

Keysight Technologies

Achieving Enhanced Digital Multimeter Accuracy in the Presence of Temperature Variation

Application Brief

Test Challenges:

- Making highly sensitive, accurate measurements in a lab with variable temperature
- Making accurate DMM rack measurements when the internal system temperature is higher than ambient

Overview

Accurate measurements with a benchtop or system Digital Multimeter (DMM) are very important. However, an often overlooked specification adder is the Temperature Coefficient (TC). The basic premise of a TC specification is that if you are using your DMM at a temperature that is not the same temperature at which you calibrated the instrument, then you need to add an error to account for the TC specification. Most DMMs are calibrated in a temperature controlled environment, nominally at 23 °C. However, often times DMM's are used in real-life environments where the temperature is not the same as the calibration lab. See how the latest Truevolt Series DMMs can help minimize this TC specification adder.

Making highly sensitive, accurate measurements in a lab with variable temperature

You need to make highly sensitive measurements with your DMM, while maximizing accuracy. However, the temperature of your lab can vary by a few degrees over the course of a day. This temperature variation has a direct impact on the accuracy of your measurements and can affect the quality of your data; especially if your lab's working temperature is not the same as the temperature at which the DMM was calibrated.

The Truevolt Series DMMs for Keysight Technologies features built-in autocalibration designed to help minimize errors due to temperature drift. Using these instruments allows you to make your measurements with the added assurance that autocalibration will help adjust for any errors.

Making DMM rack measurements when the internal system temperature is higher than ambient

You have mounted your DMM into a rack. Like a good system designer, you have controlled air flow and temperature monitoring. Even with these precautions, the internal temperature of your system is 15 °C higher than ambient due to the other instruments in your system. With a 15 degree rise, your DMM reading specifications are now higher than design tolerances with the TC specification adders. Since you designed in a Truevolt Series DMM with autocalibration, you can reduce the TC adders up to 5x and still stay within your specification budget for your DMM measurements.

DMM specifications

If you look at a DMM datasheet you will normally find 90-day and 1-year specification columns. These columns are populated with percentage of reading and of range, and are based on the measurement that you are taking. Table 1 shows the datasheet for the new 34465A 6.5 digit DMM. The inclusion of 24 hour, 90 day, 1 year, and TC columns are common for high-end DMMs.

To calculate your accuracy specification, consider an example when the DCV 10-V range is used to measure 9 V. In this case, your 1-year specification (based on Table 1) would be calculated as 0.0035% reading+0.0005% range, or: $9\text{ V} * 0.003\% + 10\text{ V} * 0.0004\% = 0.00027 + 0.00004 = 0.00031\text{ V}$

Consequently, the accuracy you would expect is $9\text{ V} \pm 0.31\text{ mV}$

If your measurement environment—the ambient temperature where the DMM is operating—is not the same as the temperature of the DMM calibration, then you need to consider the TC error adder. For example, a unit was calibrated at 22 °C, but is operating at 40 °C inside of a test system. Such a rise in temperature is common in test sets inside of a system rack. We need to add in error due to TC specifications. From Table 1, the right most column contains the TC specification. For each degree C, the specification adder is: $9\text{ V} * 0.0005\% + 10\text{ V} * 0.0001\% = 0.000045\text{ V} + 0.00001\text{ V} = 0.000055\text{ V}$ (0.055 mV)

For the Truevolt 34465A DMM, the 1-year specification applies for temperatures $\pm 2\text{ °C}$ of the calibration temperature. If you are outside of the 2 °C range, in our example the threshold is 24 °C, then you need to add in the TC specification for each degree. In the example cited here that would mean adding in 16 °C of TC adder.

The total specification for this example would be: $9\text{ V} \pm (0.00032 + 16 * 0.000055) = 9\text{ V} \pm 0.00119\text{ V}$ (1.19 mV), which represents a 385 percent increase in your potential measurement error!

