VISHAY PRECISION GROUP

Facts at a Glance

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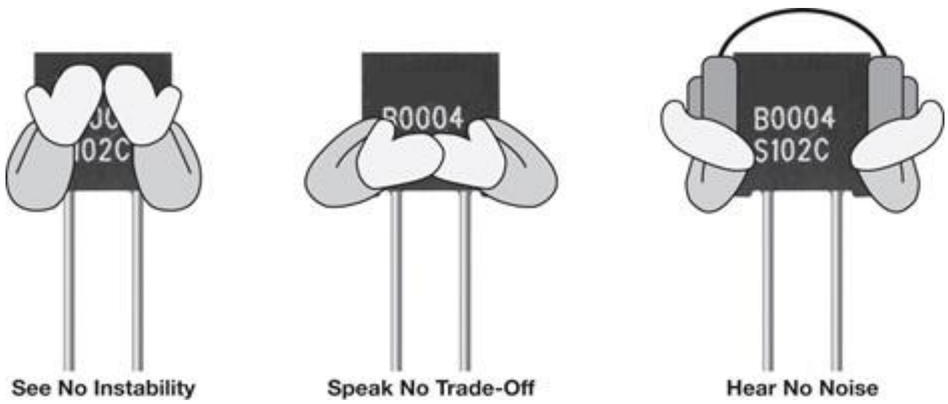
How to Select Resistors for Precision Applications



"Just as in a chess game, where the player thinks many steps ahead before making a move, the design engineer must think well ahead before selecting a resistor. Selecting a resistor that is inappropriate or not optimal can result in unexpected consequences which, in some cases, could be catastrophic for the design of the circuit."

Introduction

Every resistor type has its place in the scheme of things but not all types of resistors are appropriate for precision applications. Analog circuits, for example, are especially sensitive to resistor drift, which eliminates certain resistor categories from consideration. In this article, we discuss resistor stability in most of its forms to determine which resistor technologies are the optimum solution in terms of performance and cost. Resistors built on different technologies may seem alike on the surface, and may often have similar published specifications such as initial TCR, initial tolerance, and so forth. However, each is made of a different resistive material and produced differently. The inherent characteristics of the resistive material, as well as design and processing variations, strongly influence electrical performance, leading to different behaviors after mounting. In actuality, resistor stability needs to be judged by performance under load and temperature, and over the short term and over the long term, as the device is exposed to various electrical and mechanical stresses.

All Bulk Metal® Foil resistors undergo stabilization processing, such as repetitive short-term power overloads, to assure reliable service through the unpredictable stresses of extreme operation. Compared to Bulk Metal® Foil, Thick and Thin Film resistor elements are produced with a non-controllable material. Heat or mechanical stresses on the resistive elements cause the particles forming the film to expand. However, after these stresses are alleviated, the particles in the film matrix do not return to the exact same original position, which degenerates their overall stability.

Trimmer potentiometers with a foil resistor element are an order of magnitude better than cermet or wire trimmers in terms of electrical and mechanical characteristics, such as TCR, PCR, stability, shock, and vibration.

