Guide for Choosing Resistors that are Exposed to Different Stresses

This document provides engineers with guidelines for choosing resistors that will best suit their application needs.

When choosing resistors, engineers today encounter countless datasheets, which all claim to different product specifications. Each manufacturer and technology use their own terminology and tests (or lack of) which exhibit their products' best characteristic. This causes great confusion and frustration among engineers who want to compare different products.

Vishay has introduced a demonstration kit which performs a real-time direct evaluation and comparison of different technologies (same size and value), using the same conditions and parameters, simulating real life stresses which resistors encounter during service.

This gives a realistic understanding of the affects of these stresses in real life conditions, as opposed to published specifications.

Introduction

There is more to resistor precision than meets the eye. Resistors from different technologies may seem alike on the surface, and may often have similar published specifications; however, beneath the surface each is made differently. Inherent design and processing variations strongly influence electrical performances, leading to different behaviors after mounting.

Vishay Foil Resistors has established a new demonstration kit that illustrates the differences between Bulk Metal® foil, thin film, thick film, and wirewound resistor technologies in real time. The purpose of the presentation is to give a perceptible explanation of the primary factors that influence resistor stability.

1. Temperature Coefficient of Resistance (TCR)
2. Power Coefficient of Resistance (PCR) or “ΔR due to Self-Heating”
3. Electrostatic Discharge (ESD)
4. Short Time Overload
5. Thermal EMF
6. Humidity Resistance
7. Hot Spots

Temperature Coefficient of Resistance (TCR) is the best known parameter used to specify a resistor’s stability. It is measured in parts per million per degree celsius (ppm/°C), and is used to depict the resistive element’s sensitivity to temperature change due to ambient temperature variations.

Power Coefficient of Resistance (PCR) is a lesser-known, but still extremely important parameter. This parameter quantifies the resistance change due to self-heating when power is applied.

Electrostatic Discharge (ESD) damage to electronic devices can occur at any point in the component’s life cycle, from manufacturing to field service. Engineers are usually under the mistaken impression that ESD sensitivity is only an issue with active components. This, however, in not really the case, as resistors have also been seen to experience various ESD failures. There are three general types of ESD failures: catastrophic failure, parametric failure, and latent defect. A catastrophic or parametric failure can be detected when the resistor is tested prior to shipment; but in the case of a latent defect, the damage will go undetected until the device fails in operation. A latent defect is more difficult to identify because a resistor that is exposed to an ESD event may be partially degraded, yet continue to perform its intended function. Premature failure can occur after the resistor is already functioning in the finished product for a period of time.

Short Time Overload (STO) occurs when a circuit is subjected at one point or another to a temporary, unexpected high pulse (or overload) of at least 0.8 seconds.
This is a common cause of failure in resistors, as designers often tend to underestimate their potential for damage. Engineers usually design their circuits for steady-state conditions without taking worst-case conditions (such as STO) into account. A simple example of a STO can be a system startup, where there is a high power overload when the system is turned on.
Since resistor load life can be seen as a function of time, temperature and power, a STO test can be used as a simulator of sorts for prediction of long term stability.

Thermal Electromotive Force (Seebeck effect), which is negligible in ordinary resistors, may become a significant noise source of drift or instability in low value

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high-precision current sense resistors, and is considered a parasitic effect interfering with pure resistance. In many cases, when using low value current sense resistors, circuits experience certain drifts or inaccuracies from an unknown origin, which may actually be due to thermal EMF. It is often caused by the dissimilarity of the materials used in the resistor construction, especially at the junction of the element and the lead materials. The thermal EMF performance of a resistor can be degraded by external temperature difference between the two junctions, dissymmetry of power distribution within the element, and the dissimilarity of the molecular activity of the metals involved.

Humidity from the environment can penetrate all resin coatings to varying degrees over time, and eventually reaches the resistive surface. When this occurs, damage can result when voltage applied to the resistor causes an electrolytic conversion of the resistive alloy into compounds at the inter-granular boundaries, causing the resistance to increase until failure.

Hot spots greatly affect both the short and long term stabilities of resistors.

The existence of hot spots in the resistor is significantly influenced by the resistive element image and how it is trimmed to reach the desired value.

Vishay Foil Resistors' demonstrations show the importance of taking TCR, PCR, ESD, STO, thermal EMF, and humidity resistance into consideration when striving to achieve long term stability.

These stresses are greatly affected by many parameters, such as process, resistive element mass, construction, and design.

