HANDBOOK OF ELECTRONIC METERS Theory and Application

Thorough, simple, and highly practical approach to the most effective use of meters to test and service a variety of electronic components and circuits

Revised and Enlarged

JOHN D. LENK

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Theory and Application

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HANDBOOK OF ELECTRONIC METERS: THEORY AND APPLICATION

Revised and Enlarged

By John D. Lenk

In this revision of the widely accepted and used HANDBOOK OF ELECTRONIC METERS: THEORY AND APPLICATION, technical writer John D. Lenk again provides readers with a thorough, simple, and highly practical guide to the most effective application of electronic meters in testing and servicing components and circuits.

His comprehensive coverage includes eight well-written, illustrated chapters devoted to meter basics, accessory probes, basic operating procedures and techniques, testing and calibrating electronic meters, special measurement procedures, methods for checking individual components, methods for checking various functions of circuits, and techniques employed in the servicing of specific circuits with meters—including circuits for a variety of receivers, transmitters, amplifiers, filters, and oscillators.

AMONG THE FEATURES

- Assumes no prior familiarity with the operating principles and characteristics of electronic meters.
- Discusses fundamentals, probes, and important operating procedures.

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- Includes special measurement procedures and effective methods for cheking individual components as well as complete circuits.
- Shows how to service specific circuits with electronic meters.
- Includes the most recent advancements in electronic components and measurement techniques.

THE AUTHOR

JOHN D. LENK, is one of the most widely read technical authors in electronics. This book, his 44th easy-to-understand text, is the authoritative work on the subject of electronic meters.

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Preface

This revised edition of the HANDBOOK OF ELECTRONIC METERS: THEORY AND APPLICATION, carries through all of the features that made the first edition so successful. That is, the revised edition bridges the gap between electronic meter theory and practical applications. The new edition thus serves the dual purpose of a basic textbook for student technicians, hobbyists, and experimenters, and a factual guidebook for experienced, working technicians. All of the chapters in the revised edition have been expanded or enlarged to include new material. Existing information has been up-dated to reflect present-day trends, especially the extensive use of digital meters. Also, much of the material from the first edition has been revised for clarification and/or simplification.

The manufacturers of meters provide instruction manuals on the operation and circuit theory of their particular instruments. Rarely, however, do these manuals give any *applications data* describing the many uses of meters. Even the training films and service courses of the largest and best-known meter manufacturers are notably lacking in such material. There are exceptions to this rule, of course.

Because the voltmeter, ohmmeter, ammeter, multimeter, and multitester are such simple instruments, and in such common use, it is generally assumed that the technician will know "automatically" the procedures for using such meters, and the capabilities and limitations. This is seldom the case. For example, how do you troubleshoot transistors "in circuit" with voltage readings? Or how do you find the resonant frequency of an LC circuit with a voltmeter, or locate the firing point of a unijunction transistor, or make a "quick-check" of a solid-state oscillator?

As in the original, this edition of the handbook fills the gap in information, and can be used to supplement the operating instructions of any meter (digital or analog), whether it be a low-cost shop type or a precision laboratory instrument. This is done by providing a variety of test, measurement, service, and troubleshooting procedures using the meter as the basic tool. These procedures are presented in "cookbook" fashion. Each procedure is preceded by a brief description of the "why" and "where" for the particular test. These descriptions offer a digest to readers who may be unfamiliar with some specialized meter applications, and want to put the step-by-step procedures to immediate use. Each operation is illustrated with test connection diagrams. Although every possible use of a meter has not been included, the practical, experience-proven applications are here.

Assuming that some readers are not familiar with the operating principles and characteristics of meters, the initial chapters give simplified presentations of these details. Chapter 1 discusses meter basics. Chapters 2 and 3 cover accessory probes, and basic operating procedures, respectively. With basics out of the way, the new edition then goes on to cover test and calibration of meters (Chapter 4), special measurement procedures (Chapter 5), using meters to check individual components (Chapter 6), and to check circuit functions (Chapter 7). Chapter 8 concentrates on servicing specific circuits with meters.