Circuit Stability

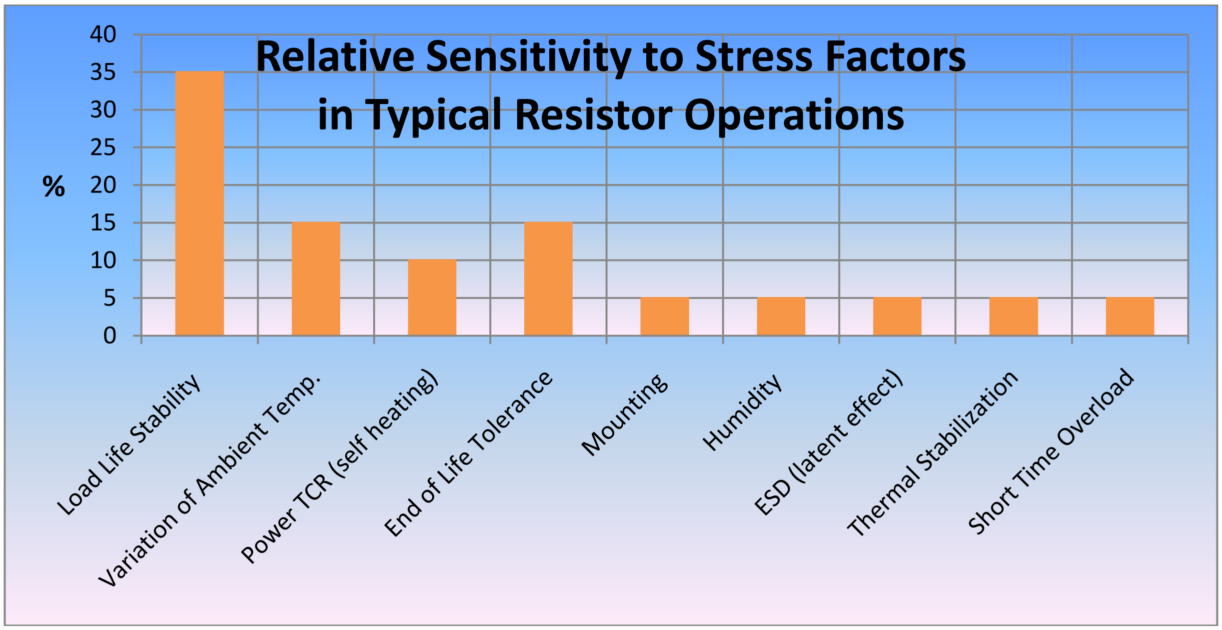
All circuits require some degree of stability to perform their intended function for a prescribed period of time. By stability, we mean getting the same output from the circuit for the same input without regard to time, temperature, vibration, power-application or other signal-distorting influences. Any resistor deviation from the installed resistance is a loss of stability to the circuit. These losses may be of minor importance, as in a digital information circuit, or of major importance, as in an analog measuring circuit.

Analog circuits are the most sensitive to circuit drift. The drift can be introduced by many components, but the resistors are the devices counted upon to maintain the circuit accuracy and are absolutely essential to circuit stability. We will discuss resistor drift and instability and their fundamental causes in the resistor manufacturing process. We will show in comparative terms where to apply the various resistor technologies available.

The stability of a resistor depends primarily on its history of exposures to temperature changes. Stability is mainly affected by:

- Changes in the ambient temperature and heat from adjacent components (as defined by the Temperature Coefficient of Resistance, or TCR)
- Destabilizing thermal shock, caused by a sudden application of power (defined by the power coefficient, or PCR) -- or as might be caused by a fighter jet climbing from a desert floor to a 5-mile altitude within a minute or two.
- Long-term exposure to high temperature and applied power (load-life stability)
- Repetitive stresses from being switched on and off

In very high precision resistors, the following stress effects must be taken into account to achieve high stability with changes in load (Joule Effect) and ambient temperature.



Stability over Time

Every resistor is manufactured to a specific size, value, and tolerance. The other factors affecting stability, such as Temperature Coefficient of Resistance (TCR), are shown on the datasheet and presumed applicable to this shipment. After verification to order, the parts may go directly to the floor for assembly or sit on a warehouse shelf in an environment with uncontrolled temperature and humidity and a high likelihood of being exposed to ESD. Either way, their stability is already in doubt. Assembly involves soldering, which subjects the component to a significant non-uniform temperature excursion. Board rework is a very uncertain contributor but all this can be nulled out at final test and calibration prior to shipment and we are back to minimal circuit error.

But the equipment must be shipped to its destination, unpacked, and tested in accordance with the operating instructions. Are there any potential stresses here? Now let us send the equipment into the field (maybe in the back of a pick-up truck) where the conditions may include shock and vibration, and ambient temperature excursions. Still operational, the equipment is now turned on and the circuits exercised causing internal temperature excursions. After all this, are we getting a correct reading? We hope so but we must adhere to a recalibration cycle which increases the confidence in the readings.

