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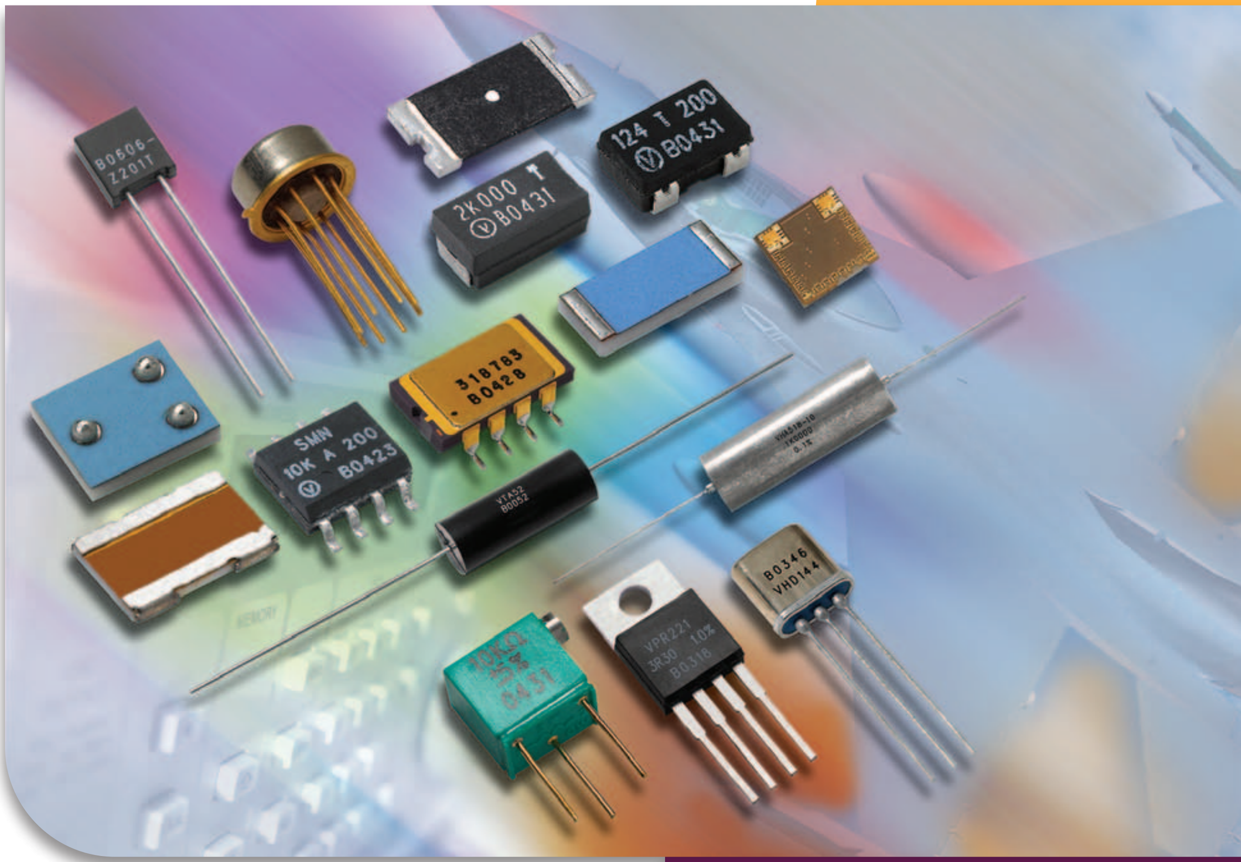

2011 Edition

# Introduction to High Precision Resistor Industry

## Vishay Foil Resistors

This document is a part of the
Design and Selector Guide for
High Precision Resistors

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# *Introduction to High Precision Resistor Industry*

The electronics industry has evolved at a remarkable rate over the past three decades. New techniques and advances have helped shrink equipment size and have put pressure on manufacturers of discrete components to develop devices that approach the ideal in performance and reliability.

Among these devices are chip resistors, which remain in high demand today and are among the basic building blocks for many circuits. They are more space efficient than discrete encapsulated resistors and require less preparation prior to assembly. As they have grown more popular, their capabilities have also become more important. Key parameters include electrostatic discharge (ESD) protection, thermal electromotive force (EMF), temperature coefficient of resistance (TCR) and self-heating properties, long-term stability, power coefficient, and noise.

In the technology comparisons to follow, wirewound resistors are discussed for their use in precision circuits. But it should be remembered that wirewound resistors are not available in true chip form (chip without a molding), and therefore are not usable in applications where weight and size limitations demand precision in the chip resistor format.

