Metrology assures quality resistance measurements

Martin Rowe - October 01, 2015

When you pull out that multimeter to measure resistance, you might give some thought as to whether you should use the meter's two-wire or four-wire probably--if it even has a four-wire option. But you probably don't give much thought as to the possible errors caused by the instrument's measurement uncertainly. Fortunately, somebody does.

Resistance, like other measurements, needs some assurance that the measurement is of a known quality, called "uncertainty" in the calibration and metrology world. That's where calibration comes in. You probably send your equipment to an in-house or third-party calibration lab on a regular basis. But what happens at the lab? For that matter, what happens at the factory before your test equipment reaches your bench? Find out, I interviewed Ralph Travise, Test Engineering and Metrology Manager at Keithley Instruments. We'll now take you through the steps and equipment in Keithley's metrology lab.

Calibration is a comparison of a measurement instrument against some reference standard that had better uncertainty. For your measurements to have validity, the equipment used to make them must belong to an unbroken chain of comparisons that is traceable to some national standard. In the U.S., that chain starts with NIST. Other national metrology labs include NPL in the U.K, and NRC in Canada. **Figure 1** shows the calibration chain that goes through Keithley's metrology lab. On the pages that follow, we'll look at each box, which represents a calibration step, in more detail.

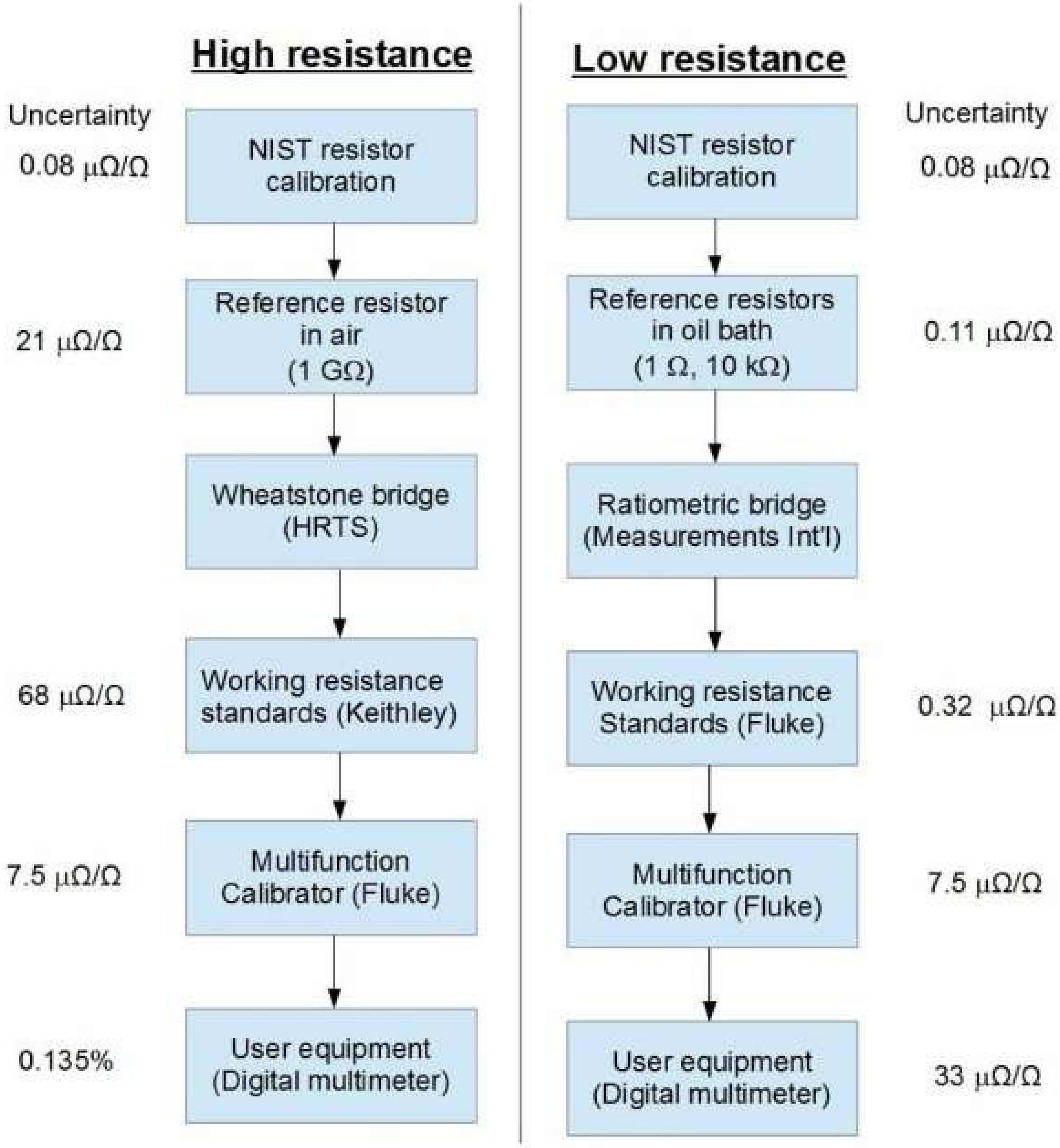

Figure 1. Keithley's chain of calibrations for resistance runs from reference resistors to measurement equipment that users use to make measurements. We'll run through Figure 1 from the bottom up, starting with the multifunction calibrator. As we proceed up the chain, measurement uncertainty decreases.