The Manifestations of Instability

Circuit instability resulting in false readings could be a consequence of the resistor choice originally selected for the circuit design and, of course, any subsequent abuse by the end user. Table I shows the various types of circuit instability or undesirable/unwanted contributions to the instruments readings.

Table 1: Types of instability and their effect

TYPE	EFFECT
Inductive Reactance	If a resistor is inductive it is probably not a good choice for anything but direct current (DC) circuits. Inductive reactance slows the circuit response and misses the single pulse or the elevated frequency. Wirewound and spiraled Thin Film resistors are the most prevalent contributors to inductance. The Bulk Metal® Foil resistor is virtually non-inductive, with an inductance of 0.08 µH.
Noise Insertion	If a resistor is noisy it is probably not a good choice for frequency-sensitive measurements. The noise inserted by the resistor may distort the measured signal to the point of causing an incorrect reading. The noise level also limits the sensitivity of measurement circuits, particularly when most analog sensors put out signals in the microvolt range. Most resistors have some level of noise insertion but the Foil resistor has the lowest level at up to 0.010 µV$_{RMS}$/V of applied voltage (< - 40 dB).
Temperature Coefficient Of Resistance (TCR)	Temperature Coefficient of Resistance (TCR) is the best-known parameter used to specify a resistor's stability, and is used to depict the resistive element's sensitivity to temperature change due to ambient temperature variations. TCR will show how resistors behave under high and low operating temperatures. But what happens to the purchased absolute TCR after we mount the resistor and start to use it? Yes, it can change depending on resistor type. Through-hole Vishay Foil Resistors experience the least change (no effect of the PCB). The TCR is 0.2 ppm/°C (-55° C to +125° C with +25° as reference), or at least 15 times better than any other technology.
Power Coefficient of (PCR)	Power Coefficient of Resistance (PCR) is a lesser-known, but still an extremely important parameter. This parameter quantifies the resistance change due to self-heating when power is applied. If a resistor changes its value with applied load, the circuit can become resistance-unbalanced and give a false reading (as in the loading of the input resistor vs. feedback resistor in an operational amplifier). This is of greater importance as the applied power, particularly in sense resistor circuits such as electronic scales or in deflection amplifiers where the stability of a radar display depends on the stability of the sense resistor as current pulses repeatedly hit the sense resistor. Here again the Foil resistor has the smallest PCR at 5 ppm absolute resistance change at rated power.
Load Life Stability	Power over time and temperature is a critical factor that differentiates a resistor. Resistor drift may be minimal at room temperature, but heat the resistor up by applying power and the difference becomes dramatic. The impact of load-life drift will be discussed later but the Foil resistor has the fastest stabilization response to load. This response is due to a slight stress relaxation of the foil's internal construction. This relaxation is not continuous and is completed in 500 hours for foil resistors. Load life data for other resistor types may be published for up to 1000 or 2000 hours, but major changes continue beyond those timeframes for Thick Film and Thin Film resistors.
Temperature Cycling	Frequent and repetitive changes in temperature apply thermal stresses to the resistive structure, resulting in a resistance change. These temperature excursions can be from external changes or frequent power cycling. In either case the resistor has been exercised. The robust structure of the Foil resistor makes it the least sensitive to temperature cycling.
Short Time Overload (STO)	Like temperature cycling, a short time overload (STO) applies mechanical forces to the resistive structure but adds the additional element of excess temperatures sufficient to evaporate a thin metal deposit. This is easily demonstrated by increasing the applied voltage beyond the specified maximum to the Thin Film resistor. While the latter will go