Although the overall system performance is improved by upgrading each component or subsystem, it is nevertheless true that overall performance is still determined by the weakest link in the chain. Each component comes to the system with built-in tradeoffs that limit overall performance, with particular concern over short- and long-term stability, frequency response, and noise. In the discrete-resistor industry, advances have been made in wirewound, thick film, thin film, and foil resistor technologies, with each offering various tradeoffs in performance per unit cost.

A brief review of the advantages and disadvantages of various resistor technologies shows the interlinked effects of thermal and mechanical forces on resistor electrical characteristics, as summarized in Table 1.

Stresses, whether mechanical or thermal, cause a resistor to change its electrical parameters. If such aspects as shape, length, geometry, configuration, or molecular structure are changed by mechanical or other means, the electrical parameters are also changed.

When current passes through a resistor element, heat is generated, and the temperature change causes mechanical changes by expansion or contraction in each of the materials involved in the component. The ideal resistor element would, therefore, incorporate those natural phenomena into a self-balancing, stability-enhancing system that maintains its physical integrity through the resistor manufacturing process, and eliminates the need to compensate for the effects of heat or stress during use.

## Precision Wirewound Resistors

Wirewound resistors are generally classified as either “power wirewounds” or “precision wirewounds.” Power wirewound resistors are subject to greater changes in service and are not used where precision performance is required; therefore, they are not considered in this discussion.

The wirewound resistor is usually made by winding insulated resistance wire of a specific diameter around a bobbin. Different wire diameters, lengths, and alloys provide the desired resistance and initial characteristics. Precision wirewound resistors have better ESD stability and lower noise than thin or thick film resistors. Wirewounds also have a lower TCR and better stability.

The initial tolerance of wirewound resistors can be as low as ± 0.005 %. The TCR, which is the amount of resistance change with each degree Centigrade change in temperature, can be as little as 3 ppm/°C typical; but for low resistance values, wirewounds are generally in the region of 15 ppm/°C to 25 ppm/°C. Thermal noise is low, and TCR tracking to ± 2 ppm/°C over a limited temperature range is possible.

In the process of manufacturing wirewound resistors, the wire has its inner surface (the side closest to the bobbin) under compression, while its outer surface is under tension. Permanent deformations —

**Table 1. Characteristics of Different Types of Resistors**

| Technology | Temperature Coefficient of Resistance (TCR) - 55 °C to + 125 °C, + 25 °C Ref. | Initial Tolerance | End of Life Tolerance | Load-Life Stability at + 70 °C, Rated Power 2000 Hours and 10,000 Hours | ESD (V) | Thermal Stabilization | Noise (dB) |
|---|---|---|---|---|---|---|---|
| Bulk Metal Foil | 0.2 ppm/°C | From 0.005 % | < 0.05 % | 0.005 % (50 ppm)<br>0.01 % (100 ppm) | 25,000 | < 1 second | - 42 |
| High Precision Thin Film | 5 ppm/°C | From 0.05 % | < 0.4 % | 0.05 % (500 ppm)<br>0.15 % (1500 ppm) | 2500 | > few minutes | - 20 |
| Precision Thick Film | 50 ppm/°C | From 0.5 % | < 5 % | 0.5 % (5000 ppm)<br>2 % (20,000 ppm) | 2000 | > few minutes | + 20 |
| Wirewound | 3 ppm/°C | From 0.005 % | < 0.5 % | 0.05 % (500 ppm)<br>0.15 % (1500 ppm) | 25,000 | > few minutes | - 35 |

as compared to elastic or reversible deformations — caused by this process and subsequent in-service annealing of the wire are irreversible. Permanent mechanical changes, which happen unpredictably, cause equally random changes in the electrical parameters of the wire and the resistance. The result is that the resistance elements can have variable electrical performance characteristics.

Because of their coiled-wire construction, wirewound resistors are inductors, and the proximity of the turns creates intercoil capacitance. To increase the response time in service, special winding techniques may be used to reduce the inductance. Due to the inductance and capacitance inherent in the design, wirewound resistors have poor high-frequency characteristics, particularly above 50 kHz.

It is difficult to make two wirewound resistors that accurately track each other over a specified temperature range when they are of the same nominal resistance value, and especially so when their values are not the same or when they are of different sizes (e.g., to meet different power requirements). The difficulty increases as the divergence of the resistance values increases.

The reason for this disparity is that a 1kΩ resistor is made with a different diameter, length, and possibly alloy of wire than, for example, a 100kΩ resistor. Moreover, the core sizes and turns per inch are different — again, mechanical properties affect electrical properties. Since the different values have different thermo-mechanical characteristics, their in-service stabilities vary and designed resistor ratios diverge more through equipment life. The TCR tracking and ratio stability are extremely important in high-precision circuitry.