Temperature Coefficient of Resistance (TCR)

The TCR test consists of two electrically isolated circuits (see Figure 1). The test resistor (Rx) is connected to a precision ohmmeter on one circuit. The second circuit has a 100 Ω power resistor physically mounted to a substrate. A current is passed through the power resistor for a predetermined period of time. The temperature rise of the power resistor, and to Rx as a result, are predetermined time functions. After the heat rise of the resistor, the current flow through the power resistor is stopped, and Rx is monitored periodically as it cools down. The temperature coefficient is then calculated according to the resistance change of Rx relative to the temperature drop.

The temperature coefficient of Vishay Bulk Metal foil resistors is the result of matching the variation in resistance of the alloy with temperature, and the variation of the resistance of the alloy with stress. These two effects occur simultaneously with changes in temperature. The result is an unusually low and predictable TCR.

Owing to the Vishay Bulk Metal foil resistor design, this TCR characteristic is accomplished automatically, without selection, and regardless of the resistance value or the date of manufacture - even if years apart!

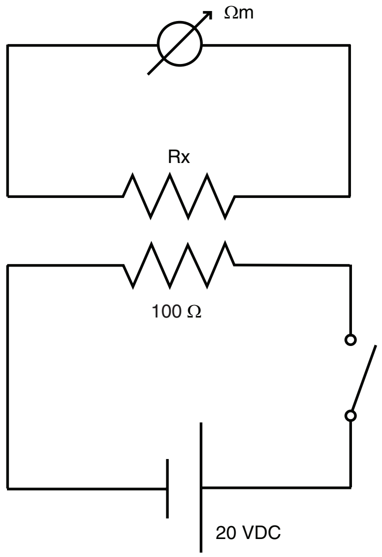

Figure 1

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Power Coefficient of Resistance (PCR) and PCR Tracking Demonstrations

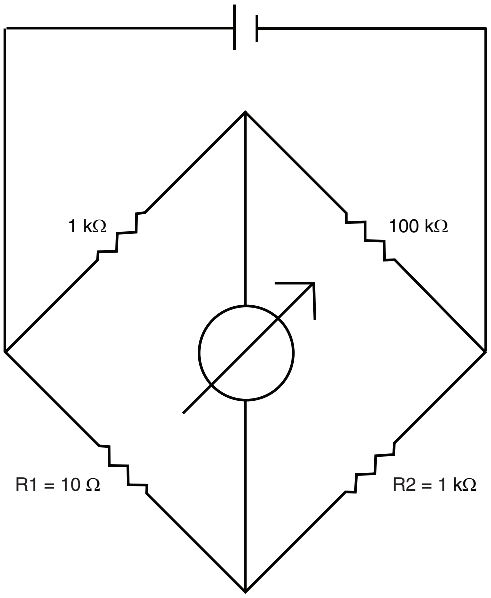

Figure 2

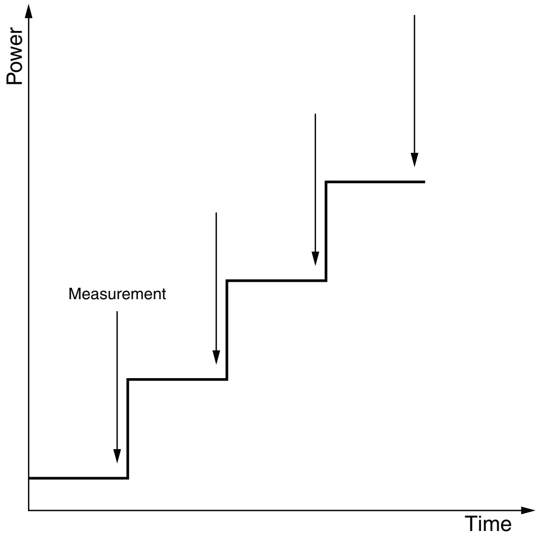

Figure 3

The power coefficient of resistance (PCR) demonstration operates as a basic bridge circuit (see Figure 2). The resistor under test is R_1. The other three legs of the bridge consist of high-Watt, low-TCR foil resistors designed and selected to ensure zero drift when voltage is applied across the bridge. For the PCR tracking demonstration, R_1 and R_2 represent the two resistors being tested. The other two legs of the bridge are high-value resistors, and therefore undergo an insignificant load.

