

Multimeters are wonderful instruments, but they have their limitations.

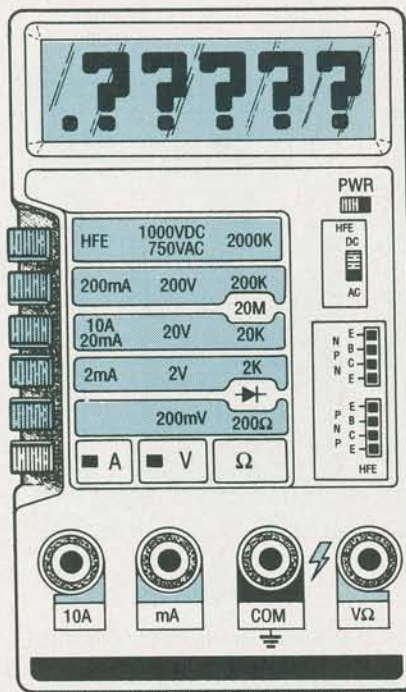
Learn what not to expect from them in this informative article.

If you are actively engaged in electronics, either professionally or as a hobby, then it is a good bet that you will at some time use a voltmeter for making measurements in a circuit. It is very easy to take the meter reading as absolute truth, especially when the instrument is high priced. After all, the meter is an "authority figure" of sorts, and it couldn't lie to you ... could it? You bet it could! Real meters often read something other than the voltage in the circuit and convert that into a hopefully equivalent voltage reading. There are certain situations that can affect the accuracy of this conversion process and thereby lead you astray. Understanding the conditions that produce such inaccuracies can prevent you from unknowingly taking erroneous readings.

In this article, we will look at common multimeters (*i.e.*, those meters that contain an AC/DC voltmeter, ohmmeter, and current meter all in one package). There are three different forms of multimeter on the market: analog volt-ohm-milliammeters (VOM's), electronic analog multimeters, and digital multimeters (DMM's). We will concentrate mainly on the performance of VOM's and DMM's because they are the most common forms currently on the market, and the most dissimilar to each other.

How Meters Work. An analog VOM contains an electro-mechanical DC meter movement. The basic meter has a full-scale current range, such as 0 to 100 μ A, or 0 to 1 mA. A resistor connected in parallel with the meter movement increases the full-scale current range. A "multiplier resistor" in series with the basic meter movement makes the current meter into a voltmeter. If a rectifier is used with the meter, then it will read alternating current instead of direct current. That's all there is to an analog meter.

A digital multimeter is completely dif-



BY JOSEPH J. CARR

ferent. In this type of instrument, an integrating analog-to-digital (A/D) converter is used to measure the applied voltage by comparing it to an internal precision reference voltage. So while an analog meter senses current, a DMM is sensitive to voltage. In order to measure current, a tiny resistance is placed in series with the load and the DMM measures the voltage drop across this standardized resistance and converts it to a current measurement.

There are two basic designs for the integrating A/D converter: a single-slope integrator and a dual-slope integrator. Of these, the latter is considered the better for most applications.

An example of a single-slope integrator is shown in Fig. 1. The principal components of this circuit are an input amplifier, a Miller integrator, a comparator, a main gate, and a binary counter. The input amplifier may or may not be used in any given single-slope integrator. It is optional, and is merely used to scale the input signal to a level that optimizes the operation of the integrator circuit—too-small a signal would take a long time to charge the integrator capacitor. For the sake of discussion, we will assume that the input amplifier has a gain of unity, so the input

Does Your Meter Lie To You?

to the integrator is the unknown input voltage V_x .

The Miller integrator uses an operational amplifier and a resistor-capacitor combination to produce an output voltage (V_1) that is proportional to the integral (*i.e.*, time-average) of the applied input signal. That signal is then sent to the comparator.

A comparator is sometimes called an amplifier with too much gain. Indeed, we can make a comparator using an operational amplifier with an open feedback loop. An amplifier operating in this manner can have a gain of 50,000 to over 1,000,000 depending on the quality of the unit. Obviously, a few millivolts of input signal will saturate the output of such an amplifier. That is how a comparator operates: it produces an output level that indicates when the two input voltages are equal (*i.e.*, output zero) or which of the two is highest. In the limited case shown here, one input of the comparator is grounded (at zero volts potential), so the output will be zero when V_1 is zero and high when V_1 is more than a few millivolts higher than ground. When the output of the comparator is high, the gate is enabled and can pass pulses from the clock to the counter provided that the

"start-logic" pulse (the function of which will become obvious in a moment) is also high.