Traditional wirewound manufacturing methods do not isolate the resistive element from the various stresses arising out of the handling, packaging, insertion, and lead forming processes. Tension is often applied to axial leads during the mounting process and pressure can be exerted on the package by mechanically induced forces. Both can change the resistance, either with or without power applied. Over long periods of time, the wound element tends to change physically as the wire adjusts to its new shape.

## Thin Film Resistors

Thin film resistors consist of a metallic deposition (made by vacuum deposition or sputtering process) with a 50 to 250 angstrom thickness on a ceramic substrate [recall that one angstrom (Å) = one nanometer = $10^{-10}$ meter]. Thin films can produce a higher resistance per given area than wirewound or Bulk Metal® Foil resistors, and are cheaper as well. This makes them quite economical and more space-efficient where high resistances are needed with intermediate levels of precision.

They have a temperature-sensitive optimum deposit thickness, but making all values at the optimum film thickness severely limits the range of possible values. Therefore, various deposit thicknesses are used to achieve various ranges of values.

The stability of the film is affected by elevated temperatures. The film aging-stabilization process varies depending upon the film thickness required to achieve various resistance values and is, therefore, variable throughout the resistance range. This chemical/mechanical aging also includes elevated temperature oxidation of the resistance alloy.

Also, the TCR is adversely affected by the shift from optimum film thickness. A high-resistance thin film resistor has a much greater deterioration rate because the thinner deposition is more responsive to oxidation. Since the mass of a thin film resistor is small, it is very susceptible to ESD.

Because of their small mass of metal, thin film resistors are also much more susceptible to self-etching in the presence of moisture. Water vapor picks up impurities as it penetrates through the encapsulant, and develops chemical etchants that can cause a thin film resistor to go open within a matter of hours in a low-voltage DC application.

## Thick Film Resistors

In the preceding discussion, it was noted that wirewound resistors are not available in chip format because of their size, bulk, and weight. While offering far less precision than wirewounds, thick film resistors are much more universally used because of their much greater resistance density (high resistance/small size) and much lower cost.

They have faster frequency response, similar to thin films and foil, but are the noisiest of all currently used resistor technologies. While being of lesser precision than the other technologies, they are discussed here because of their extremely broad use in almost every type of circuit, including the less-demanding sections of high-precision circuits.

Thick film relies on particle-to-particle contact in a glass matrix to develop the resistance 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 continually increases in value with time and temperature. Thus, thick films are less stable (time, temperature, and power) than other resistor technologies.

The granular structure also accounts for the high noise of thick films due to the bunch-and-release electron charge movement through the structure. The higher the resistance value for a given size, the less the metal content, the greater the noise, and the less the stability. The glass content of the thick film structure forms a glassy phase protective coat during the curing of the resistor, and this gives the thick film resistor greater moisture resistance than the thin film resistor.

## Foil Resistors

A specific foil alloy with known and controllable properties (Ni/Cr with additives) is cemented to a special ceramic substrate, resulting in a thermo-mechanic balance of forces. A resistive pattern is then photo-etched in the foil. This process uniquely combines the important characteristics of low TCR, long-term stability, non-inductance, ESD insensitivity, low capacitance, fast thermal stabilization, and low noise in one single resistor technology.

These capabilities bring high stability and reliability to system performance without any compromise between accuracy, stability, and speed. To acquire a precision resistance value, the Bulk Metal Foil chip is trimmed by selectively removing built-in “shorting bars.” To increase the resistance in known increments, selected areas are cut, producing progressively smaller increases in resistance.

Standard temperature coefficients of ± 1 ppm/°C over the range of 0 °C to + 60 °C (0.05 ppm/°C for Z-Foil) are derived from the properties of the alloy and its interactive thermo-mechanical balance with the substrate (Figure 1).

In the planar foil, the parallel patterned element design reduces inductance; maximum total inductance of the resistor is 0.08 μH. Capacitance is 0.5 pF maximum. A 1-kΩ resistor has a settling time of less than 1 ns up to 100 MHz. Rise time depends on resistance value, but higher and lower values are only slightly slower than mid-range values. Absence of ringing is especially important in high-speed switching as in, for example, signal conversion.

