

PART 1

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Focus on traditional VOM's and analog-type electronic multimeters.

THE MULTIMETER, the workhorse of electronics servicing and experimenting, is usually the first instrument you reach for and the last you put away. What makes this instrument so popular is its versatility in performing tests and making measurements of a number of different electrical parameters. Needless to say, there is a wide variety of multimeters on the market, ranging from the traditional VOM to sophisticated digital instruments. Selecting a multimeter, therefore, requires a basic understanding of what each instrument can and cannot do. Even more important, you must understand how to use the instruments to obtain the maximum benefit from them.

Examined here will be problems common to all electronic measurements, including some of the lesser known, but very important pitfalls to be avoided. We will also discuss the problems often encountered in making measurements in modern state-of-the-art circuits.

In this first part, we focus on the traditional VOM and analog-type electronic multimeters.

Technical Details. Multimeters can be classified into two general categories. In one category we have passive VOM's. All other types of multimeters—VTVM's, TMM's, and DMM's—are classified as electronic or active types. The big difference between the two

categories is that passive instruments must extract current from the circuit under test to deflect the meter movement, while electronic instruments have their own power supplies to drive the display.

In extracting current from a circuit, a VOM can upset circuit conditions. This "loading" effect on the circuit can cause inaccurate measurements. How much the conditions are upset depends on the resistance between the meter's test leads. The circuit shown in Fig. 1 demonstrates the effects of meter loading. Without the meter connected across R_2 , total circuit resistance is 200,000 ohms, divided equally between the two resistors. The actual voltage drop across each resistor is 30 volts without the meter connected to the circuit. When it is connected as shown, the meter's 100,000-ohm resistance is in parallel with the 100,000-ohm value of R_2 , which yields a net resistance of 50,000 ohms for the parallel combination and a total circuit resistance of 150,000 ohms. Because of the meter's loading on the

circuit, the measured voltage across R_2 will be 20 volts, a 33.3% inaccuracy.

With all conditions remaining the same in the Fig. 1 circuit, using a meter with an 11-megohm input resistance, the parallel resistance of R_2 and R_m would for all practical purposes be 100,000 ohms. Hence, the voltage dropped across R_2 , with minimal meter loading, would register roughly 30 volts.

The resistance of a VOM depends on the full-scale voltage. Hence, the meter's sensitivity is specified in ohms/volt. To determine resistance, the meter's sensitivity is multiplied by the full-scale voltage. This means that the resistance of a 1000 ohms/volt meter on the 100-volt range is 100,000 ohms, while for a standard 20,000 ohms/volt meter on the 100-volt range, the resistance would be 2 megohms. For a high-resistance circuit like that in Fig. 1, a 20,000 ohms/volt meter would be acceptable, but a 1000 ohms/volt meter would be unacceptable. (The ohms/volt rating is generally specified for the dc function only. The sensitivity on the ac function is typically only 20% to 50% of the dc sensitivity, or 5000 ohms/volt versus 20,000 ohms/volt.)

Loading can occur in low-voltage as well as high-resistance circuits. The resistance of a 20,000 ohms/volt meter is only 10,000 ohms on the 0.5-volt range. For service measurements, the meter's resistance should exceed 10 times the

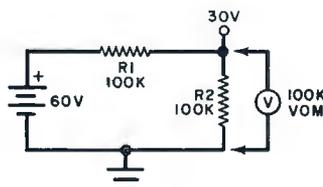


Fig. 1. The VOM here loads down the circuit, causing 33.3% inaccuracy.

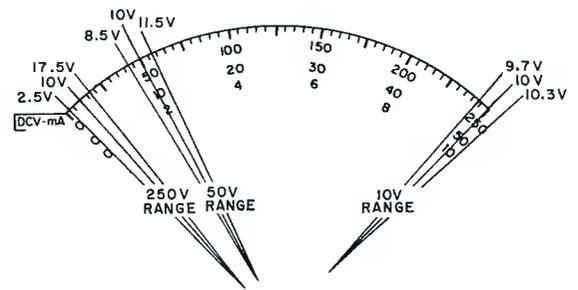
source impedance of the voltage to be measured to avoid excessive errors. This means that a 20,000 ohms/volt meter would be unsuitable for measuring 0.4 volt if the source impedance is more than 1000 ohms, but a 100,000 ohms/volt meter could measure a 0.4-volt potential across impedances up to 5000 ohms. Circuits with both low voltages and high impedances place critical demands on the meter.

For very accurate measurements, the resistance of the meter should exceed 25 times the source impedance. The loading error will then be maintained at less than 2%, which would be in the range of the meter's accuracy.

