PC-Based Measurements Get Real

by Tee Sheffer, Signametrics

Present-day benchtop and rack-and-stack automated test systems predominantly utilize IEEE 488 digital multimeters (DMMs) while PC-based test systems tend to use data acquisition boards as the primary measurement instruments. This is because PC plug-in DMMs have not been around very long, and many of the early plug-ins failed to meet the requirements of benchtop and system DMMs.

Newly developed 4.5-, 5.5-, and 6.5-digit PC plug-in DMMs are making inroads into test systems, ranging from automotive and disk-drive manufacturing to just about any automated test application. These new PC plug-in DMMs work without the extra interface cards and cables required with an external DMM.

Fundamental differences between PC plug-in DMMs and data acquisition boards can make a difference in the test application. Data acquisition boards are a good, economical choice for many applications, particularly when it comes to handling a large number of channels at sampling rates less than 500 S/s.

On the other hand, DMMs require additional scanning or multiplexing hardware to handle multiple channels. The maximum rate for most modern PC plug-in DMMs is 60 to 200 measurements/s; a few have measurement rates as high as 1,000/s. In many data acquisition board applications, averaging is used to reduce noise which results in lower throughput.

In applications where the required sampling rate can be handled by a PC plug-in DMM, consider the advantages carefully. Part of the decision process is the trade-off in speed vs accuracy.

> **If it's accuracy you want, look to today's DMMs. The market offers many options—the challenge is learning how to match the features to your application.**

A DMM's accuracy tends to decline faster with measurement rate than that of a data acquisition board. Of course, at slow sampling rates, a DMM's accuracy is much higher than that of a data acquisition board, so it still may be the better instrument, even when used at higher speeds.

To be certain that you have made the right choice, read the specifications carefully. If you're still not sure, discuss your application with the vendor.

A very significant factor in a DMM's performance is its high-voltage isolation barrier that presents extremely high impedance between the input terminals and the host PC and ground. It prevents ground loops, helps reject common-mode noise, and makes DMMs truly differential measuring instruments.

One advantage of a true differential input is the capability to measure a few microvolts of signal while the input terminals are elevated to several hundred volts DC or AC common-mode. The differential topology gives predictable and repeatable test results, independent of the test environment.

Single-ended measurement systems can produce headaches. In one case, although the test system performed well during the development phase, noise problems were encountered when it was moved to an off-shore production facility. In contrast, the reason most DMMs can provide at least 16 bits of resolution is the good noise rejection.

Overall, if lower measurement rates are acceptable for an application, a PC DMM has several attributes that make it a better measurement tool. Some of these include a much higher resolution, better accuracy and stability, greater versatility, and excellent noise rejection.

Although DMMs are not considered to have signal conditioning, they have built-in isolation, current sources, frequency counters, rms converters, current shunts, four-wire Kelvin sensing, and software to measure a variety of sensors. These features eliminate the need for additional signal-conditioning hardware while facilitating the acquisition of many different types of signals with great accuracy.

While data acquisition boards may use successive approximation register analog-to-digital converters (ADC) and a sampling front end, most DMMs use a high-resolution, integrating type of ADC with a controlled conversion cycle. In conjunction with the isolation barrier, an integrating ADC provides exceptionally high power line and differential noise rejection. This is a significant benefit because powerline voltages, currents, and their harmonics are major contributors to noise in the test environment.

Versatility

Using data acquisition boards for complex measurements requires the addition of signal-conditioning hardware. Functions such as low-pass filters, current sources, isolation amplifiers, and attenuators can be added to enhance the capabilities of the measurement system. Signal conditioning can reduce measurement noise, provide stimulus for passive compo-

On-the-Job Accuracy

The application for a DMM can have a profound effect on the actual accuracy achieved. Let's look at the proverbial 1-kΩ source imbalance impedance that is commonly used in specifying a DMM's common-mode rejection ratio.

This value represents a sensor's source resistance. To analyze the error contributed by this 1-kΩ sensor, assume it has a DC voltage output in the range of 0 V to ±2.5 V. Assume there are two similar DMMs, both with a DC accuracy of 0.02%, but one has a 10-MΩ input resistance and the other one has 1 MΩ. Since the 1-kΩ source forms a voltage divider with the DMM input, the lower impedance DMM will have an added error of 0.1% or a total of 0.12%. The DMM with the higher impedance will have a degradation of 0.01% or a total error of 0.03% (**Figure 1**).

