Meter manufacturers bet their reputations on how a large population of instruments is going to behave for the duration of calibration cycle. (A typical calibration cycle is one year.) Instrument engineers and metrologists use laboratory testing and carefully applied statistics to set the specs.

DMM specifications apply to a particular model (i.e. design), not to any individual instrument. Any single instrument of a particular design should perform well within the specification, especially toward the beginning of its calibration cycle. A model's specs are based on testing a significant sample of products and analyzing the collected data from the instruments.

If we take measurements of a nominal input from, say, 50 instruments of the same design, we are going to get a range of readings. Many of the instruments will have the same readings, but we would expect some variation due to normal uncertainty. For example, we can record the readings from 50 Fluke Model xyz DMM's hooked up to the same precision calibrator outputting 10 volts. We will record a narrow spread of readings around 10 volts. We can calculate the mean (average) of all the measurements, which we would expect to be 10 V. We can also calculate the standard deviation of the readings (Equation 1).

$$\sigma = \sqrt{\frac{\sum_{i=1}^{N} (x_i - \bar{x})^2}{N - 1}}$$

Equation 1. N = sample size
X = measurement

The standard deviation is a measure of the "spread" of the sample of measurements, outward from the mean. This measure of spread is the basis of uncertainty specifications.

If we plot the number of times each reading occurs, we should see a bell-shaped normal distribution. (Almost all measurements follow a normal distribution, including those made with simple instruments like rulers and measuring cups.) Figure 1 shows a normal distribution curve centered at 10 V.

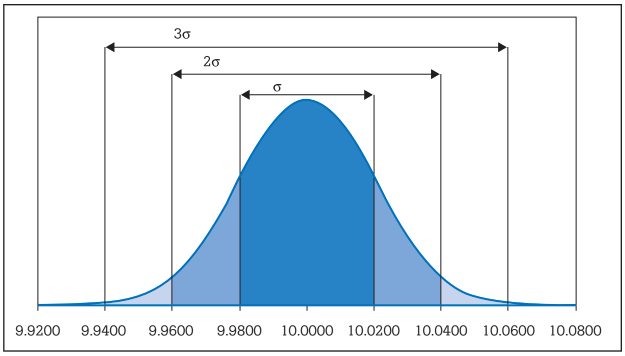

Figure 1: A normal distribution with a mean of 10 volts and standard deviation 0.02 volts.

Using experimentation and experience, instrument designers set specifications by assuming a normal distribution and finding the standard deviation for a significant number of design samples. Adopting a normal distribution allows us to relate standard deviation to the percentage of readings that occur, by measuring the area under the curve.

68 % of the readings will be within 1 standard deviation of the mean

95 % of the readings will fall within 2 standard deviations of the mean

99.7 % of the readings will fall within 3 standard deviations of the mean

Statisticians refer to these percentages as confidence intervals. They might say, "We are 95 % confident that a reading will not be more than 2 standard deviations of the actual value."

In the simple example above

1 standard deviation corresponds to ± 0.02 V

2 standard deviations corresponds to ± 0.04 V

3 standard deviations corresponds to ± 0.06 V

So the questions for the manufacturer become, "How many standard deviations do we use for our spec?" "What confidence interval do we use to build our specs?" The higher the number of standard deviations, the lower the probability that an instrument will fall out of spec between calibrations. The manufacturer's internal engineering standards will determine how many standard deviations are used to set the spec. Fluke uses a confidence of 99 %, which corresponds to 2.6 standard deviations on a normal distribution.

Traceability and specifications

So far we have described how much uncertainty we can expect from a DMM, but we have not discussed how we make sure we're all talking about the same volt, ohm or amp. DMMs must trace their measurement performance back to national laboratory standards.

DMMs are usually calibrated using multifunction calibrators like the Fluke 5700A or Fluke 9100. But there are usually a number of links between the DMM and national standards, including calibrators and transfer standards. As you move through the chain between your DMM and the national standards lab, the calibration standards become increasingly accurate. Each calibration standard must be traceable to national standards through an through an unbroken chain of comparisons, all having stated uncertainties.

So the uncertainty of a DMM depends on the uncertainty of the calibrator used to calibrate it. Most DMM specs are written assuming two things:

- The DMM has been calibrated using a particular model of calibrator, usually specified in the DMM service manual.
- The calibrator was within its operating limits and traceable to national standards.

This allows a DMM manufacturer to include the uncertainty of the calibrator in the DMM uncertainty specs. If you see an uncertainty listed as "relative" this means the uncertainty in the calibrator output *has not been considered* and it must be added to the DMM uncertainty.