Keep in mind just what calibration means in this case. "Calibration" simply means that a piece of measurement equipment is compared against a standard of lower uncertainty, ideally by a 4:1 ratio, called a TUR (test uncertainty ratio). It doesn't necessarily mean that the EUT (equipment under test) was adjusted. That depends on the user's requirements. For some, no adjustment is needed as long as the EUT is within manufacturer's specifications. Only when the EUT's uncertainty is out of manufacturer's tolerance would adjustment be required. Some, however, might require tighter tolerances. It depends on how the test equipment is used.

In other industries, particularly process control, the word "calibration" is assumed to include adjustment. See "Calibration means different things in different professions" for an explanation. The following pages take up the resistance calibration chain, starting with a multifunction calibrator and ending with reference resistors in oil baths.

Multifunction calibrator

Keithley uses Fluke 5720A and 5730A multifunction calibrators as the main sources to calibrate multimeters. The calibrator produces voltage, current, and frequency, in addition to resistance. Many calibration labs in the industry and at independent labs use these calibrators to calibrate the instruments you use in your lab or production line.

Figure 2. Keithley uses a Fluke 5730A Multifunction calibrator to calibrate multimeters. Photo courtesy of Fluke.

Why not send the calibrators to Fluke for calibration? Travise explained that keeping the calibrators in house cuts down on shipping costs and provides in-house control of calibration parameters. The instruments are not exposed to transportation risks such as vibration, shock, or changes in temperature when kept in house.

When asked how often Keithley calibrates the multifunction calibrators, Travise replied "every three months. Fluke specifies uncertainly at three month and one-year intervals. We use the shorter interval to maintain a lower uncertainty of 7.5 ppm at the 10 kΩ level.

How does the 7.5 ppm uncertainty compare with the next step of the calibration ladder? On the next page, we'll look at Keithley's working resistance standards.

Working resistance standards calibrate the calibrator

How do you know if the calibrator used to calibrate your equipment has an uncertainty within tolerance? You compare it to something better. In this case, Keithley checks its Fluke calibrators against a set of Fluke 742A resistance standards, which serve as working resistance standards (**Figure 3**). Keithley has 12 individual resistance values in the lab. Values range from 1Ω to 19 MΩ with uncertainties of 0.3 ppm even though Fluke's published uncertainly is ±2 ppm over one year. This is accomplished by calibrating them in-house.

Figure 3. Fluke 742A resistance standards are used to check multifunction calibrators for resistance.

To calibrate a multifunction calibrator with a resistance standard, you need a transfer standard because the calibrator and resistors are both sources. Thus, measurements of both are needed. Keithley uses a Fluke 8508A DMM (**Figure 4**) to measure and compare the multifunction calibrators' resistance outputs against the working resistance standards. The 8508A has two sets of four-wire resistance inputs and a compare mode. "The Fluke 8508A is used in ratio mode to measure the resistance outputs of the multifunction calibrators by comparing resistance outputs to the working resistance standards," said Travise. "The 8508A returns the ratio of UUT-to-standard resistor (R_{UUT}/R_{STD}). The predicted value of the standard resistor is multiplied by the reported ratio, yielding the value of R_{UUT}."

Figure 4. A Fluke 8508A DMM measures the outputs of the working resistance standards for transferring to the multifunction calibrator. Photo courtesy of Fluke.

Calibrating the working resistance standards

Now that you see how Keithley calibrates the multifunction calibrators, we look at how they trust the values of the working resistance standards. Again, they could send the working standards to Fluke for calibration, but that also requires shipping, which carries risk of drifting caused by temperature changes, shock, and vibration—no matter how well the resistance standards are packed.

Looking back on **Figure 1**, you can see that there are two possible methods for calibrating the working resistors, depending on the working resistor's value. Bridge configurations let Keithley compare the value of the working resistance standards against two reference resistors with values of

10kΩ and 1GΩ. **Figure 5** shows four basic methods used, which cover some 15 decades of values from 0.01 Ω to 10 TΩ.