When looking at a DMM's spec, remember to include the additional ADC levels that modify the basic accuracy. These additional levels or counts represent the measurement floor and dominate measurement accuracy at the low end of a selected range.

To convert these counts to the equivalent output voltage, multiply by the resolution for the specified range. If the accuracy of the 300-mV range of a 5.5-digit DMM having a 1-µV resolution is specified as 0.024% ±6 counts, the total error with an input of 20 mV will be ±0.024% ±6 µV or 0.054%. Another DMM could appear to have a better specification of 0.01% ±25 counts for the same range, resulting in a 0.135% error under the same conditions. For a 200-mV input, the 0.024% instrument exhibits a 0.027% error while the 0.01% DMM has only a 0.0225% error. Read the specifications carefully, and don't hesitate to ask questions.

Heating effects on input dividers also can become an error source, particularly while measuring high voltages. The heat dissipated in the input divider of a DMM can cause errors that will show up as drift. For instance, if measuring 300 VDC, this power will be as much as 90 mW for a 1-MΩ input and 9 mW with a 10-MΩ input.

The effects of input divider heating can be alleviated to some extent by reducing the amount of time the DMM is connected to the high-voltage source.

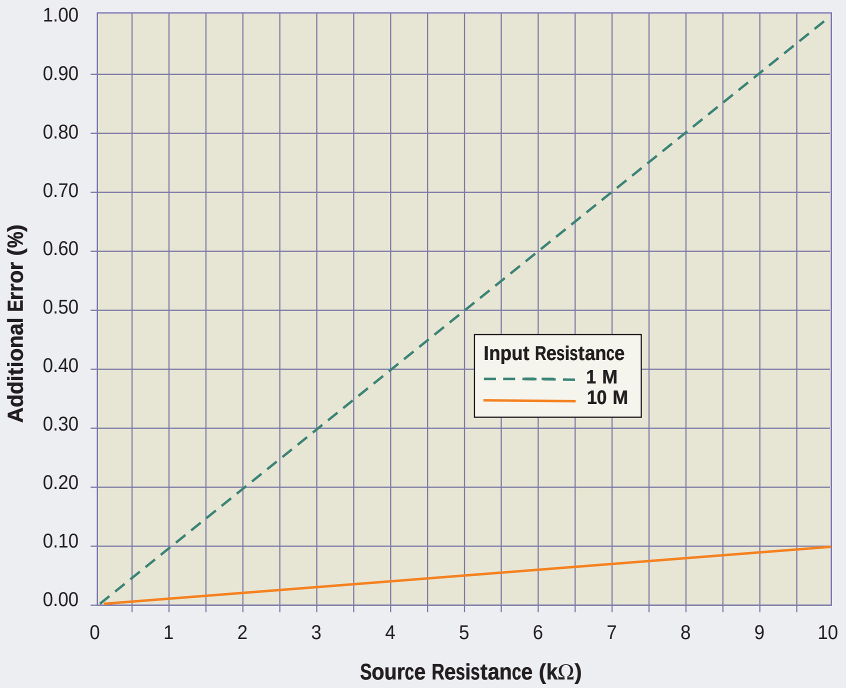

Figure 1. Additional Error in DCV Due to Sensor's Source Resistance

This allowance for heating may or may not have been included in the specification.

DMM Counts	Digits of Resolution	Approximate Bits of Resolution	Typical Range Scheme DCV	Resolution
±20,000	4-1/3	16 bits	200.00 mV, 2.000 V...	10 µV, 100 µV...
±25,000	4-2/5	16 bits	250.00 mV, 2.500 V...	10 µV, 100 µV...
±120,000	5	18 bits	120.000 mV, 1.20000 V...	1 µV, 10 µV...
±200,000	5-1/3	19 bits	200.000 mV, 2.00000 V...	1 µV, 10 µV...
±250,000	5-2/5	19 bits	250.000 mV, 2.50000 V...	1 µV, 10 µV...
±310,000	5-1/2	20 bits	310.000 mV, 3.10000 V...	1 µV, 10 µV...
±1,200,000	6	21 bits	120.0000 mV, 1.200000 V...	100 nV, 1 µV...
±3,300,000	6-1/2	22 bits	330.0000 mV, 3.300000 V...	100 nV, 1 µV...

Table 1. Comparison of DMM Resolution Digits and Counts

When measuring resistive devices, it is the number of different current sources and their stability that matters. Ideally, there should be as many current sources as there are ohms ranges. However, this gets expensive. As a result, some DMMs have as few as two current sources while others may have as many as six. The currents are commonly in the range of 10 nA to 10 mA.