Specification \pm (% of reading + % of range)

| Range | 24 hours $T_{ACAL} \pm 1\text{ °C}$ | 90 days $T_{ACAL} \pm 2\text{ °C}$ | 1 year $T_{ACAL} \pm 2\text{ °C}$ | 2 years $T_{ACAL} \pm 2\text{ °C}$ | Non ACAL temperature coefficient/°C | With ACAL temperature coefficient/°C |
|--------------------------|--|---------------------------------------|--------------------------------------|---------------------------------------|---|--|
| DC voltage: 34465 | | | | | | |
| 100 mV | 0.0030 + 0.0030 | 0.0040 + 0.0035 | 0.0050 + 0.0035 | 0.0065 + 0.0035 | 0.0005 + 0.0005 | 0.0002 + 0.0005 |
| 1 V | 0.0015 + 0.0004 | 0.0025 + 0.0004 | 0.0035 + 0.0004 | 0.0050 + 0.0004 | 0.0005 + 0.0001 | 0.0002 + 0.0001 |
| 10 V | 0.0010 + 0.0003 | 0.0020 + 0.0004 | 0.0030 + 0.0004 | 0.0045 + 0.0004 | 0.0005 + 0.0001 | 0.0002 + 0.0001 |
| 100 V | 0.0020 + 0.0006 | 0.0035 + 0.0006 | 0.0040 + 0.0006 | 0.0055 + 0.0006 | 0.0005 + 0.0001 | 0.0002 + 0.0001 |
| 1000 V | 0.0020 + 0.0006 | 0.0035 + 0.0006 | 0.0040 + 0.0006 | 0.0055 + 0.0006 | 0.0005 + 0.0001 | 0.0002 + 0.0001 |

Figure 1. Shown here are the 34465A DCV specifications. Please refer to the Truevolt Series DMM data sheet, publication number 5991-1983EN, for additional specification details.

Truevolt autocalibration

The new 34465A and 34470A Truevolt Series DMMs feature autocalibration (ACAL), which greatly reduces temperature drift error. ACAL is the built-in ability of the DMM to compensate for temperature drift and internal errors. This is also known as self calibration. The only other Keysight DMM with ACAL is the high-end 3458A with its high-end price; a bestselling 8.5-digit DMM. The new 34465A and 34470A Truevolt DMMs at 6.5 digits and 7.5 digits, respectively, are lower performance and with prices at a fraction of the cost of the 3458A.

The 34465A and 34470A Truevolt DMMs feature ACAL circuitry that adjusts the calibration for DCV, OHM and the internal Analog-to-Digital Converter (ADC) circuitry. Keysight designers were able to optimize the calibration for cost, accuracy and speed. The ACAL operation is a short 15 to 20 seconds; greatly improved over the 3458A ACAL DMM operations, which could take 12 minutes to complete.

With this improved ACAL, Keysight is able to optimize the circuit design to offer a high-end DMM that is price competitive with non-ACAL DMMs. This economical solution is ideal for high accuracy needs in DCV and Ohms functions, both of which are often the most challenging measurements for engineers needing the most accuracy.

In a higher accuracy DMM, temperature stability is a larger factor. Temperature variations affect voltage and ADC accuracy. With the 34465 and 34470A, the base specifications are applicable for $T_{CAL} \pm 2\text{ }^{\circ}\text{C}$. This means that the specification would apply for a range of 21 $^{\circ}\text{C}$ to 25 $^{\circ}\text{C}$ if the unit was calibrated at 23 $^{\circ}\text{C}$. While this range is tighter than most 6.5-digit DMMs, it is also wider than the 3458A, which is specified at $T_{CAL} \pm 1\text{ }^{\circ}\text{C}$.

Because the 34465A and 34470A DMMs have a built-in temperature reference, it is easier to track the temperature at which your instrument was calibrated. The calibration menu shows what the current temperature is, the calibration temperature and the temperature change. Figure 1 illustrates the new information available in the calibration screen.