The counter will have either binary or BCD formats (the BCD format is used in voltmeter digital converters) and thus can be connected to a digital-display device such as an LCD panel. An overflow indicator is used to denote when the input voltage is overrange.

The start logic generates a pulse that closes switch S1 briefly in order to discharge capacitor C1 so that no accumulated charge will foul the results. Switch S1 is then opened, allowing C1 to begin charging at a rate that is determined by the input voltage V_x . As soon as the integrator output voltage is more than a few millivolts higher than ground, the output of the comparator will snap high, enabling the gate.

The start logic then transmits a pulse to the gate that completely enables it, so the gate allows a clock pulse to flow into the counter. The start pulse stays on for a period T and prevents the integrator from continuing to charge until the counter overflows. The count (or data) at the end of the timing period is proportional to the applied voltage, so at the end of the count the display is enabled to show the count.

One major problem with the single-slope integrator is that it is sensitive to noise riding on the input signal. A noisy signal will usually produce an erroneous result.

The dual-slope integrator of Fig. 2 solves the noise problem. The principal difference between the two converters is that the dual-slope converter makes the conversion in two steps. During the first step, the integrator is charged from the unknown input signal V_x . The output voltage of the integrator continues to rise as long as the input switch S1 is connected to the input amplifier. The binary/BCD counter is allowed to overflow, and this overflow signal tells the control logic circuits to switch S1 to position B, the output of a precision reference-voltage source. The polarity of this voltage is such that it will cause the integrator to discharge at a fixed rate.

The counter state at the instant the switch is changed is 0000 and begins incrementing from there. The counter will continue to increment until the reference source completely discharges the integrator capacitor. At that instant, the output of the comparator will drop low again, thereby stopping the flow of clock pulses to the counter. The state of the counter output at that instant is pro-

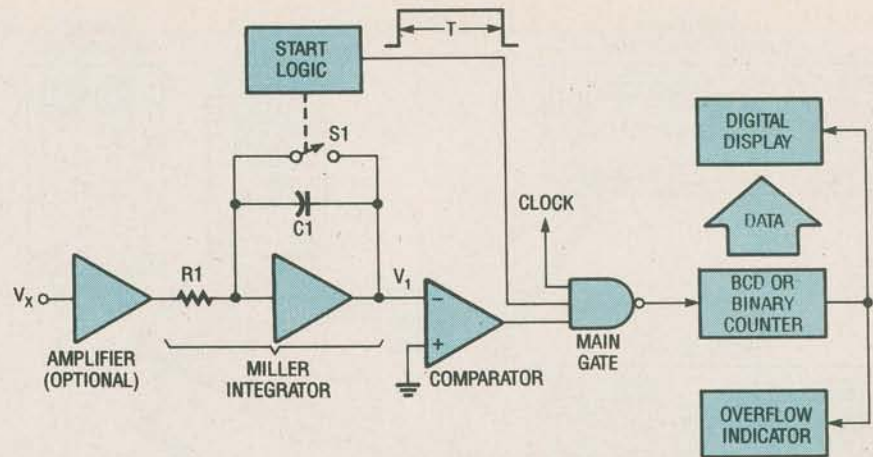


Fig. 1. A meter with a single-slope integrator design, like that shown here can be accurate, but not in situations where a lot of noise is present.

