# Measuring Temperature with 4-20 mA Tiltmeters

## Tech Note

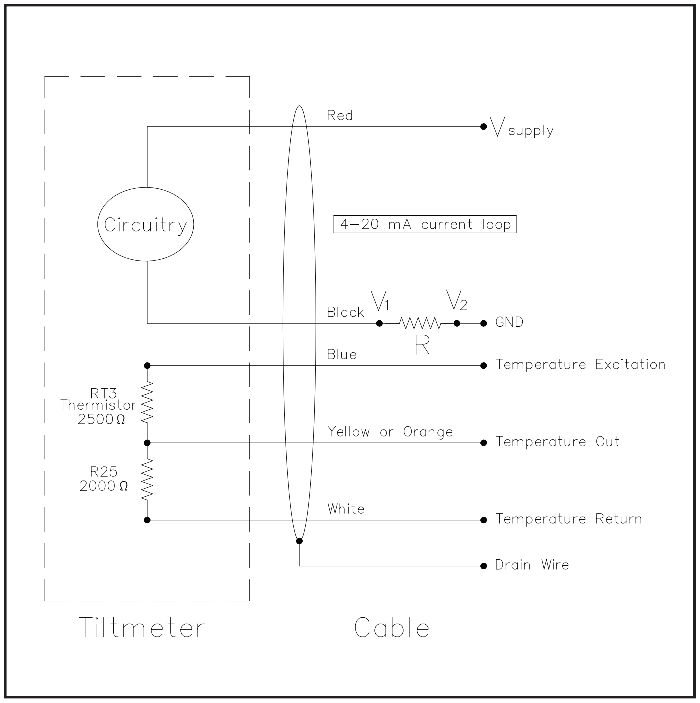


*Figure 1. Tilt angle is measured by the 4-20 mA current loop. Current is measured indirectly using a shunt resistor, R. Ohm's Law states that $V_1 - V_2 = IR$, where I is current in Amperes, R resistance in Ohms, and $V_1$ and $V_2$ the voltages measured on opposite sides of the sense resistor. Temperature is measured using the thermistor, RT3.*

Applied Geomechanics offers four tilt measurement products with 4-20 mA output:

- **TULIP** – A board level clinometer similar to voltage output Models 901 and 902
- **Clinometer Pak 420** – The 4-20 mA equivalent of the Model 904-T Clinometer Pak. This product houses the TULIP clinometer in a rugged weatherproof enclosure.
- **Tuff Tilt 420** – The 4-20 mA version of the Model 801 Tuff Tilt. The Tuff Tilt 420 is a high-precision tiltmeter with 4-20 mA output.
- **Tulip SC** – A 4-20 mA signal conditioning card for use with all of our Miniature Tilt Sensors.

Each of these products also measures temperature using a thermistor mounted on the circuit board. The thermistor resistance is nonlinearly proportional to temperature. In other words, while the tilt output is measured using a 4-20 mA current loop, the temperature is indicated by the resistance of the thermistor.

The wiring diagram for measurements is shown in Figure 1.

### Temperature Measurement

Your clinometer contains an internal *thermistor* for measuring temperature. This thermistor has a negative temperature coefficient, which means that its resistance decreases as the temperature goes up. Its resistance at 25°C is approximately 2500 Ohms. The wiring diagram for the thermistor, RT3, is shown in Figure 1. When making a temperature measurement, the thermistor should be powered only briefly (<1 second is good) to avoid self-heating.

There are two ways to use the thermistor to measure temperature inside your tiltmeter:

1) Measure the thermistor resistance directly using an ohmmeter connected to the "Temperature Excitation" and "Temperature Out" wires, and then convert this resistance to temperature. This conversion may be done with the help of Figures 2, 3 and 4. Figure 2 graphs thermistor resistance vs. the full temperature range of –50° to +70°C. Figures 3 and 4 are enlargements of the regions below and above 0°C.