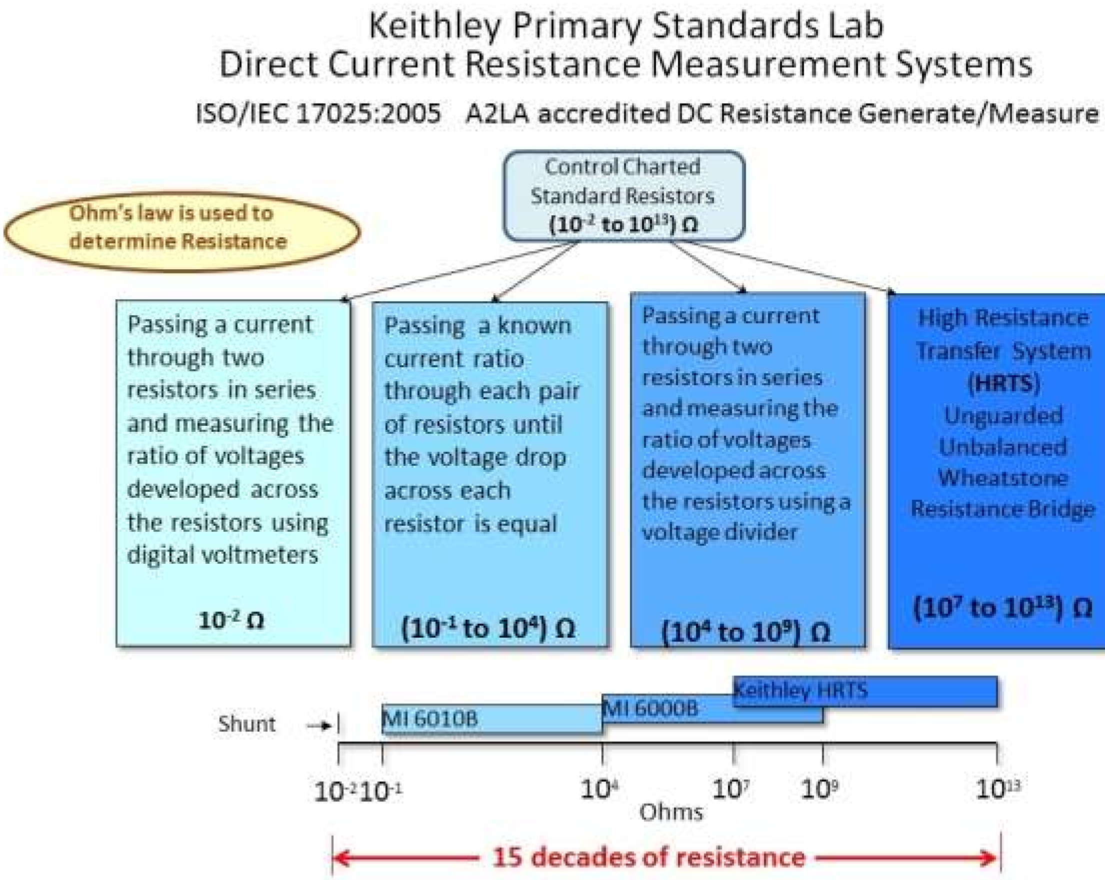

Figure 5. Keithley uses different methods for calibrating working resistors against reference resistors, depending on the resistor values.

Figure 6 shows the test setup, which uses resistance bridges to transfer values for the reference resistors to the working resistors for comparison. The instruments are used to measure voltage across the reference resistors and working resistors under test varies with setup. This forms a ratiometric bridge to enable the transfer of decade values from the NIST reference standard to higher value resistances of transfer standards.

Figure 6. This rack contains resistance bridges to transfer resistance values from reference resistors to the working resistors shown in Figure 3.

For resistances from 10 MΩ to 10 TΩ, Keithley uses what it calls an HRTS (High-Resistance Transfer System). This system consists of an accurate decade divider, voltage source and an electrometer that acts as a null detector. As in the case above, this forms a ratiometric bridge to enable the transfer of decade values from the NIST reference standard to higher value resistances of transfer standards.

One the next page, you'll see the resistors at the top of Keithley's resistance chain.

The top of the resistance chain

Keithley's reference resistors reside in oil baths (**Figure 7**), which help maintain constant temperature and humidity. But, these resistors need calibration too. When calibration time comes, Keithley ships the resistors to NIST's Gaithersburg, Maryland facility. Each resistor is measured before and after shipping. Because Keithley maintains control charts on the reference resistors (and many other devices as well), they can predict the reference resistor's value when it arrives back in Cleveland. If that predicted value is close to the measured value measured at NIST, the resistor is put back into service. If there's a discrepancy, Keithley can tell if something went wrong during shipping and on which trip. In that case, the resistor won't return to service and instead, will go back to NIST or be monitored internally.

Figure 7. At the top of the resistance chain, Fluke reference resistors reside in oil baths for temperature stability.

Conclusion

There are several links in the resistance calibration chain, as there are for other measurements--voltage, current, temperature, etc. As uncertainty requirements get tighter the higher up you go, more care is needed to assure those requirements are met. So the next time you make a measurement, remember that there's a lot of metrology--measurement science—that goes into that measurement.

Also see:

- Follow the chain to NIST-traceable calibrations
- AC metrology at the top of the chain
- *T&MW* Goes to the Calibration Lab
- Calibration means different things in different professions
- Calibration simplified
- Go inside Fluke's electrical metrology lab
- How to extend calibration cycles