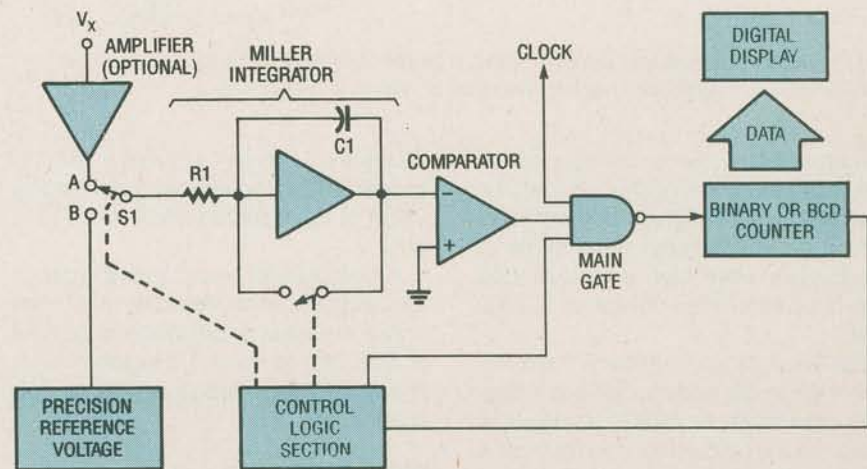


Fig. 2. A dual-slope integrator based meter can integrate-out noise to give more accurate readings than a single-slope device.

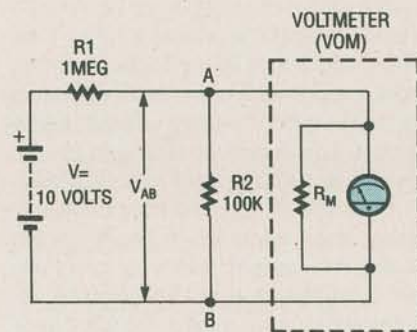


Fig. 3. A meter's internal resistance loads the circuit under test down, which can cause significant errors in measurement.

portional to the input voltage, V_x .

Since the counter state occurred as the result of a constant integrator-output slope, it will not contain noise errors. The noise errors are integrated out of the data by the action of the integrator. Now let's take a look at some problems that can occur with VOM's and DMM's.

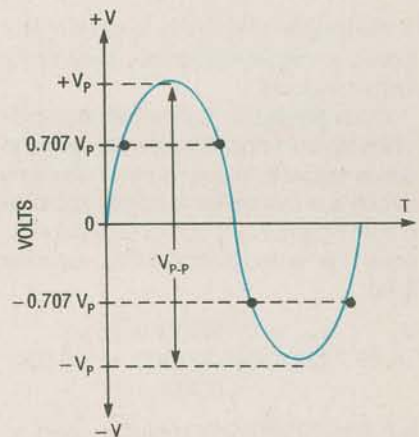


Fig. 4. What voltage should be read off this sine wave: rms, peak, or peak-to-peak?

A Built-in VOM Defect. A VOM can fool you in some circuits, especially when the circuit impedances are high. The problem is related to the sensitivity of the instrument. The sensitivity of the VOM is based on the impedance of the

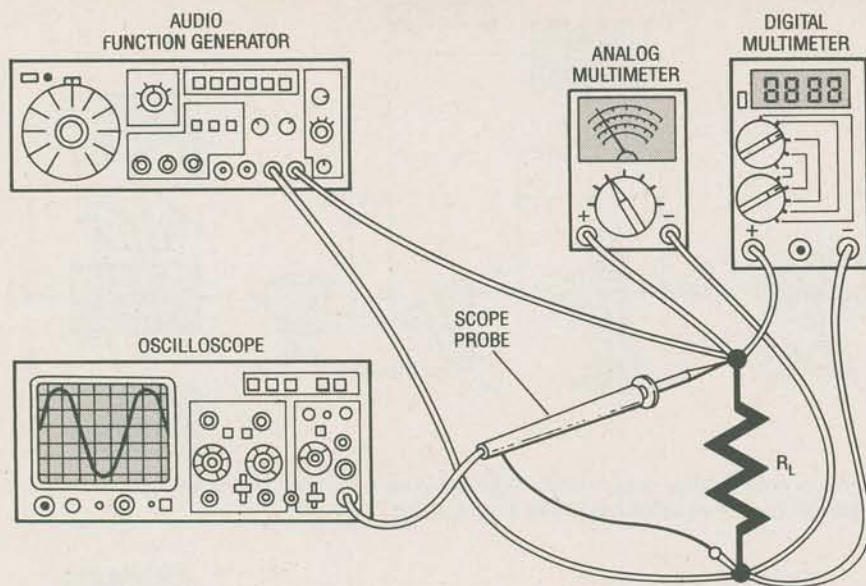


Fig. 5. In this experimental set-up, a VOM, a DMM, and an oscilloscope are wired in parallel across a load and a signal generator is used as a signal source.

instrument (*i.e.*, the resistance across the input terminals of the device). It is specified in units of ohms-per-volt (Ω/V). Common VOM's have a sensitivity of 20,000 Ω/V , while high priced models can have sensitivities as high as 100,000 Ω/V .