Instead of using a graph, you may compute temperature from thermistor resistance with the following equation:

T = 1/[A + B Ln(RT3) + C Ln(RT3)^3 + D Ln(RT3)^5] – 273.15 (eq. 1)

where T is in degrees Celsius and
RT3 = thermistor resistance
A = 7.34862E-04
B = 3.38205E-04
C = -1.30862E-07
D = 1.21751E-09

2)The second method of determining temperature is to use the thermistor RT3 and fixed resistor R25 as a voltage divider (see Figure 1). By applying a known voltage Vin at the end of the "Temperature Excitation" wire and measuring the voltage $V_{out}$ on the "Temperature Out" wire, the thermistor resistance is obtained indirectly, as shown below. Both $V_{in}$ and $V_{out}$ are referenced to ground at the end of the "Temperature Return" wire.

The equation for $V_{out}$ is:

$V_{out} = V_{in}$ R25/(RT3 + R25)     (eq. 2)

Rearranging gives:

RT3 = R25($V_{in}/V_{out}$ – 1)     (eq. 3)

As shown by equation 3, the input voltage can vary during your measurements. What is important, however, is that the ratio of the input voltage to the output voltage, $V_{in}/V_{out}$, be accurately known. Once your have obtained the value of RT3 from equation 3, use Figures 2, 3 and 4 or equation 1 to obtain the internal tiltmeter temperature.

If your tiltmeter has a long cable, you will improve the accuracy of your thermistor resistance measurements by subtracting cable resistance from your readings. Applied Geomechanics tiltmeter cables contain stranded copper conductor wires with a gauge of 24 AWG. Each wire has a resistance of approximately 26 Ohms per 1000 ft (85 Ohms/km) at 25°C. In the case of a 1000 ft cable and direct resistance measurement using an Ohmmeter, you would subtract 2 x 26 Ohms from your reading to get the true resistance of RT3. Thus, a total of 52 Ohms would be subtracted, accounting for the resistance of the two wires through which the measurement was made.

If you plan to use the voltage divider circuit to determine temperature, equation 2 must be rewritten to account for the resistance R* of the "Temperature Excitation" and "Temperature Return" wires:

$V_{out} = V_{in}$ (R25 + R*)/(RT3 + R25 + 2R*)     (eq. 4)

Rearranging gives this equation for thermistor resistance RT3:

RT3 = (R25 + R*)($V_{in}/V_{out}$ – 1) – R*     (eq. 5)

You must decide whether lead wire resistance is important enough to take it into consideration in your measurements. For temperatures around 25°C and a 500 ft (152m) cable, wire resistance is about 1% of the thermistor resistance. The temperature error caused by not taking wire resistance into consideration is <<1°C. In geotechnical and earth science applications temperature trends and relative changes are normally more important than highly accurate absolute temperature readings. In some of these applications lead wire resistance may not be important.

For further information on the properties and use of thermistors for temperature measurement, visit the U.S. Sensor Corp. website, www.ussensor.com. The thermistor used in your tiltmeter has a B type curve and is U.S. Sensor part no. LR252B1K.

WARNING !
NEVER USE AN OHMMETER TO MEASURE THE ELECTROLYTIC TILT SENSOR INSIDE THE TILTMETER. APPLYING DC CURRENT THROUGH THE SENSORS WILL CAUSE PERMANENT DAMMAGE THAT IS NOT COVERED BY THE WARRANTY!