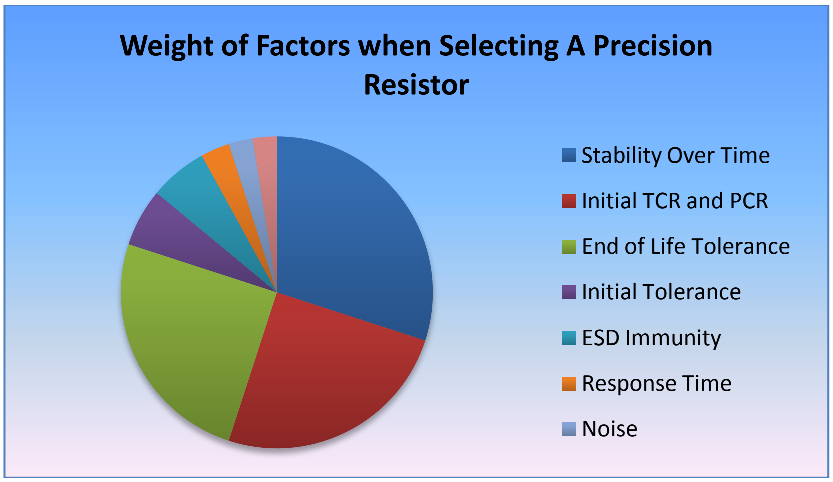
TYPE	EFFECT
	up in smoke, the Foil resistor is unaffected because the foil is hundreds of times thicker and is a cold rolled alloy as opposed to a sputtered structure or a paste.
Electrostatic Discharge (ESD)	Electrostatic discharge (ESD) damage to electronic devices can occur at any point in the component's life cycle, from manufacturing to field service. Generally, ESD damage is classified as either a catastrophic failure or latent defect. A catastrophic 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. Foil resistors will withstand at least 30 kV.
Thermal EMF	Thermal electromotive force (EMF) occurs when a temperature difference between two junctions of two dissimilar metals, such as the lead-to-resistive element termination, causes a voltage to be generated. While negligible in ordinary resistors, thermal EMF may become a significant source of noise, drift, or instability in high-precision resistors for low-value DC applications, and is considered a parasitic effect interfering with pure resistance. 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. The thermal EMF of Foil resistors is 0.05 µV/°C.

The End of Life Concept

These instabilities may be cumulative but the equipment is still supposed to be operational at the end of its calibration cycle or useful life, and thus circuit performance needs to remain within its specified limits. By accounting for this expected accumulation of instabilities in each application, it is possible to work back to a specified tolerance that will allow for these instabilities at the end of life.

Sometimes the cumulative instabilities are more than the application can tolerate for a given resistor type and another more stable resistor must be substituted. The initial tolerance calculation must be modified to make allowance for the instability effects down the road. An initial tolerance that is tighter than originally calculated must therefore be applied to the Bill of Materials. This often leads designers to select Vishay Precision Group's Foil based resistor, since this choice alone substantially reduces instability allowances. For example, if a circuit has an end of life tolerance of 1% taking into account the service stresses for this application, a Thin Film resistor might leave no headroom for the Bill of Materials tolerance, but Vishay Foil Resistors might satisfy the application at 0.1%.

What Factors Do Design Engineers Look For?



Resistor Constructions

Wirewound Resistor

Precision wirewound resistors have the lead wires embedded in each end of the bobbin. A thin narrow ribbon is folded over the resistance wire and then welded to the lead wire so as to weld both the resistance and the lead wires at the same time.

The result is a resistance wire sandwiched between two pieces of metal ribbon and welded all the way through to the lead wire. The assembler must find the exact point on the wire to get the correct resistance value, then sand the varnish off the wire at that point so that it can be welded.

If not welded perfectly, long term reliability can be compromised. Then, if the operator cannot find and weld the exact point for high precision, he may sand off the varnish over some area of the outer layer of wire and abrade the wire, thereby reducing the cross-sectional area of a small portion of wire which increases the resistance up to the exact value and tolerance required.

For high precision, manufacturers may expose the resistor to thermal cycles of high temp to try to stabilize it before the final weld and calibration. The sanded wires are also a point of potential failure after thermal stressing, throughout the life of the component.

