Ambient Temperature Measurements
using Hioki and Keithley Meters

Summary of Operation

Hioki uses a dedicated ambient temperature probe and a dedicated ambient temperature probe connecter. Remote software can read the temperature. The temperature probe can be used when either the front panel or the MUX is being used for resistance measurements. The Hioki meter can calculate internally the temperature-corrected resistance values for each channel using different coefficients for each channel. The resistance value read by the software can be the corrected value or the uncorrected value. Single resistance measurements can be made using the front panel connecter. For multiple resistance measurements, the MUX must be used.

Keithley does not have a dedicated temperature probe nor does it have a dedicated temperature connecter. Temperature is one of multiple parameters that can be read by remote software (voltage, resistance, temperature, capacitance, etc.). Keithley has a front panel connecter that can be used for any one of the parameters. To make more than one measurement the MUX must be used. This means that making single resistance measurements using the front panel will not allow measuring also the temperature. With the MUX, any of these parameters can be read by any one of the channels. It is necessary to specify each channel for every new test setup, there is no default. The Keithley meters do not correct resistance values for temperature changes. If needed, it must be done by the remote software.

Temperature Effect on Conductors

The measured resistance of a conductor changes with temperature. If you measure the resistance when the sample is under some kind of mechanical stress like tension or compression, the measured value will also depend on the ambient temperature of the sample. If you wish to isolate the effect of the mechanical stress, the test must be conducted at constant temperature. If you wish to compare the results of one Laboratory with another Laboratory, the tests should be conducted at a standard temperature, typically 20°C.

Why does the resistance vary with temperature? In conductors, electrical current flows due to the exchange of electrons between atoms. As electrons move through a conductor, some collide with atoms, other electrons or impurities. Heating the conductor causes atoms to vibrate more, which in turn makes it more difficult for the electrons to flow, hence increasing resistance.

If it is not possible to keep a constant 20°C ambient temperature, you can use an equation to correct the resistance value to a standardized temperature:

$$\textbf{Equation 1} \quad R_m = R_{ref} [1 + \alpha * (T_m - T_{ref})]$$

where R_m is the actual measured resistance and T_m is the actual temperature at the time of measurement. R_{ref} would be the measured resistance at the standard temperature T_{ref}.

Normally we want to know the value R_{ref} and that can be found by solving Equation 1 for R_{ref}:

Equation 2 $R_{ref} = R_m / [1 + \alpha * (T_m - T_{ref})]$

Different materials have different temperature coefficients. Some examples, expressed as ppm, are:

Table 1   Temperature Coefficients (ppm)

Nickel	5866
Iron	5681
Tungsten	4403
Aluminum	4308
Copper	4041
Silver	3819
Gold	3715
Constantan	-74

Note that some conductors can have a negative temperature coefficient, meaning that the resistance decreases as the temperature increases.

One of the difficulties can be that conductors used in E-Textiles, for example, are modified from a standard material to be usable on a flexible substrate. This means that a direct look-up of the temperature coefficient might not be available, however the manufacturer of the material might be able to tell you the temperature coefficient.

I encountered the problems in my own Lab. Without having a constant ambient temperature, and without having the temperature coefficient, I had to determine the temperature coefficient myself. By measuring the resistance with nothing changing except the temperature, I could then calculate the temperature coefficient. In this case you solve Equation 1 for α:

Equation 3 $\alpha = (R_m - R_{ref}) / (T_m - T_{ref})$

If you plot the measured resistance against the measured temperature, the slope of the line is α, the temperature coefficient. If the reference temperature did not exist during the resistance measurements (like in my Lab, it was never as cool as 20°C), you simply extend the plot through the temperature of 20°C and then the value R_{ref} will be the value at 20°C on the plot. This is how I determined the temperature coefficient when I needed it.

Hioki RM3545-2

The Hioki RM3545 comes with a temperature probe that plugs into a dedicated connecter on the back panel of the meter.

The probe is intended only for ambient temperature, not for sample temperature. The ambient temperature can be read on the front panel of the meter if the panel is set to show the temperature. The temperature can be read with remote software.

The temperature coefficient can be set using the front panel or using remote software. It can be set separately for the front panel connecter and for each and every one of the MUX channels. The default setting is 3930 for every channel. From Table 1, you can see that this is a value between silver and copper, perhaps an average of typical conductors. To have the meter correct for temperature, it is necessary to turn ON the feature for each separate channel. Then you can set the coefficient for that channel to a different value.

Keithley DMM6500 and DAQ6510

The Keithley meters do not have a dedicated ambient temperature connecter. But you can read ambient temperature, indeed any temperature within the range of the temperature probe, by using one of the regular connecters, whether a panel connecter or a MUX channel.

Keithley does not have their own temperature probe. Different types of probes can be used, thermocouples, thermistors, RTDs, etc. We will need to procure one separately. A probe we have used, and it will work with the Keithley, is the DT4910 probe made by Hioki, a K-type thermocouple. It costs $37 on the Internet. This thermocouple has banana plugs and will work in the front panel connecter of the DMM or DAQ, or the rear panel connecter on the DMM. For FlexData, it would be connected to screw terminals when using the MUX, so a probe without a connecter might be preferred.

