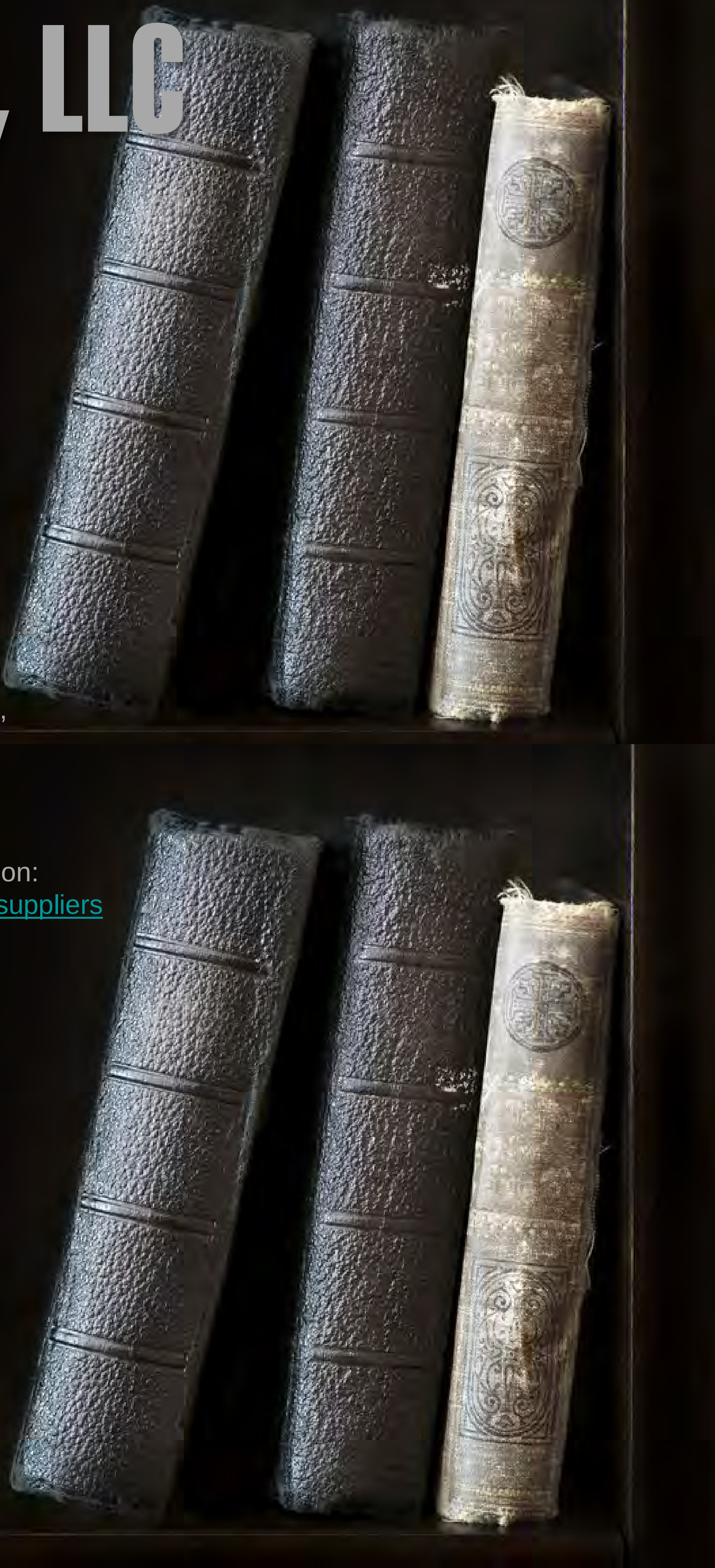

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