EE431 Lab 3

Measuring the Temperature Coefficient of a Resistor

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The purpose of this lab exercise is to measure the temperature coefficient of resistance of a variety of carbon film resistors. A secondary purpose is to understand that all electronic components are affected by temperature.

Background

The resistance of all resistors varies with temperature. Ideally, the variation is small and one of the characteristics bought with higher price is low temperature coefficient. The temperature coefficient of resistance (TCR) of a resistor is generally specified in parts per million per degree Celsius. The abbreviation is ppm/°C. An old fashion carbon composition resistor may have a TCR of over 1000 ppm/°C and a 10k resistor would change around 100 ohms for a 10 C in temperature. That is considered to be a lot. Common modern carbon film resistors have a TCR generally in the -100 to -250 ppm/°C range. Metal film resistors have a TCR generally in the 50 to 100 ppm/°C range. Premium resistors can be purchased (at a premium price) that have a TCR in the 5 to 10 ppm/°C range. The TCR may be either positive (the resistance increases with temperature) or negative (the resistance decreases with temperature). The TCR is generally not constant with temperature and may even change polarities over the operating temperature range of the resistor. It is possible that different batches of the same type of resistor may have different polarities of TCR.

One method of achieving a low net TCR is to combine two or more resistors of different constructions that have different polarities of TCR such that the combined resistance has a low net TCR over a particular operating range. This process is known as temperature compensation.

Calculations with temperature coefficient

Example 1: Let us consider a 10 kOhm resistor that has a TCR of -200 ppm/°C. Calculate how much the resistance will change as its temperature is increased by 15°C.

$$\mathbf{R_{delta} = R_{nominal} * T_{delta} * TCR / 1{,}000{,}000} \qquad \textbf{(1)}$$

Note that Equation 1 provides an estimate of the change when the resistance and absolute temperatures are not accurately known.

R_{delta} = 10,000 * 15 * -200 / 1,000,000 = <u>-30 Ohms</u>

Example 2: Calculate the resistance change if its temperature is decreased by 45°C.

R_{delta} = 10,000 * -45 * -200 / 1,000,000 = +90 Ohms

Example 3: If the resistance of a resistor is 2653 Ohms at 27°C and 2721 Ohms at 43°C, what is its average TCR?

When specific resistances and temperatures are known, Equation 1 is then written as follows:

$$R_{delta} = R@T_{high} - R@T_{low} = R_{avg} * (T_{high} - T_{low}) * TCR / 1{,}000{,}000 \quad (2)$$

Note that $R_{avg} = (R@T_{high} + R@T_{low}) / 2$ **(3)**

Solving Equation 2 for TCR produces

$$TCR = \frac{R@T_{high} - R@T_{low}}{R_{avg} * (T_{high} - T_{low})} * 1{,}000{,}000 \quad (4)$$

Substituting the data into Equation 4:

$$TCR = \frac{2721 - 2653}{((2721 + 2653) / 2) * (43 - 27)} * 1{,}000{,}000 = +1{,}582 \text{ ppm/°C}$$

Lab Procedure

1.0 Your laboratory ohmmeter can measure resistance up to six digits of resolution (not necessarily six digits of accuracy – there is a difference) and is capable of directly measuring the change in resistance of the typical lab resistor (carbon-film) when heated by touching the resistor. We will assume that the ambient temperature is 23 C and that holding the resistor for about a minute raises its temperature to 35 C – approximately your body temperature less some imperfections in thermal coupling. This is good enough for demonstration. It is very important to make connections to the resistor such that changes in the quality of the connection do not affect your measurements – this can be a challenge – basically it requires securing everything so that it cannot move. Do the following steps for resistors with nominal resistance values of 100, 1,000, 10,000, 100,000, and 1,000,000 ohms (nominal because you can use any convenient value within plus or minus 30 percent – i.e. for a 1K you could use any convenient resistor from about 680 to 1,300 ohms – just note the actual value of resistance used. Put the results in a data table (Excel is very handy for this) with columns for nominal resistance at room temperature, heated resistance, TCR, and cooled resistance. In all cases the computed TCR should generally be in the range of +-200 ppm. Significant differences imply that errors have been made.

1.1 Measure and record to six places the resistance of the resistor. Use meter leads with connection clips on the resistor. Wait until the measurement settles before taking data – this will probably take around one minute. You may observe that the measurement is sensitive to where you stand, air currents, etc. The point here is that making high resolution measurements can be a challenge.

1.2 Without disturbing the set-up, hold the resistor with light to medium force between your thumb and index finger. High mechanical force must be avoided as mechanical stresses will cause changes in resistance. Try not to touch the metal leads of the resistor because that would put your body resistance in parallel with the resistor and upset the measurement. Hold the resistor for about a minute or more until the measurement settles to at least four places. Record the new resistance value. Some people have unusually low body temperatures at their extremities and will thus observe very little change in resistance.

1.3 Do not disturb the measurement set up. Allow at least one minute for the resistor to cool back to room temperature while you compute the TCR (in PPM per C) of the resistor using the methods described earlier.

1.4 Record the cooled value of the resistor and compare with the original value in step 1.1. It may not be the original value – this is a hysteresis effect from a combination of the temperature change and the mechanical force you applied to the resistor which also makes measurement a challenge.

2.0 Summarize all of the data in a table. Present the data in a plot showing any trend in TCR with resistance. Plot the resistor value on the x-axis using a log scale (do not compute the log – you will lose points – format the axis in Excel to the logarithmic) and the temperature coefficient on the y-axis using a linear scale. What conclusions can be made?