The inherent accuracy of meters is commonly expressed as a percentage of the full-scale reading. A reading on the 250-volt range of a 3% meter could be off by as much as 7.5 volts (250 volts \times 0.03 = 7.5 volts). A 200-volt reading could indicate anywhere between 192.5 and 207.5 volts.

On the ac ranges, the accuracy might vary with frequency and range. For example, the rated accuracy of a good VOM might apply up to 100,000 Hz on all ranges up to 50 volts but only to 20,000 Hz on the 250-volt range.

Fig. 2. Reading of 10 volts may indicate 9.7 to 10.3, 8.5 to 11.5, or 2.5 to 17.5 volts depending on the range setting.



In taking a voltage or current measurement, always start out on a higher range than necessary to protect the meter from possibly damaging overloads. For best accuracy, however, take your final reading on the lowest usable range so that the meter's pointer indicates in the upper portion of the scale where it is most accurate. As Fig. 2 demonstrates, a reading of 10 volts on a 3% meter can be between 9.7 and 10.3 volts on the 10-volt range, between 8.5 and 11.5 volts on the 50-volt range, and between 2.5 and 17.5 volts on the 250-volt range. In the last case, the inaccuracy is so great that the reading would be meaningless.

Worst-case accuracy occurs when the voltage to be measured just exceeds full-scale on one range so that the next higher range must be used. For a 3%

meter with ranges of 3, 12, 60 volts, etc., the worst-case accuracy is $\pm 15\%$, obtained when measuring just over 12 volts on the 60-volt range. Using a 3% meter with 1.5-, 5-, 15-volt, etc., ranges provides an improvement in the worst-case accuracy of $\pm 9\%$. Needless to say, the scaling sequence can have an important effect on accuracy.

An Old Favorite. The VOM, or volt-ohm-milliammeter, was probably the first instrument most of us learned to use and the first one we bought. In many cases, we still reach for it when we must measure a voltage, current, or resistance. The VOM is extremely versatile, capable of measuring just about any ac or dc parameter that can be related to Ohm's law. And it is rugged and



Sencore's FF27 "Big Henry" is a field-effect multimeter with P-P and RMS ac scales.



High-voltage multiplier probe made by B&K Precision.



B&K Precision's Model 177 vacuum-tube voltmeter has a large 7" mirrored meter and a special 0.5-V dc scale.

also battery powered. Add to this its operating ease and low cost, and it is no wonder that the VOM has retained its high popularity.

A typical VOM has 0.25- and 1.0-volt full-scale ranges in both the ac and dc functions; dc current ranges as low as 50 μ A to as high as 500 mA full-scale; and resistance ranges of up to 30 megohms. The decibel ranges cover from -20 to +50 dB, with 0 dB specified as 1 mW into 600 ohms.

Most VOM's are rated at 20,000 ohms/volt and will range between \$25 and \$125. There are still some VOM's around with a 1000-ohm/volt sensitivity, but these are of very limited usefulness for electronics measurements. Sensitive VOM's with ratings of 100,000 ohms or even 1 megohm/volt are also available for between \$65 and \$250.

The accuracy of the typical VOM is within 2% of full-scale on the dc ranges, 3% on the ac ranges, and 2% to 3% of scale length on the resistance ranges.

All VOM's come with separate red and black test leads. The black lead is inserted into the common, or reference, jack on the meter (marked COM, NEG, or -). The red lead goes into the "hot" jack (marked V, Ω , MA, or +). For the very

highest and lowest voltage ranges and current ranges, the red lead is inserted into an extra positive jack that is appropriately labelled.

Most VOM's are similar in the way they operate. A polarity-reversing switch, usually labelled +DC/-DC) provides a convenient means of transposing test lead polarity on dc and resistance measurements. For normal operation, this switch is set to the +DC position. Then, using the black test lead as the reference, positive-polarity signals produce an up-scale deflection. Conversely, negative signals are accommodated without transposing test probes simply by switching to -DC.

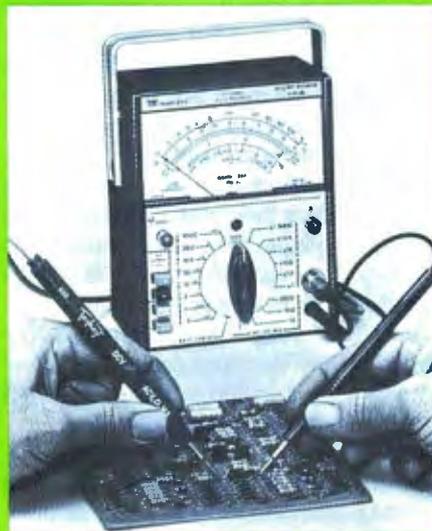
The uppermost scale on a typical VOM unit is for resistance and is usually color coded in black. If the RANGE switch is set to any position other than $R \times 1$, the reading obtained must be multiplied by the resistance multiplier indicated by the switch setting. For resistance, the scale is inverse and nonlinear. The most accurate measurements are obtained when the pointer is in the lower one-third to one-half of the scale, where the calibrations have the widest separation. All other VOM scales are most accurate at their high ends.

