Understanding Uncertainty Specifications for Electrical Test Equipment

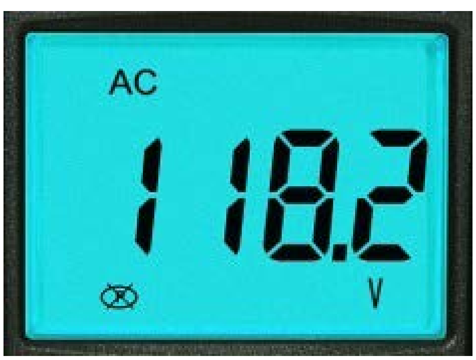
A critical characteristic of any measurement instrument is its accuracy – in other words, how closely the instrument's reading reflects the true value being measured with a minimum of uncertainty. Unfortunately, the relevant specifications for electronic measurement equipment are often expressed in terms unfamiliar to less experienced users. The specs for a digital multimeter may list its uncertainty for measuring DC voltage as "±(0.2% + 2 counts)" with no further explanation about what this formula means and how it applies to the displayed measurement. This can make it difficult to compare the accuracy of different products, or even know whether or not a particular instrument is suited to your requirements.

This article describes how to determine accuracy for electrical measurement instruments. We define terms such as digits, counts, resolution, uncertainty, and error. We also explain the importance of selecting the right measurement range when taking a reading.

In this article we use a digital multimeter (DMM) as our demonstration instrument. However, most of what we'll cover also applies to other types of instruments.

Digits and Counts

Two terms critical to understanding accuracy are digits and counts. It's important to note that neither term defines accuracy; instead they define an instrument's resolution (more on this point later). Resolution is a key factor in calculating accuracy and uncertainty, so we need to clearly understand these concepts.



Digits defines the number of digits an instrument can display. For example, a 4-digit DMM can display four 0 through 9 digits (10.00, -0.024, 9999, and so on).

This fairly simple concept becomes more complex when the left-most digit (called the *most significant digit*) cannot display the full range of numbers. For example, a so-called "3½-digit" DMM can display either a 1 or 0 as its most significant digit. Thus the highest reading this instrument can display within a single measurement range is 1999. Readings greater than this must be displayed in a higher range, if available. For instance a reading of 20 volts could be displayed as 020.0V, with the decimal point shifted one digit to the right. This is further complicated when the most significant digit can be numbers other than 0 or 1. There is no uniformly adopted standard for expressing this as a fraction. For example, a 3¾-digit DMM typically refers to an instrument whose most significant digit can be 0, 1, or 2. But this fraction is also used on occasion for instruments that can display 3, 4, or 5 as the most significant digit.

To minimize this confusion, many manufacturers now describe their products in terms of *counts* rather than digits. Basically, this defines the number of different readings the instrument can display within a measurement range. For example, the 3½ -digit DMM described above is a 2000-count instrument, since it is capable of displaying readings from 0 to ±1999.
The value of each count is determined by the reading's right-most number, called the *least significant digit*. In the preceding example, for a reading of 19.99V each count equals 0.01V; for a reading of 020.0V each count equals 0.1V. Therefore an instrument's measurement range can significantly impact accuracy, as we'll discover later in this article.

Accuracy vs Resolution

Users often refer to resolution and accuracy interchangeably; but it's important to understand the distinction between these terms. Generally speaking, ***resolution*** defines the smallest possible measurement change the instrument can detect. Thus at their lowest ranges, a 1000 count DMM can display a change of .001 unit, while a 10,000 count instrument can detect .0001 – in other words, 10 times the resolution of the 1000 count DMM. And since resolution depends on the size of each unit (the smaller the better), the lowest possible measurement range should be selected when making high-resolution readings.

However, these numbers say nothing about an instrument's accuracy. The 1000 count DMM may have a measurement uncertainty much smaller than the 10,000 count model, and therefore produces more accurate readings. Although resolution is a critical factor in calculating uncertainty, it is not the sole factor.

Percent of Reading vs Percent of Range

A second factor in calculating uncertainty is expressed as a percentage. Recall our previous example specification of "±(0.2% + 2 counts)." This indicates that the total uncertainty is 2 counts plus a percentage of a value. This can be a percentage of the reading, or a percentage of the instrument's range.

Uncertainty can be significantly affected by which of these values – reading or range – is used in the calculation, since the reading is generally much smaller than the range. For example, consider a 1000 count digital multimeter displaying a reading of 100V, with the range set to ±999. One percent of the reading would be 1V, while one percent of the range would be 10V. So be sure to check whether the percentage applies to the reading or the range when comparing specifications of different digital multimeter models.

Note that uncertainty specifications for all AEMC instruments are always expressed as a percentage of the reading.