Many professionals have contributed their talent and knowledge to the revision and enlargement of the new edition. The author gratefully acknowledges that the tremendous effort to make this second edition such a comprehensive work is impossible for one person, and he wishes to thank all who have contributed directly and indirectly. The author wishes to give special thanks to the following: B&K Precision, Heathkit, Hewlett-Packard, Radio Shack, Simpson Electric Co., and Triplett Electrical Instrument Co. The author also wishes to thank Mr. Joseph A. Labok of Los Angeles Valley College for his help and encouragement.

JOHN D. LENK

Contents

1

Meter Basics

It is almost impossible to get by in any phase of electronics without some form of meter. Both hobbyists and professional technicians find it necessary to check on circuits and components—to find what voltage is available, how much current is flowing, and so on. The simplest and most common instrument that will measure the three basic electrical values (*voltage, current, and resistance*) is the *voltohmmeter* or VOM. Sometimes, the terms *multimeter* or *multitester* are used in place of VOM. There are dozens, if not hundreds, of VOMs available in all price ranges. As the price goes up, accuracy is increased, more scales or functions are added, and the scales are given greater range.

In the early days of electronics, it was common practice for the experimenter to build his own VOM. Today, because of the reduced prices and the difficulty (for practical considerations) of making accurate meter scales, the homemade VOM is almost unknown. In a way, this trend is unfortunate since much can be learned by building a VOM. As resistance is added to make a basic meter movement into a working ammeter and voltmeter, or as power and resistance are added to a basic movement for conversion to an ohmmeter, many of Ohm's and Kirchhoff's laws become practical values instead of dull theories.

The first improvement on the VOM was the *vacuum-tube voltmeter* or VTVM. Today, the VTVM has been replaced by the *transistorized* or *electronic voltmeter*. The sensitivity of these instruments is much greater than that of the VOM since electronic meters contain an amplifier. Electronic meters have another advantage over the VOM in that the electronic meter amplifier presents a high impedance to the circuit or component being measured. Thus, electronic meters draw little or no current from the circuit and have little effect on circuit operation. Those electronic meters using the *field effect transistor* or FET in their amplifiers present the highest impedance and draw the least current from the circuit, since FETs have a very high impedance compared to that of other transistors. FET meters are thus used in very sensitive electronic circuits.

The VOM, VTVM, electronic meter, and FET meter are all *analog meters*. That is, they use rectifiers, amplifiers, and other circuits to generate a current that is proportional to the quantity being measured. In turn, this current drives a meter movement. Two additional types of meters, the *differential meter* and the *digital voltmeter* (or DVM), are being used in the laboratory as a supplement to (or replacement for) the analog meters. The differential voltmeter operates by comparing an unknown voltage with a known voltage. The digital voltmeter displays measurement in discrete numerals rather than as a pointer deflection on a continuous scale as commonly used in analog instruments.

It would be almost impossible and beyond the scope of this book to describe all of the circuits used in modern meters. Many of these circuits are special-purpose. Likewise, many basic circuits are used in various combinations. Rather than attempt to describe every known meter, we shall devote the remainder of this chapter to "typical" meter circuits.

For the student, the following paragraphs also describe how a VOM is made from a basic meter movement. If it is known how an instrument operates, it will be known why an instrument can produce the desired voltage, current, or resistance information.

1-1 D'ARSONVAL MOVEMENT AND THE BASIC VOM

The simplest and most commonly used movement is the *D'Arsonval* meter movement shown in Fig. 1-1. This movement is also known as the *moving-coil galvanometer*. Early D'Arsonval movements had a core made of soft iron. A coil of very fine wire was wound on an aluminum form around the core. The iron core is now usually omitted from the movement. The coil and aluminum form function somewhat like an armature mounted on a shaft seated in jewel bearings so as to be free to turn (rotate). Springs on each end of the shaft act as current leads to the coil and help steady the coil movement.