Second from the top is often the dc scale, which is usually coded black. This scale has several sets of numbers at the major calibration marks, with each set applying to one or more settings of the RANGE switch. For the Simpson Model 160, for example, the numbers from 0 to 50 apply to range/function settings of 50 μ A, 50 volts, 500 volts, and 500 mA. (On the 500-volt and 500-mA ranges, the indication provided by the meter's pointer must be multiplied by 10.)

There are usually two ac scales, both marked in red. The same scale numbers used for the dc scale are used for the upper red ac scale, while the bottom red scale, used for low ac voltage measurements, has its own numbers. Below this is the decibel (dB) scale.

Using the VOM is very simple. You just insert the test leads into their appropriate jacks, switch to the proper range and function, connect the leads to the circuit under test, and observe the position of the pointer on the scales. Note that for voltage measurements, the test probes are connected in parallel with the circuit or element under test. For current measurements, the circuit must be broken to allow the meter to be connected in series with it.

Tripplitt's Model 603 solid-state VOM has switchable isolation resistor in probe for dc and low-power-ohms function.



Hickok's pushbutton-operated Model 370 has automatic polarity indicator and anti-parallax mirror-backed scale with automatic polarity indicator and FET input.



The Leader Model LEM-75, a transistor multimeter, has a temperature scale that is used with an accessory probe.



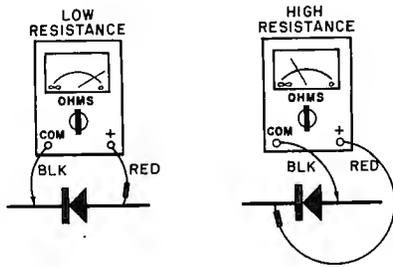


Fig. 3. In checking a diode, resistance in one direction should be 100 times more than in the other direction.

Ohmmeter Use. Resistance measurements are only a little less simple to perform than voltage measurements with a VOM. Always bear in mind that the ohmmeter must *never* be connected to a powered circuit or it will be damaged. Make sure all power is shut off and that all electrolytic capacitors, if any, are discharged.

Since the ohmmeter incorporates a battery to supply current to the measurement circuit, it is necessary to correct for battery and other circuit changes. You do this by setting the selector switch to the desired range, shorting together the test probes, and operating the ZERO ADJUST control until the meter pointer is resting exactly at 0 on the scale. If the meter cannot be zeroed, the battery must be replaced. Repeat this procedure whenever you change ranges.

The ohmmeter can also be used to check the condition of diodes out-of-circuit, as shown in Fig. 3. You simply measure the diode's resistance in one direction, reverse the test leads (or flip the polarity-reversing switch) to measure its resistance in the other direction, and compare your readings. For a good diode, the readings should differ by 100 or more times. If the resistance is zero in both directions, the diode is shorted; if it is infinity in both directions, the diode is open.

Though it is not usually recommended as a safe procedure, transistor junctions can also be tested with an ohmmeter—if certain precautions are exercised. Always bear in mind that some ohmmeters and some ranges on all ohmmeters can damage low-voltage semiconductors and electrolytic capacitors. In testing semiconductors, use the $R \times 100$ range of the ohmmeter. Avoid using the highest and lowest ranges because they can supply excessive voltage and excessive current, respectively, to the device under test.

The resistance of nonlinear components, such as diodes, will measure different values on different ranges. For

example, a diode could measure 80 ohms on the $R \times 1$ range and 300 ohms on the $R \times 100$ range. This is normal and is the result of the diode characteristic.

In-circuit resistance measurements can be misleading as well as damaging, as follows. Assume that in the Fig. 4 circuit you took a measurement across R_B with the positive test probe touching ground. Since R_E is also connected to ground, the voltage applied by the ohmmeter would forward bias the emitter-base junction of the transistor. In effect, R_E would be in parallel with R_B . One way around this problem would be to disconnect one end of R_B from the circuit for the test. Another way would be to use an ohmmeter with a low-power-ohms circuit. Such an instrument applies a voltage that is too low to bias on or damage a junction. The Simpson low-power-ohms probe adds this feature to any VOM with a 250-mV (50- μ A) jack and a 12-ohm center-scale meter. An open-circuit voltage of only 30 mV or less is applied to the circuit under test.