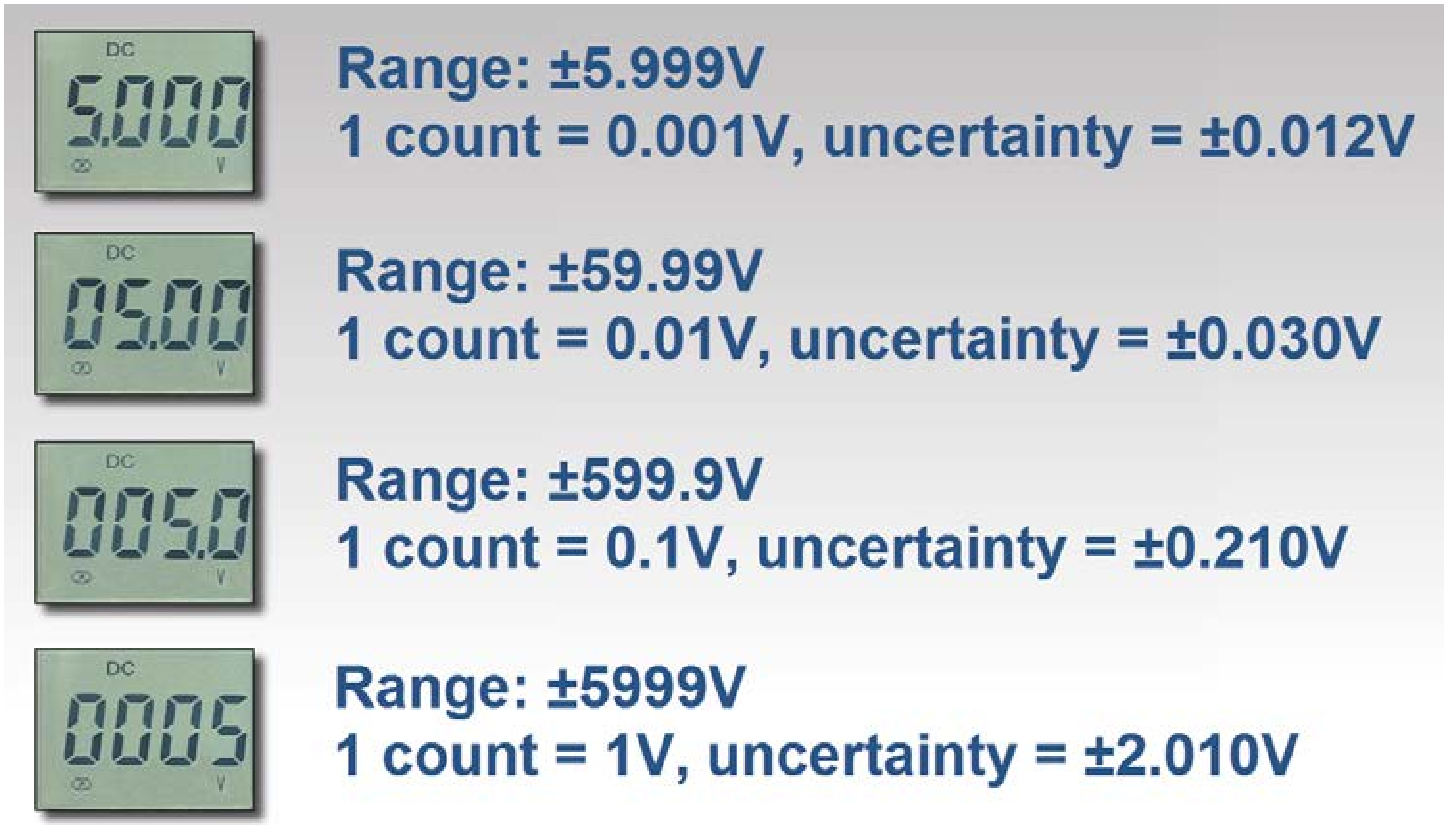
Deciphering Uncertainty Specifications

Now let's apply what we've learned. Suppose we hook up a 6000 count multimeter to a battery. This instrument features an uncertainty specification of ±(0.2% (reading) + 2 counts) when measuring DC voltage. With the range at the lowest setting, we get a reading of 5.000V.

Since the percentage is based on the reading, we start by deriving 0.2% of 5.000V, or approximately 0.010V. We then add 2 counts. Taking the least significant digit, we define each count as 0.001V. Thus the sum of two counts equals 0.002V.

Adding the percentage and counts together, we calculate an uncertainty of around ±0.012V. Thus for the reading shown above, the actual value falls within the range of 4.988V (5.000 - 0.012V) to 5.012V (5.000 + 0.012V). Or stated in terms of accuracy, this reading reflects an accuracy of 99.76%, with an uncertainty of 0.24% (0.012 divided by 5.000).

This calculation highlights the importance of selecting the optimal measurement range. To demonstrate this point, consider what happens as we change the range from ±5.999 to ±59.99, ±599.9, and finally ±5999:



As the preceding illustration shows, the decimal point moves to the right with each change of range. This indicates an order of magnitude increase in our least significant digit, and as a result, a commensurate increase in the value of one count. At the highest range, the reading is 0005V, with one count equal to 1V. Applying the formula, the uncertainty in this case would be approximately ±2V, producing a measurement range of around 3 to 7V, orders of magnitude greater than our original uncertainty of 0.012V. Such a reading would of course have no practical value. This highlights the importance of selecting the correct range for a measurement.

Note that AEMC digital multimeters feature auto-ranging for automatically selecting the most appropriate range for the measurement.

This also illustrates the advantage of higher count instruments. For example, a 6000 count multimeter can display 1000 more readings than a 5000 count model without changing to the next higher range. Since these 1000 additional readings will have a lower per-count unit value, they will result in a lower uncertainty.

Uncertainty vs. Error

Before leaving this topic, we should point out the difference between uncertainty and error. Although the terms are sometimes used interchangeably, uncertainty represents the range within which the true measurement falls, while error defines the absolute amount the reading differs from the true value. Although it may seem initially counter-intuitive, it would be easier to accommodate error than uncertainty: all we would need to do is offset the measurement by the amount of the error to obtain 100% accurate results!

Conclusion

Let's review a few of the key points we've covered:

- It's important to understand uncertainty specifications to properly judge an instrument's accuracy.
- Digits and counts define an instrument's resolution, but not its accuracy.
- When comparing performance, bear in mind whether an instrument's uncertainty is based on percentage of measurement or percentage of range.
- Be sure to select the optimal range (generally the lowest possible) when making a measurement.
- Higher count instruments can produce more readings without changing ranges than lower count instruments.

We hope this will help you better understand and interpret uncertainty specifications and how they define an instrument's accuracy. This in turn will enable you to make more informed decisions when choosing the instrument best suited to your requirements.