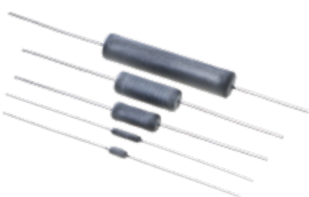
APPLICATION NOTE

Understanding Resistor Orientation and the Thermoelectric Effect to Achieve Balanced Circuit Design



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Introduction

It is important to maintain a constant temperature surrounding precision circuitry to help ensure correct and stable operation of amplifier and balanced circuits. Experienced circuit designers know this and heed caution by placing precision components away from heat sources or close to forced air cooling. Yet even an experienced designer may neglect this precaution with the unassuming resistor. Resistors are inherently temperature dependent. For example, one such attribute of a resistor's temperature dependence is described as the Temperature Coefficient of Resistance (TCR). Well documented, this phenomenon describes the change in nominal resistance value with change in temperature.

However, there is another insidious characteristic of resistors that many designers do not account for: the thermoelectric effect. This effect generates voltage at dissimilar material junctions in the presence of temperature gradients. Although insignificant in regular use cases, this effect can wreak havoc on circuits that require precision and balance. Therefore, it is very important that developers minimize the thermoelectric effect in precision resistors during the design process.

What is the Thermoelectric Effect?

The thermoelectric effect (also known as the Seebeck effect) occurs when two different materials, operating at different temperatures, are joined together. The temperature variation between the two conductors causes a voltage or electromotive force (EMF) to be produced, which can be attributed to electrons flowing from the hot material to the cooler one. The resulting voltage is dependent on the materials joined and can vary from a couple of microvolts per degrees C (μV/°C) to hundreds of μV/°C.

This effect isn't new and is frequently utilized to measure temperature. For example, thermocouples entwine two different material types of wire to create a temperature sensor. What is less well documented is EMF's detrimental relationship to resistors.

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What is the Thermoelectric Effect? (Continued)

Figure 1 illustrates the junctions that are formed by dissimilar materials of a wirewound resistor. These junctions act as thermocouples as well and have varying voltages dependent on the thermal gradient present to the resistor. Precision resistors, such as wirewound types, can produce a couple of µV/°C. But it's not just wirewound resistors that are affected by this phenomenon.

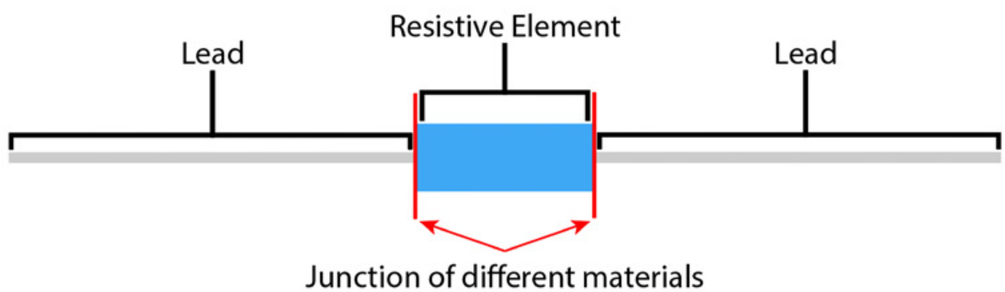

Figure 1. Wirewound resistor forming dissimilar material junctions

Metal film resistors will produce into the tens of µV/°C. Certain non-precision carbon resistors can generate even higher voltage levels, often creeping up to a few hundred µV/°C. Most of the time, this voltage is too small to make a real difference. However, in the case of applications that require precision resistors, such as in high gain systems, critically balanced circuits, or where low ohm values are demanded, unwanted DC voltage can present significant challenges. For example, measurements made across a carbon resistor with a Seebeck coefficient of 100 µV/°C in the presence of a 3 °C temperature gradient can introduce 300 µV of noise. For circuits that make ~1 mV measurements, 300 µV of noise can attribute to a ~30 % error. To reduce this error, designers can choose a resistor with a lower Seebeck coefficient or reduce thermal gradients by proper placement.