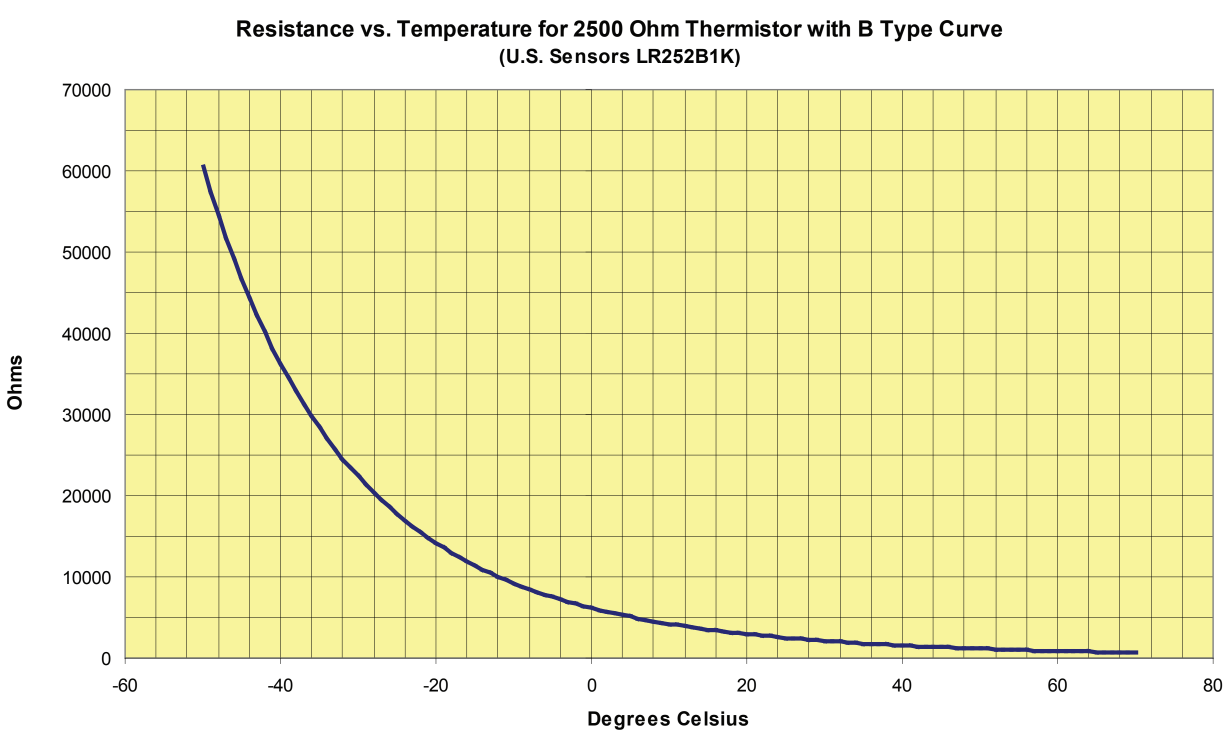


*Figure 2. Thermistor resistance vs. temperature, -60° to +70°C.*

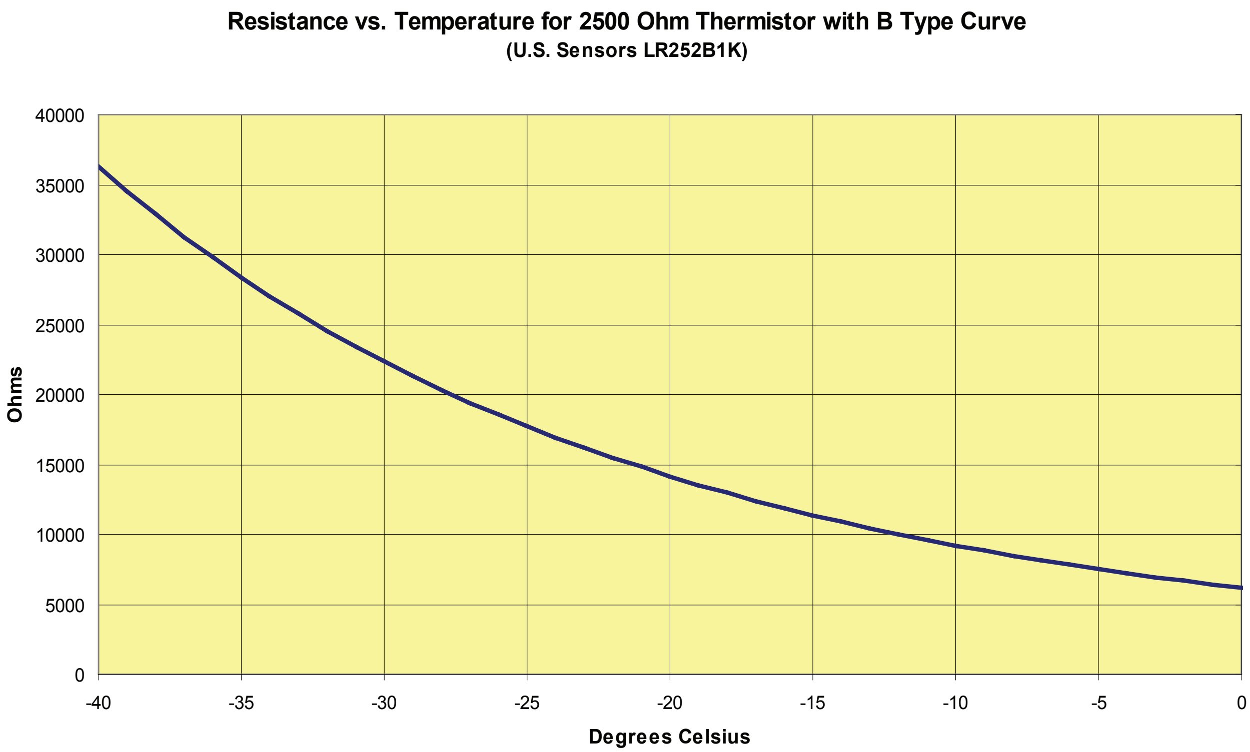