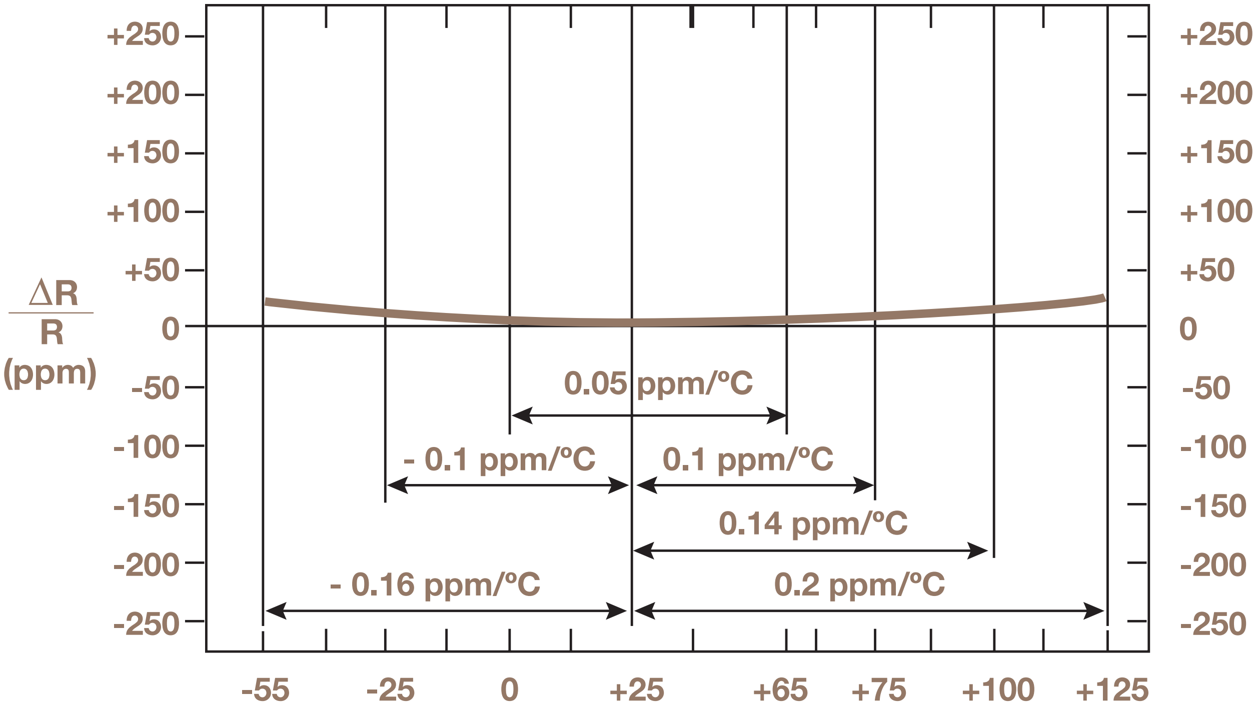

Figure 1: Ambient temperature coefficient and TCR chord slopes for different temperature ranges (note: the TCR slopes for <100 Ω are influenced by the termination composition and result in deviation from this curve).

The DC resistance of 1-kΩ Bulk Metal Foil resistor compared with its AC resistance at 100 MHz can be expressed as follows:

AC resistance/DC resistance = 1.001

Foil techniques produce a combination of highly desirable and previously unattainable resistor specifications. These include low temperature coefficients of resistance (0.05 ppm/°C from 0 °C to + 60 °C), tolerances as low as ± 0.005 % (down to ± 0.001 % when hermetically sealed), load-life stability of ± 0.005 % (50 ppm) at + 70 °C and rated power for 1000 hours, tracking between resistors of 0.1 ppm/°C from 0 °C to + 60 °C, and ESD immunity at least to 25 kV.

## How Much Performance?

Naturally, not every engineer needs an entire high-performance package for their circuitry. Resistors with much poorer specifications can be used satisfactorily in many applications, so the question of need is divided into four basic categories:

1. Existing applications that can be upgraded by relying on the total performance package of Bulk Metal Foil resistors.
2. Existing applications that require one or more, but not necessary all, of the performance parameters to be “industry best.”
3. State-of-the-art circuitry that can only be developed now because of the availability of improved specifications for precision resistors.
4. Purposeful pre-planning use of precision resistors to allow for future upgrading (e.g., cost savings can be realized by having the circuit accuracy maintained by the resistors rather than by the active devices, which would greatly increase cost for only slightly better levels of performance).

In category two (2), for example, the need for a single parameter must be weighed against the economics of the whole package. It could cost less to use a resistor with superior overall performance specifications, because the need for compensating circuitry (and the cost of the associated components plus their assembly) may be eliminated. Cost savings may also be achieved by concentrating precision in the resistors rather than in the active devices, because active devices have greater cost per marginal performance improvement than the resistors do.

Another question that might be posed is: “Would utilizing a higher-performance resistor in order to upgrade equipment performance enhance market acceptance of the equipment?”