The PCR test measures and graphs the stability of R_1 relative to the other three legs of the bridge as it is subjected to continuous and increasing power. The graphic display shows the change in resistance of R_1 from the nominal reading, measured in PPM. The nominal reading is taken at 0.1 W. Readings are then taken in 1/10 W increments up to 1 W for leaded parts, and 0.5 W for surface-mount units (see Figure 3). The demonstration measures the PCR (ΔR due to self-healing). The test results can indirectly indicate the TCR of the part.

The PCR tracking test measures and graphs the stability of R_1 compared to R_2 as they are subjected to continuous and increasing power. The graphic display shows the tracking stability between R_1 and R_2, measured in PPM, under increasing loads. At 25 mW, the value of the target voltage divider, R_1 and R_2, is read. The difference between R_1 and R_2 is set to zero, as shown graphically on the display. As subsequent readings are taken, the graph shows the change from the original R_1/R_2 reading, measured in parts per million (ppm). The readings are taken in 25 mW increments up to 250 mW.

This demonstration measures the stability of the R_1/R_2 ratio under increasing load within a voltage divider (ΔR_1-$R_2/\Delta P$, measured as ppm/W). The change in ratio occurs as a result of the absolute TCR of the target resistors. Both resistors are simultaneously loaded with the same amount of power, but they don’t heat up at the same rate, due to small differences in their thermal resistance. Therefore, the resistance of each resistor changes differently as a result of the TCR. If the two resistors have nearly identical low TCR, they will exhibit very good tracking stability under applied power. However, if the resistors do not have a similarly low TCR, they will exhibit poor tracking under applied power.

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Short-Time Overload Demonstration

The tested resistor (Rx) is connected to a 6.5 digit precision digital multi-meter (DMM), which takes the initial resistance reading (see Figure 4). After the reading is taken, the resistor is switched over to a power supply that applies an overload voltage for 5 s. After a sufficient cool-down time, the subject resistor is then switched back to the DMM, and the resistance is read again. The ΔR is displayed.

The test measures the change in resistance of the subject resistor due to the applied overload. The screen displays the ΔR, which is the difference in the resistance readings taken before and after the overload.

This demonstration measures the ΔR (measured in PPM) of a 100 R resistor subjected to an overload of 7 W for 5 s. This overload exceeds the power ratings of each device under test, specifically by a factor of 9 for the Vishay VSMP2512 resistor and a factor of 7.5 for the thin film resistors.

The power rating of foil resistors is chosen as the power at which the resistor can continuously function at the highest stability levels, with minimum drift. Overload possibilities are taken into account, and in fact the short time overload test is performed 100 % as part of the manufacturing process on most of the foil product lines, further guaranteeing long term stability and reliability even under worst case conditions.

The performance of STO during production also serves to alleviate internal stresses which are caused by manufacturing.

Foil resistors are about 100 times thicker than thin film. The high heat capacity of the foil resistor results in a low temperature rise of the resistor element under a 5 s pulse. The thin film resistors lack the pure mass (heat capacity) to handle the heat generated, and will typically burn up and fail.

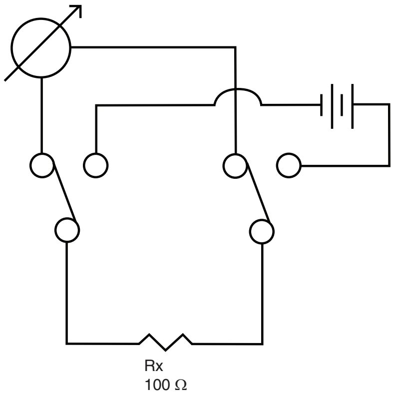

Figure 4

Current Sense Demonstration

The current sense demonstration is a simple bridge circuit (see Figure 5). The tested resistor is Rx. R_{std} is a massive, high-power, low-TCR heat-sinked resistor capable of handling very high current while exhibiting zero drift. The other two legs of the bridge are comprised of high-value, low-TCR foil resistors designed and selected to ensure zero drift when voltage is applied across the bridge.

The test measures and graphs the stability of Rx relative to R_{std} as it is subjected to continuous and increasing current (and voltage). The graphic display shows the change in resistance of Rx from the nominal reading, measured in ppm. The nominal reading is taken at 0.1 A. Readings are taken in 0.1 A increments up to 1 A.

This demonstration indirectly measures the power coefficient of resistance (PCR). The graphic display shows the change in resistance with increasing current (ΔR/R)/ΔI, measured as ppm/A). The test results indirectly indicate the PCR as a function of Ohm’s law. The subject resistor under test needs to have a resistance value of 1 Ω. The power can be calculated from Ohm’s law using the ohmic value (1 Ω) and the current applied (in A).

