# About 4-wire Kelvin Connections

When to use 4-wire Kelvin Connections for voltage measurement is determined by the measurement circuit and the level of current involved in producing the voltage to be measured.

In the case of Heater Voltage measurement for Thermal Test Chips, the connection circuit is -

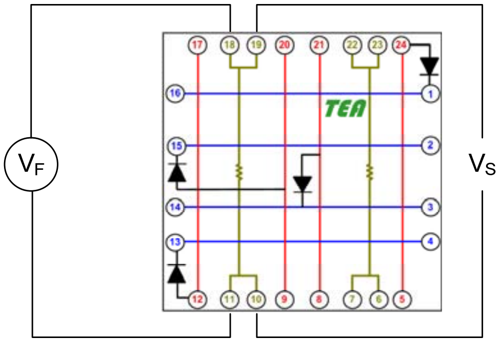

Figure 1a
Simplified Heater Connection Circuit

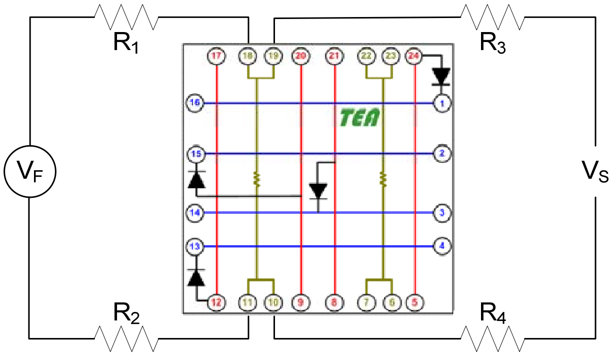

Figure 1b
Detailed Heater Connection Circuit

The simplified circuit of Figure 1a makes use of the dual connection pad at each end of the Heater Resistor – the TTC-1002 Unit Cell is pictured but the connection circuit is equally applicable to the TTC-1001 Unit Cell. In this diagram, the power supply Voltage Force ($V_F$) is connected to a single pad at each end of the resistor. The voltage sense ($V_S$) measurement is made by connecting to the other set of resistor pads. When $V_F$ is set to some voltage, $V_S$ will read some lesser voltage, the difference in voltages being proportional to the amount of current drawn from the power supply. The explanation for this difference is shown in Figure 1b. The resistors $R_1$ & $R_2$ represent all the individual resistors in the path between the power supply and the Heating Resistor pads – power supply connector resistance to the wire, wire resistance, wire to pcb trace to package connection resistance, pcb trace resistance, pcb trace to package connection resistance, package lead (or ball) resistance, package to chip connection resistance, etc. The same type of resistances will occur on the Sense Voltage measurement side of the circuit, although some of the resistance values will be different; the actual wire may be significantly smaller, hence the wire resistance will be higher. For example purposes, assume the $R_H$ is 7.5Ω, the $V_H$ is 6V. Then $I_H$ is 0.8A. If $R_1$ and $R_2$ are both 1Ω each, then each will have a voltage drop of 0.8V, resulting in an actual applied voltage of 4.4V [= 6V - (2 X 0.8V)]. This lower voltage will significantly understate the power dissipation in the Heating Resistor if $V_F$ is use to calculate power. If the Sense Voltage measurement instrument has a high input resistance, say 1MΩ or more (most typical DMMs have an input resistance ≥10MΩ), then the 2Ω associated with the connection circuit has negligible effect on the measured voltage – one part in 500,000 or less – and the $V_S$ reading will be 4.40V.

The same kind of connection circuit for measuring the Diode Temperature Sensor voltage ($V_M$) is shown in Figure 2

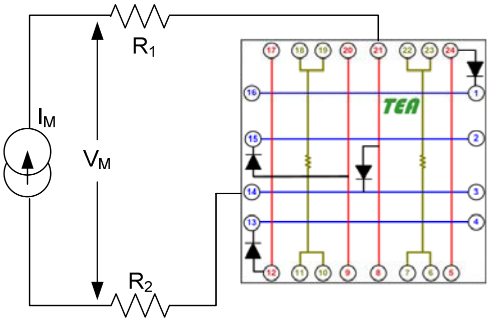

Figure 2
Diode Temperature Sensor Connection Circuit

Note that the $V_M$ measurement is done at the current source IM before $R_1$ and $R_2$. VM is equal to the sum of the voltage drops for each resistor plus the diode voltage drop, i.e. –

$$V_M = (R_1 \times I_M) + V_{Diode} + (R_2 \times I_M) \qquad (1)$$

If $R_1$ and $R_2$ are each 1Ω and $I_M$ is 1mA, then

$$V_M = V_{Diode} + 2mV \qquad (2)$$

The $V_{Diode}$ value is approximately 720mV at ~20ºC, resulting in a $V_M$ error of just 2mV or 0.3%. If using $V_{Diode}$ to measure absolute temperature, the resistance-caused offsets corresponds to about a 1ºC error. The error can be eliminated by measuring $V_{Diode}$ using the Unit Cell pads 8 and 3 shown in Figure 2.

As most thermal measurements are based on temperature differentials, the voltage offset due to the connection resistors $R_1$ and $R_2$ drops out –

$$\Delta V_{Diode} = [V_{Diode2} + I_M(R_{1'} + R_{2'})] - [V_{Diode1} + I_M(R_1 + R_2)] \qquad (3)$$

- if $R_{1'}$ and $R_{2'}$ at temperature 2 equals $R_1$ and $R_2$ at temperature 1, respectively, and $I_M$ remains constant.

The question as to whether the connection resistance are the same at two different temperature can be addressed by using the equation for the temperature coefficient of resistance equation –

$$R' = R[1 + \alpha(T' - T)] \qquad (4)$$

where T' is the higher temperature
T is the lower temperature
R' is the resistance at T'
R is the resistance at T
α is the Temperature Coefficient of Resistance

The connection resistors $R_1$ and $R_2$ shown in Figure 2 are the result of the same assortment of elements discussed previously for the Heater Resistance – made mostly of Copper and Aluminum, with α values of 0.004041/ºC and 0.004308/ºC respectively. For example purposes, assume that each resistor is divided into half Copper conductor and half Aluminum conductor. Then the average α value is 0.004175/ºC. If T = 20ºC and T' = 120ºC, ΔT = 100ºC. Inserting these values into Equation 4, R' = 1.4175R. However, in most semiconductor thermal measurements, the entire R1 and R2 resistors are not subjected to elevated temperature even when the semiconductor junction is at 120ºC. Probably less than 20% of the resistance is subject to the higher temperature, thus R' = [1 + (0.4175/5)]R = 1.0835R. Under these conditions, comparing the results with and without correction for R1 and R2 temperature changes shows a difference error of 0.0835%. If this error level is acceptable, as it is in most thermal measurements, then no correction for resistance temperature change is necessary.