But what does sensitivity mean in terms of meter resistance? If a meter with a sensitivity of 20,000 Ω/V is set to the 0-10-volts scale, then the resistance of the meter (R_m) is:

$$20,000 \Omega/V \times 10 \text{ volts} \\ = 200,000 \text{ ohms}$$

If the meter resistance is small compared to circuit resistances, then problems will occur.

Consider Fig. 3. In that circuit, a pair of resistors (R_1 and R_2) are connected in series across a 10-volt source, V . This little circuit is a model for a lot of circuits or circuit fragments in actual practical circuits. The "output voltage," V_{AB} , is found from:

$$V_{AB} = V \times R_2 / (R_1 + R_2) \\ = 10 \times 100,000 / (1,000,000 + 100,000) \\ = 0.909$$

But if a 20,000 Ω/V meter is used to measure this voltage (say, on the 1.5 VDC scale), it places its own resistance (R_m) in parallel with R_2 . The value of the meter resistance is:

$$20,000 \Omega/V \times 1.5 \text{ volts} \\ = 30,000 \text{ ohms}$$

The parallel combination of R_2 and R_m is effectively 23 kilohms, so the meter reads the voltage across 23 kilohms, not

100 kilohms. When this value is used in place of R_2 in the equation above, the value of V_{AB} is 0.225 volts. That's a 75% error!

A typical DMM overcomes the circuit loading problem suffered by VOM's because the input impedance of a DMM is typically at least 1 megohm, with many of them reaching 10 to 100 megohms.

DMM Defects. The DMM may overcome circuit loading, but it is not error free. If a DC DMM is used to measure smooth, clean, noise-free DC levels, then it will function perfectly. However, if the DC being measured is noisy, then errors can occur. As mentioned before, dual-slope DMM's are a lot less sensitive to noise than cheaper single-slope meters, however even they can render an erroneous reading on a noisy signal.

A VOM does not suffer this problem in many cases because the inertia of the meter movement tends to integrate (*i.e.*, time-average) out the reading, ignoring all but the most serious forms of noise.

If you work on high power radio-frequency devices, such as radio transmitters, then you may want to select the VOM over the DMM for another reason. It seems that many DMM's are sensitive to RF radiation, while VOM's are not. In other words, the RF will bias the reading on a DMM, but not a VOM.

AC Voltmeters. An AC voltmeter reads AC volts, but there are three common ways of measuring an AC voltage:

you can determine its rms voltage, peak voltage, or peak-to-peak voltage. To make things more interesting, a meter circuit designed to measure the rms voltage of a sine wave will not be able to accurately measure the rms voltage of any other waveform.

To explain this, let's look at a simple, undistorted sine wave (see Fig. 4). The voltage starts at zero on each cycle, and then climbs to a peak value ($+V_p$). It passes the peak, and then falls back to zero. The current then reverses direction, so the voltage now goes negative. It then falls to a negative "peak" ($-V_p$).

The peak values are merely the highest voltages on each half cycle. The peak-to-peak voltage is the voltage difference between the positive peak and the negative peak. For a perfect sine wave (*i.e.*, one that is symmetrical about zero volts and undistorted) the peak-to-peak voltage is twice the peak voltage ($V_{pp} = 2V_p$). That relationship is easy to see from Fig. 4.

But there is also the rms, or root-mean-square voltage. That voltage can be defined mathematically, but a practical definition of the rms voltage is the DC voltage level that would produce the same amount of heat in a resistor as the applied sine wave. In other words, if an AC voltage is said to be 115 volts rms, then it will produce the same amount of heat when applied to a resistor as 115 volts DC.

The rms value of an undistorted sine wave (and only for a sine wave) is:

$$V_p / \sqrt{2}$$

In other words, you can find the rms-voltage value for any pure sine wave by multiplying the peak value by 0.707.