Winding also produces a permanent deformation of the wire, hence changing its TCR and affecting its stability in time and temperature. Post curing to alleviate this effect will shift the resistance; hence the resistor will no longer be in tolerance.

Thick Film

Thick Film resistor technology relies on particle-to-particle contacts in a glass matrix to develop the resistive track. These points of contact develop the overall resistance but are interrupted by thermal strain during service. Since there are many of them in parallel, the resistor does not go open but continuously increases in value with time and temperature in combination.

Thin Film

Thin Film resistors are made with 250 Å or so of a metallic deposition (done by vacuum deposition or sputtering) on a ceramic substrate. They have a temperature-sensitive optimum deposit thickness, but making all values at the optimum film thickness severely limits the range of values possible. Therefore, the compromise is to use different deposition thicknesses for different ranges of values.

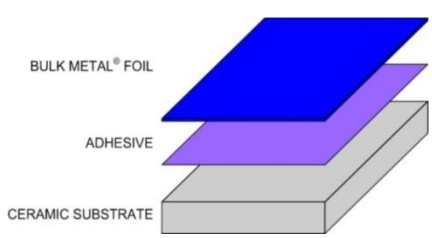
The stability of the film is affected by temperature and time aging of the deposition. This time aging varies with film thickness or resistance value and so is variable throughout the resistance range. It is chemical/metallurgical in nature and includes elevated temperature oxidation of the resistive alloy content of the deposition. The TCR is adversely affected by the shift from the optimum film thickness. A high value Thin Film resistor has a much greater deterioration rate due to the thinner deposition being more responsive to oxidation.

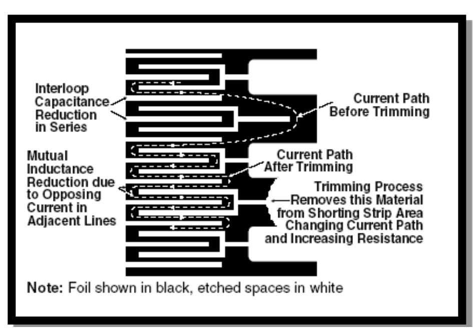
Bulk Metal® Foil Resistors

The Bulk Metal® Foil resistor is based on a special concept where a proprietary bulk metal cold-rolled Foil is cemented to a ceramic substrate. It is then photo-etched into a resistive pattern. Then, it is laser adjusted to any desired value and tolerance. Because the metals used are not drawn, wound or mistreated in any way during manufacturing process, the Bulk Metal® Foil resistor maintains all its design, physical and electrical characteristics while winding of wire or sputtering does not. Foil resistors achieve maximum stability and near-zero TCR. These performance characteristics are built-in for every unit, and do not rely on screening or other artificial means for uniform performances.

Post Manufacturing Operations (PMO) for High-Temperature Applications

Foil technology allows Vishay Precision Group to produce customer-oriented products designed to satisfy unique and specific technical requirements. In addition to the special Chip Stabilization process in the production line, Vishay Precision Group offers additional specially oriented post manufacturing operations (PMO) for high-temperature applications that require an even higher degree of reliability and stability.





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Cost Savings for Prototypes

Prototype costs can be reduced by ordering just a few Foil resistors in any value (i.e. 101.563 …± 10 ppm). There is no need to stock a wide array of precision resistors at low prices to connect them in series and parallel to obtain the desired value, when it is possible to buy only what is needed and get the resistors within days. Because this is the most precise resistor available, it should satisfy all R&D requirements. For lower-precision applications, it is possible to convert back to lower-precision resistors at the production phase in larger, more economical quantities.

Summary

The performance of Foil resistor technology is superior to Wirewound, Thin Film, and Thick Film technologies in all categories and is the best choice for high-precision and high-stability applications. The cost of Vishay Foil Resistors is initially higher but if the subsequent cost of equipment adjustment is taken into account it could be the most economical choice. For many precision applications requiring long-term stability with temperature, power and time, the Foil resistor might be the only logical choice.

For more information about this product group, please contact us at: **Foil@vishaypg.com**.

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