*Figure 3. Thermistor resistance vs. temperature, -40° to 0°C*

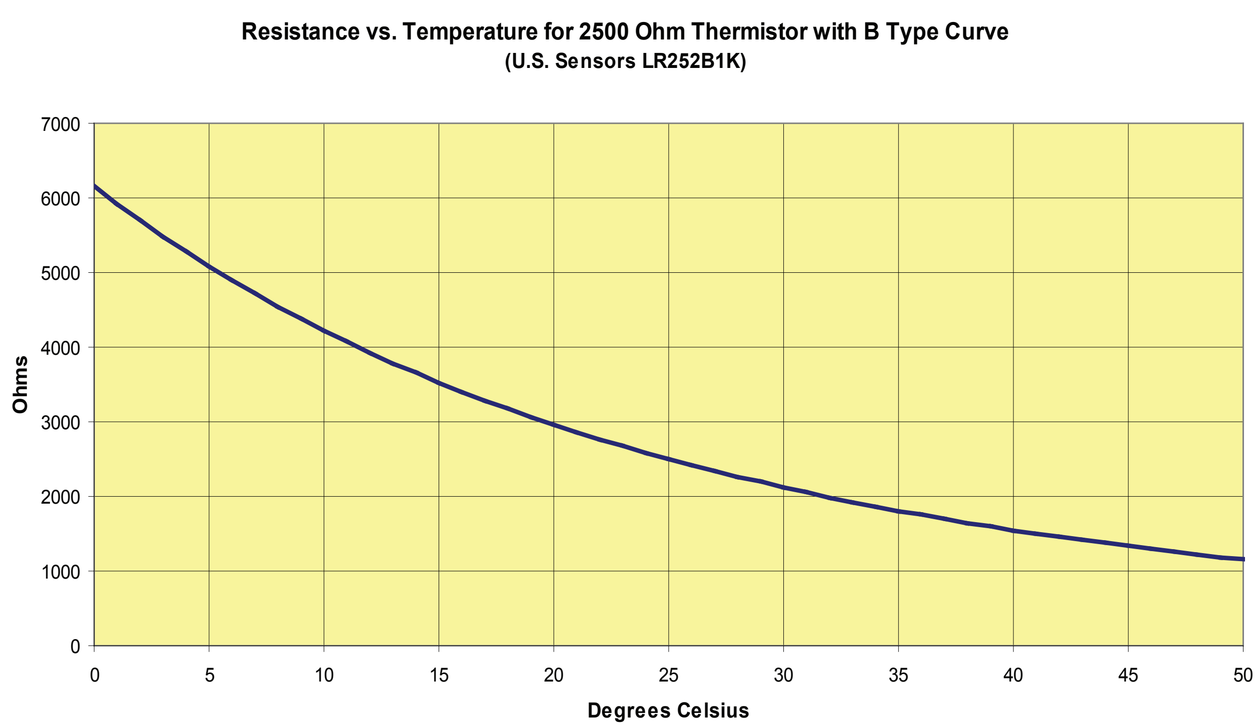


*Figure 4. Thermistor resistance vs. temperature, 0° to +50°C*