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What is the Thermoelectric Effect? (Continued)

When designing resistors into sensitive circuits, the printed circuit board layout and device orientation become crucial in order to reduce thermal gradients around critical parts of the circuits. To avoid thermal EMF, the leads and the body of the resistor need to be kept at the same temperature. Placing precision circuits away from heat and cooling sources is best practice. Of course, designing to this constraint is difficult in more compact designs where care is needed to minimize temperature gradients between the resistor leads and their respective junctions. Below are three recommendations designers can heed to help avoid the effects of thermal EMF in a design:

1) Resistors should be positioned to minimize the effects of natural convection (hot air rising). If resistors are placed vertically, natural convection will form a temperature gradient that can cause a voltage difference between the two differing material junctions. Therefore, it is highly recommended to place resistors parallel with the ground plane to lessen this effect. Figure 2 aids in describing the optimal position for a resistor soldered to a PCB.

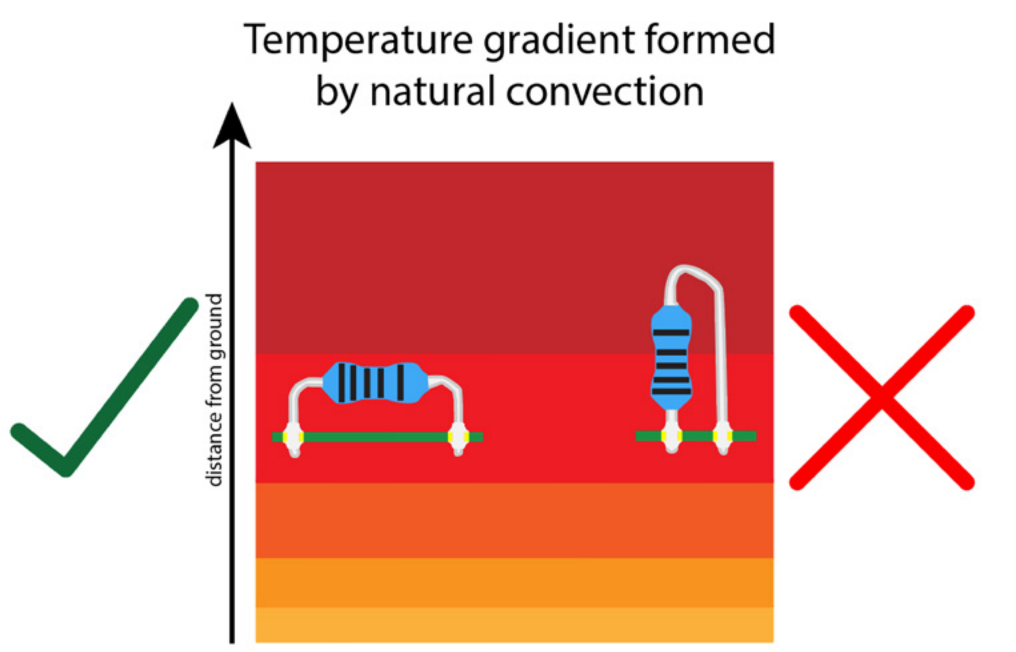

Figure 2. *Correct resistor orientation under the effects of natural convection*

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What is the Thermoelectric Effect? (Continued)

2) Resistors should be placed at right angles to any heat generating components as heat tends to generate radially from heat sources. Figure 3 simplifies this in a 2-D plane. Temperature gradients are minimized by placing the resistor where the dissimilar material junctions are equidistant from the center of the heat source. If resistor junctions are not equidistant from the external heat source, a larger temperature gradient across the two junctions will occur, inducing a higher voltage difference.