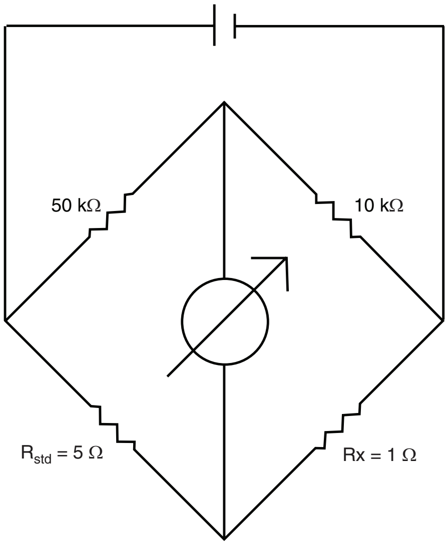

Figure 5

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Current Pulse Demonstration

The current pulse demonstration circuit is identical to the current sense demonstration cicuit (Figure 5). The resistor under test (Rx) is a 1 Ω, four-terminal resistor. R_{std} is a high power, low TCR resistor that exhibits no resistance drift when subjected to high power. The other two legs of the circuit are low-TCR resistors with values that were selected to allow for low self-heating when the circuit is energized.

The test measures and plots the stability of Rx relative R_{std} as it is subjected to a square wave pulse of 1 V, 1 A, 1 W (Figure 6). Data is recorded and graphed from the instant the pulse is applied and shows the change in resistance during the first 1.35 seconds, with measurements taken every 0.075 seconds. The test shows the inherent instantaneous stability of the Vishay Bulk Metal Foil resistor compared to other technologies when subjected to a sudden high in-rush current pulse.

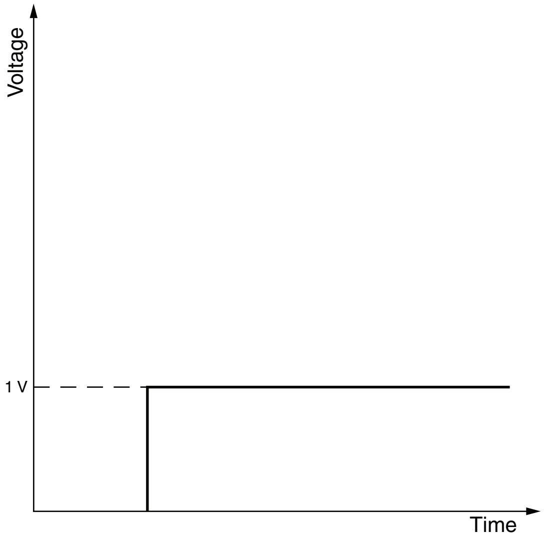

Figure 6

ESD Pulse Demonstration

This demonstration simulates an ESD pulse test. Figure 8 shows the resistor under test (Rx). After an initial resistance is taken, the 500 pF is charged to 2500 VDC, and then discharged through Rx. After this 0.5 µs pulse, the resistance of Rx is measured and the ΔR is calculated and displayed. The charging and discharging process is repeated up to 5 times, each time increasing the voltage by 500 VDC, and the ΔR is calculated based on the initial resistance reading. If the resistor opens after a discharge, the test terminates. This test is based on the human body model, which is intended to simulate the human body type ESD conditions the part would experience during normal usage.

This test shows that the Vishay Bulk Metal Foil resistor is not sesitive to high-voltage ESD-like pulses, where as other technologies will negatively affected. This test simulates how long it takes the resistor to reach its nominal value during voltage spikes which can occur in a circuit for many reasons such as switching or even a random pulse.

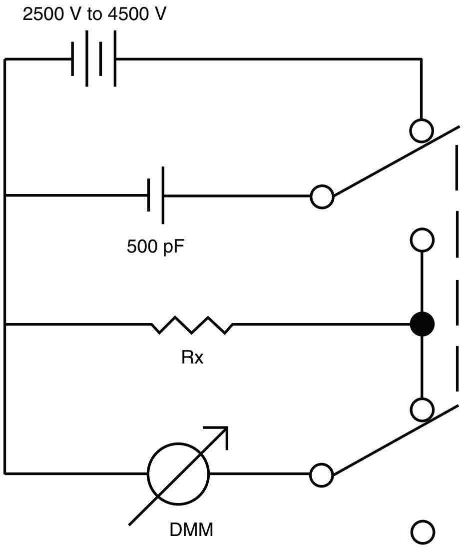

Figure 7

Thermal EMF Demonstration

The test resistor (Rx) is electrically isolated from the second circuit and connected to a precision DC voltmeter, which measures in microvolts (Figure 8). In the second circuit, two power resistors are physically mounted very close to the terminations of Rx. Power can be directed separately to each of the resistors, heating each of Rx's terminations differently, causing a thermal difference between them. The thermal EMF created by this temperature difference generates a voltage. This voltage is then measured with the precision voltmeter, without using any voltage or current source.