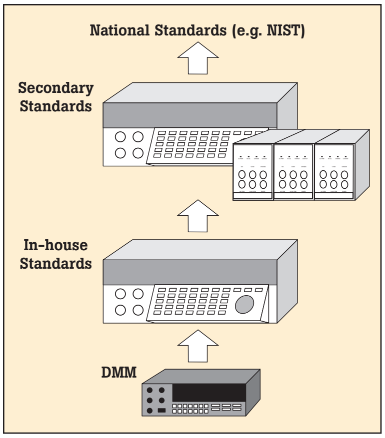

Figure 2: Traceability is the path from your DMM back to national standards.

Elements of digital multimeter specifications

Among the many standards that govern instrumentation, there is no standard for writing DMM specs. Over the years, though, manufacturers have converged on similar formats, making it a bit easier to compare multimeters. This application note covers the most common conventions for specifications.

As described above, uncertainty specifications define a range around a nominal value. When taking a measurement within the specified limits of time, temperature, humidity, etc., you can be confident that you won't get a reading outside that range.

Time and temperature are crucial for determining uncertainty. Electronic components experience small changes (or "drift") over time. Because of drift, DMM uncertainties are valid only for a specified period of time. This period usually coincides with the recommended calibration cycle and is typically one year. At calibration, the clock starts over again and the uncertainties are valid for another period.

Temperature affects the performance of every component in an instrument—from the simplest resistor to the most elegant integrated circuit. DMM designers are good at building circuits that compensate for temperature variation. This ability to operate at various temperatures is captured in a specified operating range and is often accompanied by a temperature coefficient. (More on this later.)

Multimeter uncertainties cannot be given as simple percentages, although it is tempting to over simplify. You might see a sales brochure that touts, "Basic accuracy to 0.002 %". This is only giving a small part of the picture, and it's usually an optimistic view of the data.

The reasons for complexity in the specifications have to do with the multimeter's ability to perform many different measurements, over many different ranges, using several different internal signal paths.

Consider the diagram in Figure 3. It shows the analog signal path for a dc voltage measurement, also known as "the front end". Each block contributes uncertainty in the form of nonlinearity, offset, noise and thermal effects. The front end contributes most of the uncertainty of the instrument.

Depending on the design, changing ranges affects the divider performance or the amplifier performance or both. Internal noise, for example, has a greater relative impact on lower ranges and at the low ends of ranges. Changing functions alters the signal path. For example, a resistance measurement requires the addition of a current source to the analog path. So each function and range must be specified in a way that considers the effects of non-linearities, offsets, noise and thermal effects. Table 1 shows the elements of a DMM specification and gives examples for each.

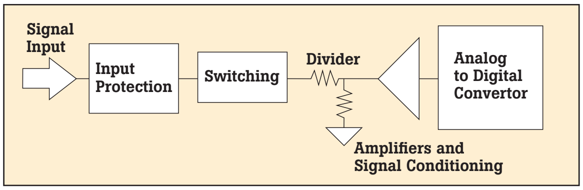

Figure 3: Simplified DMM analog signal path for dc volts measurement.

Example	
Baseline uncertainty	
Input	± (0.001 % of reading + 3 digits)
Scale term + floor	± (0.001 % of reading + 3 digits)
Uncertainty modifiers	
Temperature coefficient	± (0.003 % of reading) per °C from 0 °C to 18 °C and 28 °C to 50 °C
Time	1 year
Qualifiers	
Warm-up time	Specs are valid after 1 hour warm-up
Operating temperature	23 ± 5 °C
RH	80 % RH from 0 to 35 °C, 70 % to 50 °C
Storage temperature	40 °C to 60 °C
Vibration	Meets requirements of MIL-T-28800E for Type III, Class 3, Style E equipment
EMI susceptibility	Complies with EN 50082-1
Altitude	2000 meters
Power line regulation	100 V/ 120 V/ 220 V/ 240 V ± 10 %
Overvoltage protection	600 V overvoltage category III

Table 1: Key elements of the DMM specification.

Baseline uncertainty specifications

Baseline specifications are usually given as:

± (percent of reading + number of digits)
or
± (percent of reading + number of counts)

"Digits" or "counts" are used interchangeably and they indicate the value of the least significant digits for a particular range. They represent the resolution of the DMM for that range. If the range is 40.0000 then one digit, one count, is worth 0.0001.

Let's say you want to measure 10 V on a 20 V range in which the least significant digit represents 0.0001 V. If the uncertainty for the 20 V range is given as ± (0.003 % + 2 counts) we can calculate the uncertainty in measurement units as:
± ((0.003 % x 10 V + 2 x 0.0001 V) = ± (0.0003 V + 0.0002 V) = ± (0.0005 V) or ± 0.5 mV

Some spec sheets use the form:
± (percent of reading + percent of range)

Top three pitfalls of using DMM specs

1. Using only the percent of reading as a shortcut
2. Applying specs to DMM's that fall outside of their calibration cycle
3. Using a DMM outside its temperature range without de-rating uncertainties