When measuring ohms in the presence of semiconductors, it is important to prevent junctions from turning on, so it is necessary to consider the current being supplied. Using a higher ohms range which has a lower current can help, providing the accuracy of the higher range is adequate.

When making four-wire Kelvin ohms measurements, remember that the two additional probes associated with this measurement contribute additional leakage which degrades measurements above 100 kΩ. Fortunately, there is no compelling reason to make four-wire ohms measurements above this level.

If the application includes current measurements, make sure the DMM selected has adequate built-in shunts. The more available shunts the better the measurement results. Just like with ohms measurement, it is difficult to squeeze more than one or two ranges out of a single shunt.

Having two shunts is very common, and they are used for both AC and DC current measurements. External shunts work, but require additional, external switching to engage. They also might need more calibration since they probably are not included in the DMM calibration record.

Digits, Bits, and Dynamic Range

As is the case with data acquisition boards, when using a DMM, the measurement range should be selected so that the signal being measured is as high as possible within the range. The effect of a DMM's dynamic range is crucial. A 5-digit DMM with 120,000 counts will display a 12-V input as +12.0000. To read higher voltages, the 120-V range must be used with a 1-mV resolution instead of 100-µV resolution and with a reduced accuracy.

For instance, to measure 14 V and 28 V in automotive, military, and aviation applications, a wide dynamic-range DMM with 300,000 counts will not have to change ranges. It will measure inputs to +30.0000 V which will preserve accuracy and resolution and save the time it takes to switch ranges (**Table 1**).

Unlike data acquisition boards which define digitizer resolution in bits, a DMM is a decimal instrument; that is, resolution is expressed in digits. Some DMM manufacturers also provide a counts specification that is more specific than digits. DMMs present measurements with a decimal resolution such as 1-µV steps, where data acquisition boards have binary resolution such as 2.44-mV steps.

The digits figure of a DMM is a base 10 log of the dynamic counts. It is not an exact translation of binary bits of resolution. Not all DMMs with the same number of digits have the same resolution counts. The bottom line is how ranges are presented. If a DMM has full-scale ranges of 300.000 mV, 3.00000 mV, and so on, it has 300,000 counts or actually ±300,000 counts.

Counts of resolution do not imply accuracy. They only define the smallest measurement step that can be resolved.

nents such as resistors and RTDs, and allow the measurement of a variety of sensors.

Even with the addition of signal-conditioning hardware, the performance remains limited by the capability of the digitizer. Compare this to the cost and capabilities of a PC based plug-in DMM with signal conditioning, measurement facilities, and software.

Measurement capabilities for PC DMMs include two-wire and four-wire resistances, rms-ACV, rms-ACI, DCV, DCI, frequency, period, temperature, diodes, and RTDs. Signal conditioning is built in without add-ons and with several decades of measurement ranges from microvolts to several hundred volts, nanoamps to a few amps, and milliohms to megohms.

Things to Look For

The application should drive the selection of a DMM. There is no reason to spend more than the job requires, but a wise choice will go a long way.

If test-system reliability is important, you will find that some PC DMMs exhibit more than 75,000 hours of mean time between failures. PC plug-in DMMs are reliable because of their lack of displays, data cables, and connectors; low power consumption; and few mechanical and electromechanical components.

It is important to evaluate the software interface that forms part of the PC plug-in DMM. Always try to use open control software that does not require the purchase of additional drivers. For instance, with generic software packages such as Visual Basic or C++, you can be assured of a very straightforward interface to the DMM's DLL without using additional components. Visual Basic has a very quick learning curve and an open architecture. If time is of the essence, consider it for your test application.

Finally, most suppliers will accept a unit back within 30 days. Take advantage of this offer, and don't hesitate to send it back if it does not meet your expectations—even if it does meet its specs. Before you decide to return a unit, try to contact the vendor's technical support. This usually helps to clarify the issues.

In conjunction with the isolation barrier, an integrating ADC provides exceptionally high power line and differential noise rejection.

About the Author

Tee Sheffer is the cofounder of Signametrics. Prior to his affiliation with the company in 1991, he was a senior staff engineer and a project manager at Fluke. Mr. Sheffer received undergraduate and graduate EE degrees from the University of Washington and holds 10 patents in the area of test and measurement. Signametrics, 6073 50th Ave. NE, Seattle, WA 98115, (206) 524-4074.

EE

Reprinted from *EE-Evaluation Engineering*, August 1999