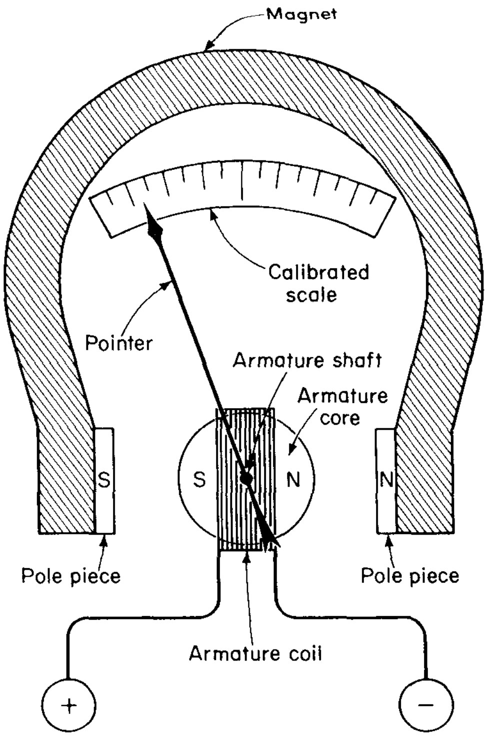

Fig. 1-1 Basic D'Arsonval meter movement. (John D. Lenk, Handbook of Electronic Test Equipment, © 1971, p. 2. Courtesy Prentice-Hall.)

The coil is placed between the poles of a U-shaped permanent magnet. One end of a pointer is fastened to the armature shaft. As the shaft rotates, the other end of the pointer moves over a calibrated dial. Current through the armature coil sets up a magnetic field that reacts with the permanent magnet's field to rotate the coil with respect to the magnet. When current passes through the coil, its magnetic field is such that the poles repel, and, since the permanent magnet cannot move, the coil rotates on its shaft. Current through the coil makes the coil turn a proportional amount. Thus, the basic meter movement is an analog device. The amount of travel of the pointer attached to the coil is related directly to the amount of current flowing through the movement. The meter scale is then related to some particular current. For example, if 1 mA is required to rotate the coil and pointer across the full scale, a half-scale reading will be equal to 0.5 mA, a quarter-scale reading will be equal to 0.25 mA, and so on.

Usually, maximum rotation of the armature (full-scale reading) is completed in less than a half turn in the clockwise direction. The complete assembly is enclosed in a glass-faced case that protects it from dust and air currents. This enclosed meter movement can be used by itself as a very sensitive ammeter. However, it is usually part of another instrument, such as a

VOM, or in a panel connected to an external circuit. In the case of a laboratory or shop meter, there is a resistor network to extend the range of the basic movement (as an ammeter) or to convert the basic movement into a voltmeter.

Basic Ammeter

The basic D'Arsonval movement, by itself, forms an *ammeter* (*am*pere *meter*). A true ammeter measures current in amperes. In electronics, current is more often measured in milliamperes or microamperes. Most movements used in electronic meters will produce a full-scale deflection when 1 mA (or a few microamperes in many cases) is passed through them.

A *shunt* must be connected across the meter movement if it is desired to measure currents greater than the full-scale range of the basic meter. The shunt can be a precision resistor, a bar of metal, or a simple piece of wire. Electronic-meter shunts are usually precision resistors that may be selected by means of a switch. Panel meters for heavy industrial work use metal bar shunts. Shunt resistance is only a fraction of the movement resistance. Current divides itself between the meter and shunt, with most of the current flowing through the shunt. Shunts must be precisely calibrated to match the meter movement.