Ac Problems. Another problem with VOM's concerns ac measurements. In a VOM, the ac voltage is rectified to provide a pulsating dc voltage that can be measured by a dc-only meter movement. Unfortunately, the VOM responds to, or measures, the average value of the ac voltage rather than the rms value in which we are more interested. Since the ratio of the rms value to the average value of a sine wave (its form factor) is known to be a constant 1.11 (Fig. 5), meter manufacturers skirt the problem by calibrating their meter scales to give the rms value of a sine wave. This means, for example, that if 100 volts is applied, the meter's pointer actually registers 63.7 volts but is registering 70.7 volts on the doctored scale. For waveforms other than the sine wave, only an approximate rms value is obtained.

Electronic Multimeters. The next step up from the VOM in sophistication, price, and performance is the electronic multimeter. Instruments in this category represent a marriage of a solid-state amplifier in the TMM or a vacuum-tube amplifier in the VTVM to a basic electrical metering circuit.

Using built-in amplification results in a sensitive instrument that is capable of measuring ac and dc voltages and resistance over a much wider range than is possible with a VOM. It also results in a much higher input resistance, typically a constant 10 megohms, and a much higher frequency limit. This makes the

electronic multimeter useful in high-impedance, low-voltage circuits and r-f circuits in which a VOM would be highly inaccurate. (In circuits within the frequency and impedance limits of the VOM, however, the passive multimeter's accuracy is similar to that of most electronic multimeters.)

The electronic multimeter category includes service-type VTVM's that cost between about \$65 and \$120 and TMM's that range in price from about \$65 to \$240. (This category also includes the digital multimeter, or DMM, which we will discuss in Part 2.)

A typical modern VTVM with an extra-long meter scale that provides maximum readability and accuracy is the Triplet Model 850. This VTVM can measure dc voltages and ac rms voltages up to 1500 volts in ranges that are similar to those of a sensitive VOM. In addition, it measures resistances to 1000 megohms and peak-to-peak voltages. VTVM's do not measure current.

As is the case with other electronic multimeters, the Triplet VTVM employs an isolation probe that is connected to the input via a coaxial cable. A coaxial cable is required because the high input impedance makes the instrument susceptible to stray-field effects, especially on the low-voltage ranges. The isolation probe has a 1-megohm resistor that is placed in series with the input on the dc voltage ranges by operating a slide switch. This resistor minimizes the effective input capacitance of the coaxial cable and permits dc measurements in oscillator and r-f tuned circuits without disturbing circuit conditions. Other probes can be used to extend the frequency range of the VTVM to 250 MHz and the voltage range to 30,000 volts such as B&K Precision's shown here.

The solid-state revolution created some new measurement problems. Fortunately, it also provided the solution by making possible the versatile transistor multimeter, or TMM. This instrument has

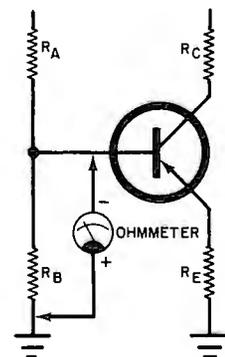


Fig. 4. This setup may cause wrong reading for base resistor.

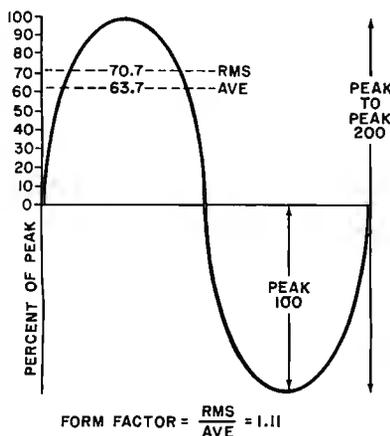


Fig. 5. The various ac values that can be measured by a meter.

the sensitivity of a VTVM, plus the advantages of solid-state design: instantaneous operation with no warmup; no heat generation and, hence, less aging and better accuracy in the long run; and cordless operation. Also, the TMM measures current. FET's ensure high input impedance.

An example of the TMM is Leader's versatile Model LEM-75. It offers a stable accuracy of 3% to 4% for almost any electronics application. The instrument features dc and ac rms voltage ranges of from 0.3 to 1000 volts full-scale; dc and ac current ranges from 30 μ A to 300 mA full-scale; and resistance ranges from 0.5 ohm to 500 megohms full-scale. There is even a temperature scale, for use with an optional thermistor probe. The minimum sensitivities of 10 mV and 1 μ A on both ac and dc make it possible to check the tiny bias and signal levels in the most advanced solid-state circuits.

