This Keithley Model 2002 DMM has 8½-digit resolution and can approach theoretical limits for sensitivity.

Choosing DMMs and more for high-performance applications

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DIGITAL MULTIMETERS are available in a wide variety of types, with an equally wide variety of specifications. There are conventional units with resolutions up to 6½ digits and high-performance ones with up to 8½ digits. Beyond that we run into different names: electrometers, picoammeters, and nanovoltmeters. With so much to choose from, it can be difficult to know just what type of instrument will meet the needs of a particular application. And, on top of that, some DMM specifications are stated in confusing ways. This article will take a look at the different classes of DMMs and their capabilities. It will also provide a translation of just what all those specs mean.

Theoretical Measurement Limits

The theoretical limit of sensitivity in any measurement is determined by the noise generated by the resistances present in the circuit. Voltage noise is proportional to the square root of the resistance, bandwidth, and absolute temperature:

$$V = \sqrt{kTR\Delta f}$$

where k = Boltzmann's constant (1.3807x10^{-23}J/K), T is absolute temperature in degrees Kelvins, R is resistance in ohms, and Δf is the bandwidth in Hz.

Figure 1 shows theoretical voltage measurement limits at room temperature with a response time of 0.1 second to 10 seconds. Note that high source resistance limits the theoretical sensitivity of the voltage measurement. While it is certainly possible to measure a 1 microvolt signal that has a 1 ohm source resistance, it is not possible to measure that same 1 microvolt signal level from a 1 teraohm source. Even with a much lower 1 megaohm source resistance, a 1 microvolt measurement is near theoretical limits (the gray area in the figure), and would be very difficult to make using an ordinary DMM.

How to tell when you need more than a standard DMM

Alternatives to a standard DMM include nanovoltmeters, electrometers, and picoammeters. Generally, a DMM is adequate for measurements at signal levels above 1 microvolt or 1 microamp, or below 1 gigaohm, which are a long way from the theoretical limits of sensitivity. If better voltage sensitivity is desired, and the source resistance is low (as it must be due to theoretical limitations), a *nanovoltmeter* provides a means of measuring at levels much closer to the theoretical limits of measurement.

When measuring voltages with very high source resistance values (for example, 1 teraohm), a DMM is not suitable because its input resistance of 10 megaohm to 10 gigaohm is several orders of magnitude less than the source resistance, resulting in severe input loading errors. Also, DMM input currents are typically many picoamps,

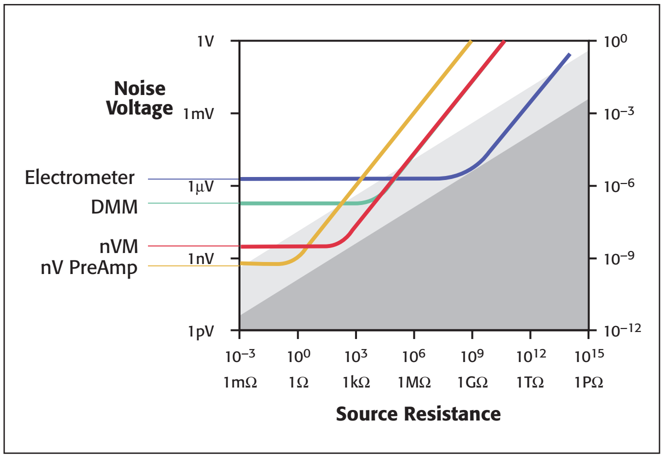

Figure 1: Typical digital multimeter (DMM), nanovoltmeter (nVM), and electrometer limits of measurement at various source resistances

creating large voltage offsets. Under these conditions, an *electrometer* is the appropriate choice.

A similar situation exists for low-level current measurements; DMMs generally have a high input voltage drop (input burden), which affects low-level current measurements, and DMM resolution is generally no better than 1nA. Thus, an *electrometer* or *picoammeter* with its much lower input burden and better sensitivity would be the best choice.

Interpreting DMM specifications

Accuracy specs

The spec sheet for a particular 5½-digit DMM gives the accuracy as ±(0.016% rdg + 3 counts). What does this mean?

The first part—0.016% rdg—is a measure of *gain error*, or error that is proportional to the measured value. In this case it means that the displayed value will be within 0.016 percent of the actual value. If the instrument displays a reading of 1.00000V, the actual voltage can be anywhere between 0.99984V to 1.00016V.

The second part, ±3 counts of the least significant digit, is a measure of *offset error*, or error that is independent of the value measured. In our example, the offset error will be no more than ±0.00003V. Combining gain error and offset error gives us the actual error band: 0.99981V to 1.00019V.

The effect of temperature

Since temperature affects accuracy, instrument specifications generally include a defined temperature range over which the stated accuracy holds. For temperatures outside of this range, some manufacturers give a temperature coefficient, such as ±(0.005 % + 0.1 count)/°C or ±(5ppm of reading + 1ppm of range)/°C.

Calibration cycle

Electronic instruments change with time, which is why specifications usually include a time period beyond which accuracy cannot be guaranteed. The time period is typically over specific increments such as 90 days or one year. Transfer stability specifications are defined for a much shorter period of time—typically five or 10 minutes.

Noise and Noise Rejection

Noise is a consideration in virtually any measurement, but especially in low-level measurements. Thus, it is important that noise specifications and terms are well understood when evaluating the performance of an instrument.

NMRR (normal-mode rejection ratio) defines how well the instrument rejects or attenuates noise that appears between the HI and LO input terminals. Normal-mode noise is an error signal that adds to the desired input signal and is detected as a peak noise or deviation in a DC signal. NMRR is calculated as:

$$NMMR = 20\,Log\,\frac{Peak\ normal\ mode\ noise}{Peak\ measurement\ deviation}$$

NMRR is given for specific frequencies and frequency ranges so as to reject noise (50Hz, 60Hz, high-frequency noise) while not rejecting low-frequency or DC normal-mode signals. Normal-mode noise effects can be minimized by shielding and filtering.

CMRR (common mode rejection ratio) specifies how well an instrument rejects noise signals that appear between both input high and input low and chassis ground. CMRR is usually measured with a 1 kΩ resistor imbalance in one of the input leads.

Although the effects of common mode noise are usually less severe than normal mode noise, it can still cause problems in sensitive measurement situations. To minimize common-mode noise, connect shields only to a single point in the test system.

NMRR and CMRR are generally specified at 50 and 60Hz, and CMRR is often specified at DC as well. Typical values for NMRR and CMRR are >80dB and >120dB, respectively.

Speed

When specified, measurement speed is usually stated as a specific number of readings per second for given instrument operating conditions. Certain factors, such as integration period and the amount of filtering, may affect overall instrument measurement speed. However, since changing operating modes may also alter resolution and accuracy, there is often a tradeoff between measurement speed and accuracy. For example, instrument accuracy specifications may be stated for measurement times expressed as a function of power line frequency for highest noise rejection. A typical specification may give accuracy for 1, 0.1, and 0.1 PLC (power line cycle—16.7ms in North America and 20ms where 50Hz power is used).

Instrument speed is most often a consideration when making low-impedance measurements. At higher impedance levels, circuit settling times become more important and are usually the overriding factor in determining overall measurement speed.

Conclusion

Whether you're thinking of a standard DMM at 4½ digits, a high-performance unit at 8½ digits, or something in between, choosing the right instrument has a direct effect on the integrity and repeatability of the measurement you're making. Understanding the differences in instrument categories, specifications, and intended applications will help ensure you're using the right instrument for the job.

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