When using the Keithley meters manually, you press a button to select voltage, or resistance, or temperature, etc. The measured value is shown on the front panel screen.

When using the front panel connecter, the MUX channels are disabled. When using the MUX channels, the front panel connecter is disabled. Relay switching is used and is controlled only with a front panel button. This button cannot be controlled with software, so it is necessary to set this switch before a test begins.

When using the meters with software control, you can specify the parameter to be measured for each and every channel. Any one of the channels can be used for any one of the possible measurement values (voltage, resistance, temperature, capacitance, etc.).

Note that it is necessary in the remote software for the Keithley meters to specify which parameter will be measured with each channel. If the operator is measuring temperature on one of the channels, the test setup will need to allow this to be set in advance in the software. Indeed, the operator will need to specify which channels are being used, and what each channel is measuring (voltage, resistance, temperature, capacitance, etc.). The software will need to record the measurement values and will need to specify volts, ohms, degrees, farads, etc. Even if nothing is being measured except resistance, that must be specified in advance. Keithley meters can measure many other parameters which makes this step necessary, while the Hioki RM3545 measures only resistance making this step unnecessary.

When you start a new test, Keithley recommends that you first reset all channels. If you do not do a reset, the previous assignments will still be present, and they might not be what you want for the new test. Then you configure each channel for proper functions and settings.

The Keithley meters do not calculate temperature-corrected resistance. To correct the resistance, it is necessary to make the calculation manually or to have software than can do the calculation.

FlexData could be used to calculate temperature-corrected resistance, if we wish, using the formula given above in Equation 2. The resistance values will be recorded by the software, the ambient temperature will be recorded by the software, only the calculation remains.

There is one big difference between the Keithley DMM6500 and DAQ6510 meters. The DMM6500 has a connecter on the front panel and a connecter on the rear panel. The DAQ6510 does not have the rear panel connecter. You can see from the photographs below that the front panels are virtually identical, the rear panels are quite different. With the DMM6500, the front and rear connectors can be "used" simultaneously, but they cannot be "read" simultaneously, the reading selection must be made using the front panel button, and this cannot be accomplished in software. Thus it is not possible to read both temperature and resistance simultaneously using the DMM6500 front and rear panel connecters. As a result, both the DMM6500 and the DAQ6510 require a MUX to simultaneously read temperature and resistance.

Hioki RM3545-2 Front and Rear Panels

Keithley DMM6500 front and rear panels
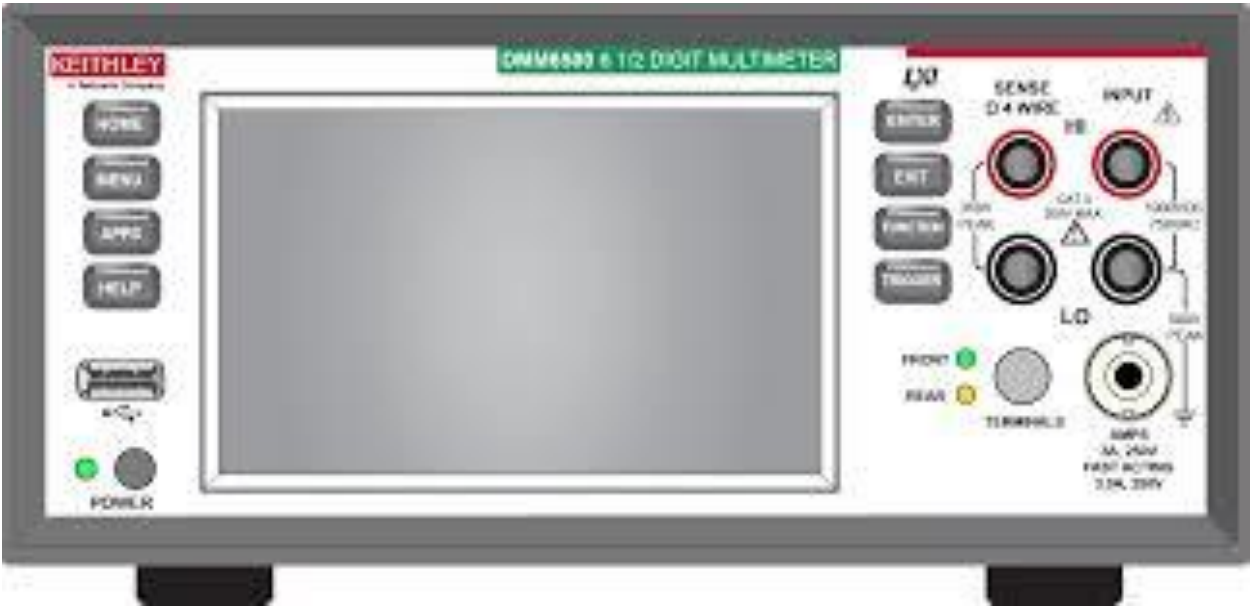
Keithley DAQ6510 front and rear panels