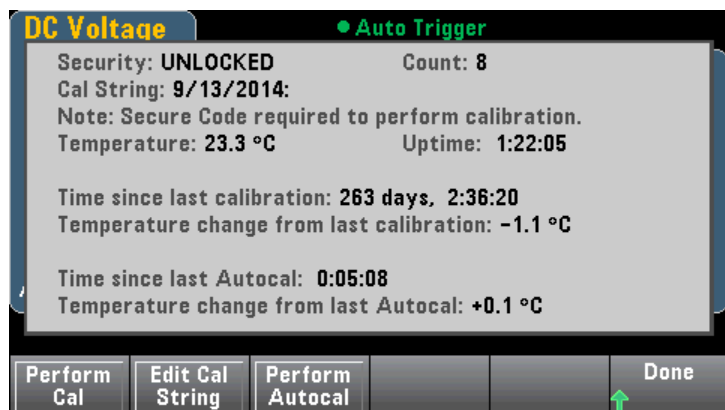


Figure 1. Shown here is the new 34465A and 34470A DMM calibration screen.

Better accuracy with ACAL

Now let's take a look at the specifications for the 34470A and see how the accuracy limits change if you perform ACAL. Using the same scenario previously presented (9-V DC reading, 10-V range, 22 °C cal temperature, and a 40 °C operating temperature), we can calculate the specifications using the table in Table 2;

$$1\text{-year base accuracy} = 9 * 0.0016\% + 10 * 0.0002\% = 0.000144 + 0.00002 = 0.000164 \text{ V} \\ (0.164 \text{ mV})$$

The base 1-year accuracy using a 34470A will be $9 \text{ V} \pm 0.164 \text{ mV}$.

There are two options for you here, depending on whether you choose to do an ACAL or not. If you skip the ACAL step, you would use the TC adder for the non-ACAL column. For each degree Celsius outside of the $T_{\text{CAL}} \pm 2 \text{ }^\circ\text{C}$, you would add in the following:

$$9 \text{ V} * 0.0005\% + 10 \text{ V} * 0.0001\% = 0.000045 \text{ V} + 0.00001 \text{ V} = 0.000055 \text{ V} (0.055 \text{ mV})$$

In this example, the base specification is applicable for $22 \text{ }^\circ\text{C} + 2 \text{ }^\circ\text{C} = 24 \text{ }^\circ\text{C}$. Since we are operating at $40 \text{ }^\circ\text{C}$, we need to multiply our TC adder by 16 degrees ($40 \text{ }^\circ\text{C} - 24 \text{ }^\circ\text{C} = 16 \text{ }^\circ\text{C}$). Consequently, the final calculation is:

$$9 \text{ V} \pm (0.000164 + 16 * 0.000055) = 9 \text{ V} \pm 0.00104 \text{ V} (1.04 \text{ mV})$$

The TC adder increases the error potential to 1.04 mV. This is over 600 percent of the original specification!

However, since we can use the ACAL, we can greatly reduce the TC error. By performing an ACAL shortly before our most accurate measurements, we can usually assume that the temperature will not change by more than $2 \text{ }^\circ\text{C}$.

Accuracy specification: DC voltage and resistance, automatic calibration (ACAL) capable, Specification \pm (% of reading + % of range)

| Range | 24 hours $T_{\text{ACAL}} \pm 1 \text{ }^\circ\text{C}$ | 90 days $T_{\text{ACAL}} \pm 2 \text{ }^\circ\text{C}$ | 1 year $T_{\text{ACAL}} \pm 2 \text{ }^\circ\text{C}$ | 2 years $T_{\text{ACAL}} \pm 2 \text{ }^\circ\text{C}$ | Non ACAL temperature coefficient/ $^\circ\text{C}$ | With ACAL temperature coefficient/ $^\circ\text{C}$ |
|--------------------------|--|---|--|---|--|---|
| DC voltage: 34470 | | | | | | |
| 100 mV | 0.0030 + 0.0030 | 0.0040 + 0.0035 | 0.0040 + 0.0035 | 0.0045 + 0.0035 | 0.0005 + 0.0005 | 0.0001 + 0.0005 |
| 1 V | 0.0010 + 0.0004 | 0.0015 + 0.0004 | 0.0020 + 0.0004 | 0.0025 + 0.0004 | 0.0005 + 0.0001 | 0.0001 + 0.0001 |
| 10 V | 0.0008 + 0.0002 | 0.0013 + 0.0002 | 0.0016 + 0.0004 | 0.0020 + 0.0002 | 0.0005 + 0.0001 | 0.0001 + 0.0001 |
| 100 V | 0.0020 + 0.0006 | 0.0032 + 0.0006 | 0.0038 + 0.0006 | 0.0040 + 0.0006 | 0.0005 + 0.0001 | 0.0001 + 0.0001 |
| 1000 V | 0.0020 + 0.0006 | 0.0032 + 0.0006 | 0.0038 + 0.0006 | 0.0040 + 0.0006 | 0.0005 + 0.0001 | 0.0001 + 0.0001 |