Figures 1-2 and 1-3 show the two typical milliammeter range-selection circuits for VOMs. In Fig. 1-2, individual shunts are selected by the range-

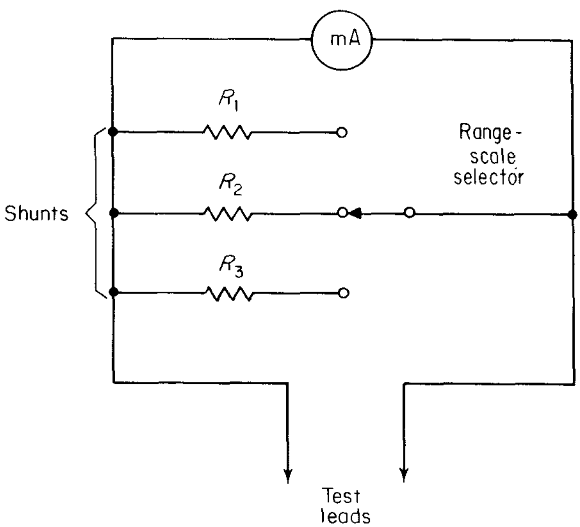

Fig. 1-2 Typical milliameter range-selection circuit (individual shunt method).

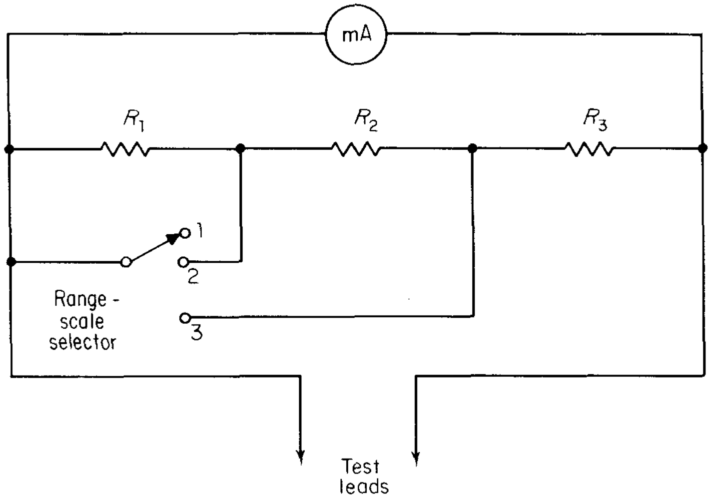

Fig. 1-3 Typical milliameter range-selection circuit (series shunt method).

scale selector. In Fig. 1-3, the shunts are cut in or out of the circuit by the selector. If the selector is in position 1, all three shunts are across the meter movement, giving the least shunting effect (most current through the movement). In position 2, resistor R_1 is shorted out of the circuit, with resistors R_2 and R_3 shunted across the movement, increasing the meter's current range. In position 3, only R_3 is shunted across the movement, and the meter reads maximum current.

It is possible to calculate the values of shunt resistance and thus convert any basic meter movement into an ammeter. The necessary equations and procedures are described in Chapter 5.

Basic Voltmeter

When the basic D'Arsonval movement is connected in *series* with resistors, a *voltmeter* is formed. The series resistance is known as a *multiplier*, since the resistance multiplies the range of the basic meter movement.

The basic voltmeter circuit is shown in Fig. 1-4. As shown, the voltage divides itself across the meter movement and the series resistance. If an 0.5-V full-scale deflection meter movement is used, and it is desired to measure a full scale of 10 V, the series resistor must drop 9.5 V. If a 100-V full scale is desired, the series resistance must drop 99.5 V, and so on. The necessary equations and procedures for calculating the values of series resistances (to convert a basic meter movement into a voltmeter) are described in Chapter 5.

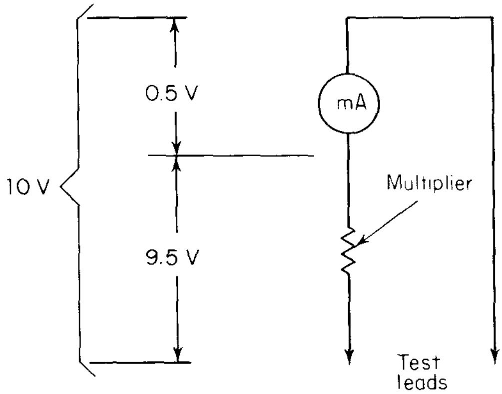

Fig. 1-4 Basic voltmeter circuit.