A key feature of Vishay Bulk Metal foil resistors is their low thermal EMF design. The flattened paddle leads make intimate contact with the chip, thereby maximizing heat transfer and minimizing temperature variations. The resistor element is designed to uniformly dissipate power without creating hot spots, and the lead material is compatible with

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the element material. These design factors result in a very low-thermal-EMF resistor.

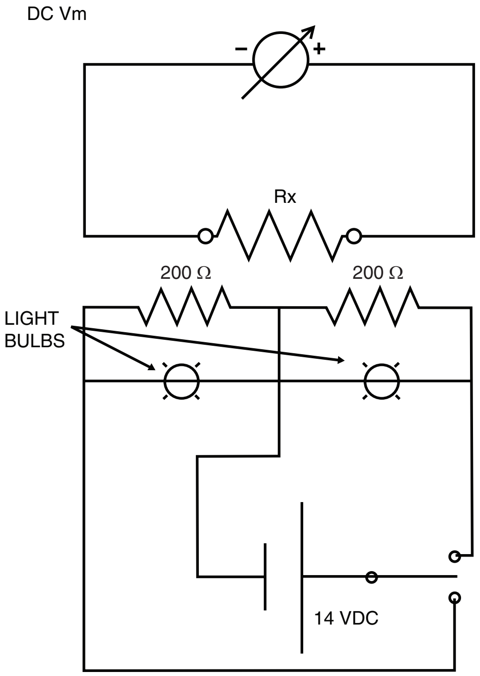

Figure 8

Manual Trimming Demo

This demo shows the Vishay foil trimming method. This demo also helps to explain the serpentine image used on most of the Vishay foil resistors.

The customer can pick any complex or custom resistance value (within limits of binned chips available). Value and image are entered into the demo computer. The hand-cal program will indicate the calibration lines to be cut until the resistor achieves the desired value.

The calibration lines and value are shown on the computer as program is running, to help demonstrate the process.

End value is displayed and will show the customer that his desired complex or custom value was achieved.

PCR Thermal Stabilization Demo

Demo shows the difference in PCR thermal stabilization times for different technology resistors. It proves that foil resistors with essentially zero TCR have little or no PCR thermal stabilization time as compared to thin or thick film resistors with high TCR and corresponding long PCR thermal stabilization times.

The test and circuit are essentially the same as the PCR demo. The major difference is that the maximum test wattage (500 mW) is applied to the test unit instantaneously and not ramped to 500 mW in 100 mW increments. The measurements start as soon as the wattage is applied and the performance curve is plotted from 0 to 9 seconds.

The low TCR foil unit stabilizes to its steady state value instantly. The thin and thick film units take several seconds to achieve a steady state value.

If the application for the resistor requires a fast steady state value, under switching, or varying voltages; a low TCR foil is vastly superior to other high TCR technologies.

Differential Op-Amp Demo

Demo uses two resistors of the same technology as a voltage divider on the input of a general purpose Op-Amp wired as a differential amplifier. The output of the Op-Amp ultimately drives a DC motor. A laser pointer is mounted on the DC motor drive shaft.

If the relative value of the two input resistors remains constant to each other, the output from the Op-Amp will remain zero and the motor will remain motionless. The laser pointer will stay fixed on one spot. If however, the value of the two resistors start to drift away from one another, the output voltage from the Op-Amp will go positive or negative (depending on which way the resistors drift) and the motor will turn the corresponding direction a relative amount. The laser pointer will move to another spot.

A voltage divider of each technology is connected to the input of the Op-Amp. A sunlamp is used to heat the voltage divider and cause the value of the resistors to change, relative to their perspective TCR.

The laser pointer will drift to new locations when the thin and thick film resistor dividers are heated with the sunlamp. The laser pointer will remain motionless when the foil resistors are heated. This demonstrates not only the low TCR of the foil resistor, but also their inherent superior TCR tracking.