Table 2. Shown here are the 34470A DCV specifications.

Please refer to the Truevolt Series DMM data sheet, publication number 5991-1983EN, for additional specification details.

Using the new TC column with ACAL specifications, the TC adder is now:

$$9 \text{ V} * 0.0001\% + 10 \text{ V} * 0.0001\% = 0.000009 \text{ V} + 0.00001 \text{ V} = 0.000019 \text{ V} (0.019 \text{ mV})$$

Multiplying by sixteen degrees we get:

$$9 \text{ V} \pm (0.000164 + 16 * 0.000019) = 9 \text{ V} \pm 0.000468 \text{ V} (0.468 \text{ mV})$$

While the TC adder is still a large effect over the base specifications, the overall accuracy with ACAL is much better than the specifications without ACAL. The accuracy is widened by 285 percent and is more accurate than a non-ACAL DMM's specifications.

Table 3 compares the accuracy specifications for the 34465A and 34470A DMMs when used with the following scenario: 9 V, tested on a 10-V range, calibrated at 22 °C, used at 40 °C.

| Model | Input voltage/range | Base spec at 22 °C | Specs w/TC at 40 °C | Specs w/TC and ACAL @ 40 °C |
|--------|---------------------|--------------------|---------------------|-----------------------------|
| 34465A | 9 V/10 V range | ± 310 µV | ± 640 µV | ± 424 µV |
| 34470A | 9 V/10 V range | ± 164 µV | ± 494 µV | ± 278 µV |

Table 3. 9-V input on a 10-V range, with calibration temperature at 22 °C and operating temperature at 40 °C.

For reference, Tables 4 and 5 are provided to allow you to compare the performance of the two DMMs.

| Model | Input voltage/range | Base spec at 22 °C | Specs w/TC at 40 °C | Specs w/TC and ACAL @ 40 °C |
|--------|---------------------|--------------------|---------------------|-----------------------------|
| 34465A | 50 V/100 V range | ± 2.6 mV | ± 8.2 mV | ± 5.8 mV |
| 34470A | 50 V/100 V range | ± 2.5 mV | ± 8.1 mV | ± 4.9 mV |

Table 4. 50-V input on a 100-V range, with calibration temperature at 22 °C and operating temperature at 40 °C.

| Model | Input voltage/range | Base spec at 22 °C | Specs w/TC at 40 °C | Specs w/TC and ACAL @ 40 °C |
|---------------|---------------------|--------------------|---------------------|-----------------------------|
| 34465A/34470A | 10 KΩ/10 KΩ range | ± 0.45 Ω | ± 1.57 Ω | ± 0.93 Ω |

Table 5. 10-KΩ input on a 10-KΩ range, with calibration temperature at 22 °C and operating temperature at 40 °C.

Summary

The operating temperature of your DMM can affect the accuracy of your readings. A DMM with ACAL capabilities can greatly minimize your TC errors. With an operation time of less than 20 seconds, ACAL is a task that you can run often to ensure optimal accuracy, as shown in the tables. The new 34465A and 34470A Truevolt Series DMMs can help ensure that your readings are accurate, even with temperature errors.

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