Figures 1-5 and 1-6 show the two typical voltmeter range-selection circuits for VOMs. In Fig. 1-5, individual multipliers are selected by the range-scale selector. In Fig. 1-6, the multipliers are cut in or out of the circuit by the selector. If the selector is in position 1, only resistor R_1 is in the circuit, giving the least voltage drop (meter will read the lowest voltage). In position 2, both R_1 and R_2 are in the circuit, giving the meter a higher voltage range. In position 3, all three resistors drop the voltage, permitting the meter to read maximum voltage.

The term *ohms per volt* is used to describe commercial VOMs. Ohms per volt is a measure of a VOM's sensitivity and represents the number of ohms required to extend the range by 1 V. For example, if the meter movement requires 1 mA for full-scale deflection, then 1000 ohms (including the movement's internal resistance) are needed for each volt that could be measured if the movement were used as a voltmeter. If the movement requires only 100 μA for full-scale deflection, then 10,000 ohms/V are needed. Thus, the more sensitive the meter movement (those requiring the least current), the higher the ohms-per-volt requirement.

Voltmeters with a high ohms-per-volt rating put less load on the circuit being measured and have a less disturbing effect on the circuit. For example, assume that a 1-V drop across a 1000-ohm circuit is to be measured with both a 100-ohms/V meter and a 20,000-ohms/V meter. A 1-V drop across a 1000-ohm circuit will produce a 1-mA current flow. With the 1000-ohms/V meter across the circuit, the 1-mA current will divide itself between the meter and the circuit. This would cut the circuit's normal current in half. With a 20,000-ohms/V meter across the same circuit, $\frac{1}{20}$ of the current will pass through the meter, and $\frac{19}{20}$ will remain in the circuit.

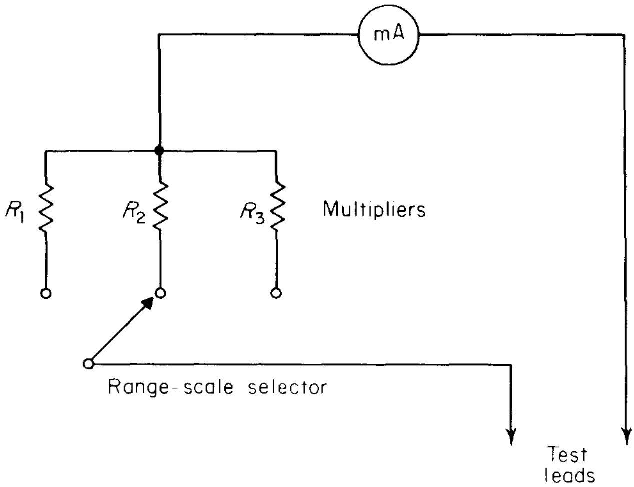

Fig. 1-5 Typical voltmeter range-selection circuit (individual multiplier method).

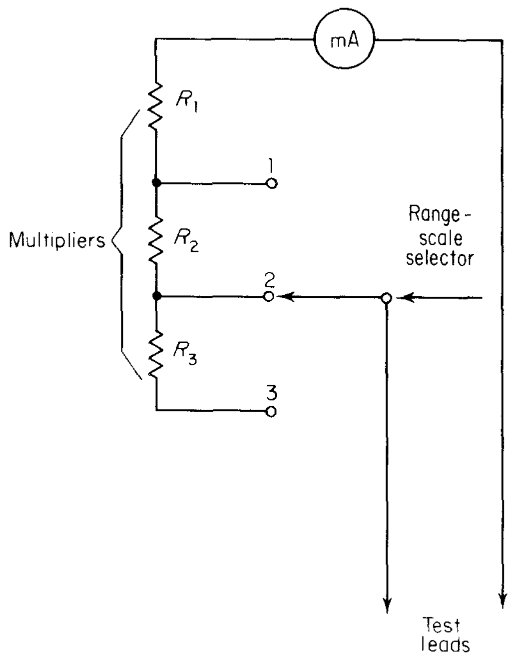

Fig. 1-6 Typical voltmeter range-selection circuit (series multiplier method).