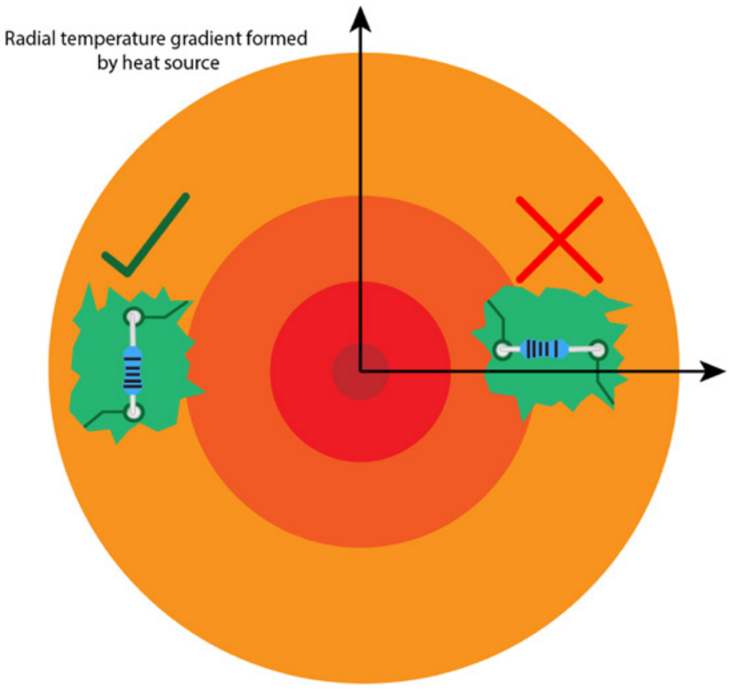

Figure 3. | *Proper placement for resistors in the presence of a heat source*

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What is the Thermoelectric Effect? (Continued)

3) If a cooling fan is present in the system, then the resistor should be perpendicular to the airflow. Figure 4 demonstrates the proper placement of a resistor in the presence of forced-air cooling. This, again, minimizes the temperature gradient that is formed between the two dissimilar material junctions.

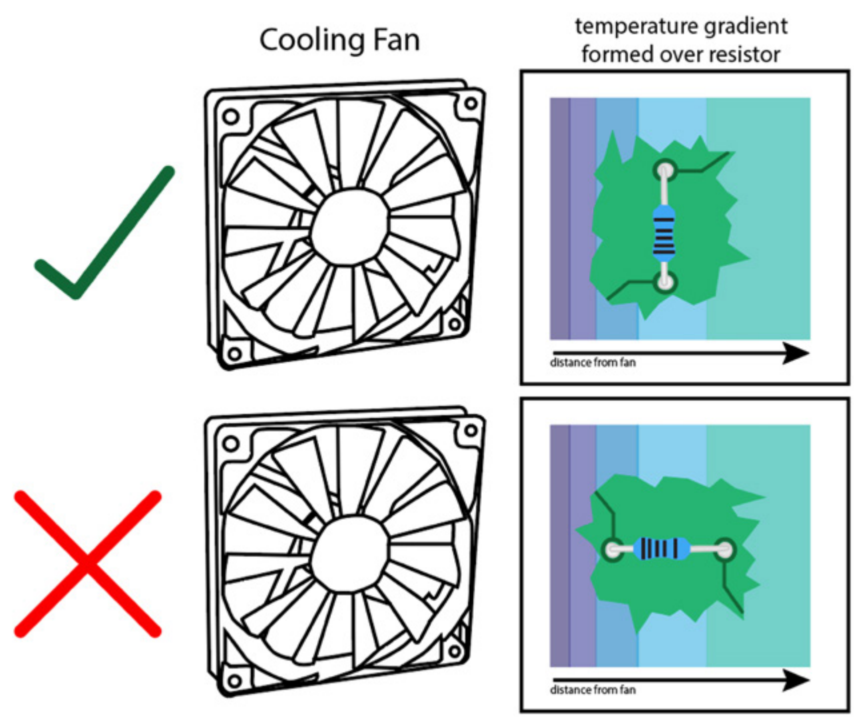

Figure 4. | *Correct positioning of resistor in a forced-air cooling system*

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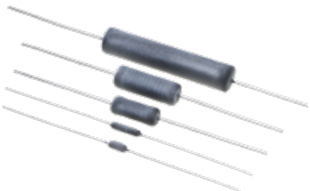

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Conclusion

Although the thermoelectric effect is often not taken into consideration, its impact on precision circuits can be detrimental. This paper has outlined how the thermoelectric effect is formed between dissimilar metal junctions in the presence of a temperature gradient. Producing noise up to hundreds of microvolts, this effect can challenge many designers to find a suitable solution to meet their high gain and balanced circuit specifications. To mitigate the thermoelectric effect on precision resistors, it is important to consider their placement in proximity to heating and cooling effects. In the world of electronics, the ultimate goal is for designs to have stable performance over a wide range of environmental conditions. As a result, the thermoelectric effect is a significant consideration for engineers to overcome when designing circuits that require high precision in a host of different environments.

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Americas: *Tel* +1-951 781-5500
Email americus@bourns.com

EMEA: *Tel* +36 88 520 390
Email eurocus@bourns.com

Asia-Pacific: *Tel* +886-2 256 241 17
Email asiacus@bourns.com

Mexico: *Tel* +52 614 478 0400
Email mexicus@bourns.com