Some people refer to the rms voltage as the "average" voltage, and that's okay when strict rigor is not needed, but it is not quite correct. You will also see some textbooks that say the average voltage of a sine wave is 0.636 times the peak voltage. This is true only for one-half of the sine wave, *i.e.*, as in a rectified situation. The actual average value of a perfect sine wave is zero! After all, the voltage goes as much positive as it goes negative, so one can almost intuitively guess that the average over one complete cycle is zero.

Unfortunately, not all sine waves are so ideal. If there is noise on the signal, it will cause some meters to read differently than if the signal was not noisy. Also, if there is a DC component to the signal, which would force the sine wave

(Continued on page 102)

DOES YOUR METER LIE

(Continued from page 40)

to oscillate above and below the DC potential rather than zero, then all bets are off. These circumstances will create havoc with some types of meter, as we will see from a little experiment below.

Meter-Reading Experiment. Two different multimeters, one an analog VOM and the other a 3½-digit DMM, were connected in parallel across a load resistor (R_L in Fig. 5). Also connected across the load resistor was the vertical-input probe from an oscilloscope. First, the two meters were set to their respective 10-volt DC scales (0 to 10 volts on the VOM and 20 VDC on the DMM). Next, an audio function generator was connected so that its output was placed across the load resistor. The sinewave output of the function generator was adjusted to show 6 volts peak-to-peak on the calibrated oscilloscope when a 60-Hz sinewave was applied; this value corresponds to a peak value of:

$$6/2 = 3 \text{ volts}$$

If the sinewave was reasonably pure, then the rms value would be:

$$0.707 \times 3 \text{ volts} = 2.12 \text{ volts}$$

For this sinewave the analog meter read 2.0 volts, while the DMM measured 2.09 volts (close enough to be considered "accurate"). There was little difference between the readings at 60 Hz. The error widened a little bit at 1000 Hz, as the VOM reading dropped to 1.8 volts and the DMM was essentially unchanged as it bounced back and forth between 2.08 and 2.09 volts. In other words, the VOM appears to have a narrower range of audio frequencies over which it operates, a situation that is not unusual unless the meter is designed as an audio voltmeter as well (some are, mine was not).

The function generator was next set to produce a squarewave also of 6 volts peak-to-peak and symmetrical about zero volts. One would expect the rms value to be one-half the peak value, or 3 volts. The VOM read 3.2 volts at 1000 Hz, while the digital meter read 3.43 volts. At 60 Hz, the analog meter read 2.8 volts and the DMM read 3.12.

A 1000-Hz triangle waveform, also at 6 volts peak-to-peak and symmetric, yielded a reading of 1.65 volts on the VOM, and 1.7 volts on the DMM. At 60 Hz, the readings were 1.4 volts on the

VOM and 1.54 volts on the DMM. These readings are a lot closer together, reflecting the different composition of the waveform.

Results with non-symmetrical waveforms—a TTL squarewave, a sawtooth, and a sinewave with a considerable DC component—were also examined.

The TTL squarewave is not symmetrical because it is intended to operate with TTL digital devices. In this case, the base line is zero volts, and the peak voltage was +4.1 volts. The 60-Hz TTL signal snapped back and forth between 0 and +4.1 volts. The average value, therefore, was $+4.1/2$, or +2.05 volts. The analog meter read, surprisingly enough, 4 volts, while the digital meter read 1.96 volts. In other words, the VOM measured the peak voltage, while the DMM measured the average voltage.

The sawtooth wave was provided by a digital sawtooth-generator circuit created by connecting a digital-to-analog converter (DAC-0806) to the output of a binary counter that was driven by a clock. The sawtooth was a 400-Hz 4-volt peak waveform. The analog meter read 9.2 volts, while the DMM read 2.25 volts.

Finally, a 60-Hz sinewave signal that had a DC component was examined. Initially, the output level of the generator without the DC component was cranked up all the way. The reading on the analog VOM was 2.8 volts, and it bobbed between 2.08 and 2.09 volts on the DMM, very nearly identical readings. But when a +5-volt DC component was added, the VOM read +10 volts and the DMM read 3.12 volts. Similarly, when the DC offset was switched to -5 volts, the VOM read -10 volts and the the DMM read 2.81 (with no polarity sign showing!).

Understanding the effects of different signals on the reading produced by a meter will make it easier to use the meter in situations where the input signal is other than a fixed DC level, or a pure, noise-free sinewave. ■