On most TMM's and VTVM's, a ZERO control is used to set the meter pointer to 0 on the scale with the input probes shorted together and the power turned on before measurements are made. It is advisable to check for zero indication whenever you change either range or function or both. Before making a resistance measurement, it is also necessary to adjust the OHMS control to set the meter's pointer at infinity, with the probes not touching each other.

The scales on VTVM's and TMM's are similar to those on VOM's with two notable exceptions. First, the electronic multimeter usually has a zero-center scale that is useful for aligning discriminator and other balanced circuits. Secondly, the resistance scale increases in the same direction as the other scales, not inversely as on VOM's.

Some disadvantages of electronic

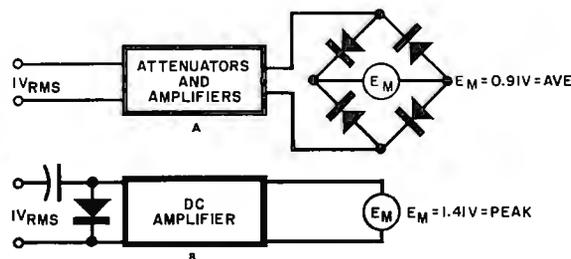
multimeters, with respect to VOM's, are warm-up time and drift, higher battery drain, slightly more complicated operation, stray pickup, and grounding requirements. For many, however, the much lower loading effect of the electronic multimeter makes it a favored instrument.

Electronic multimeters are fitted with a ground lead that must be connected to the ground or lowest-potential point of the circuit under test. The ground lead must not be connected to a point at a potential in excess of that recommended by the manufacturer, which is typically 400 volts ac or 600 volts dc.

The ground lead is often internally connected to the power line ground. Accordingly, you must not touch the ground lead to a test point at power-line potential or the line fuse will blow. When making measurements on a line-powered circuit, check the circuit ground to determine if it is isolated from circuit ground. If it is not, orient the circuit ground so that it is at the same potential as line ground.

The Circuits. Electronic multimeters can be classified according to whether the amplifier or the rectifier comes first.

Fig. 6. Arrangement (A) gives a sensitive, average-responding meter. (B), used in service-type DVM's, gives a peak-responding meter.



The amplifier-rectifier arrangement shown in Fig. 6A is used in very sensitive laboratory instruments that can measure potentials on the order of microvolts. As with the VOM, these are average-responding meters, calibrated to indicate rms values of sine waves. Since average-responding meters can give useful rms indications for waveforms with 10% or greater distortion, they are widely used as substitutes for expensive instruments that are true rms responding.

In the rectifier-amplifier, or peak-responding, circuit shown in Fig. 6B, a storage capacitor charges up through a diode to the peak value of the input voltage. The capacitor voltage is amplified by a dc amplifier to drive a meter movement. The high input impedance of the amplifier means that only a very small current is drawn from the circuit under test to keep the capacitor charged. The

input impedance has been pretty much standardized at 10 megohms—11 megohms with the probe resistor.

Without the diode and storage capacitor, the peak-responding meter serves as a dc voltmeter and, by adding shunts and an internal dc source, as a milliammeter and ohmmeter. Most VTVM's and TMM's use this principle.

One big advantage of the peak-responding meter is that the diode and capacitor can be placed in the probe so that the measured ac signal has to travel no farther than the probe. This reduces the loading caused by the capacitance of the test leads and input circuit.

With an r-f probe, available as an accessory item, the electronic multimeter can measure voltages at frequencies in the hundreds of megahertz range with tolerable loading. The input impedance decreases to between 50,000 and 100,000 ohms at 100 MHz. The error becomes especially serious for the higher voltages at high frequencies.

If the waveform measured by a peak-responding instrument is not symmetrical, a different reading will be obtained if the leads are reversed, thereby charging the capacitor to the alternate peak value. This turnover effect is eliminated in

some instruments by using a voltage doubler circuit that rectifies both alternations of the input signal voltage and gives a peak-to-peak response. The rms scales of these meters are accurate for sine waves, while the peak-to-peak scales are accurate for nonsinusoidal and complex waveforms. This permits accurate measurement of TV sweep and video waveforms, which are often specified in peak-to-peak voltages.

The zero-center scale on electronic multimeters is useful in solid-state servicing when it is not known whether the voltage being measured is positive or negative with respect to ground. Also, VTVM's and TMM's normally use a 1.5-volt cell in the ohmmeter section, which is relatively safe for semiconductor measurements.

Coming up. The major focus in Part 2 will be on digital multimeters. \diamond