Vishay Precision Group

7 Technical Reasons To Specify Bulk Metal® Foil Resistors From Texas Components Corporation

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Bulk Metal® Foil Technology Resistive Components

1. EXTREMELY LOW TEMPERATURE COEFFICIENT OF RESISTANCE

2. TIGHT RESISTANCE TOLERANCE

3. EXCELLENT LOAD-LIFE STABILITY

4. HIGH SPEED

5. LOW NOISE

6. LOW THERMAL EMF

7. NON-MEASURABLE VOLTAGE COEFFICIENT

Bulk Metal® Foil Technology Resistive Components

REASON 1

EXTREMELY LOW TEMPERATURE COEFFICIENT OF RESISTANCE (TCR)

"Why are extremely low TCR resistors required?" is a proper question when evaluating system cost. The answers are as numerous as the systems in which they are installed but a few examples may provide insight:

1. A remote TV transmitter that started up cold in the morning and warmed up during the day required manual color discrimination adjustment during the day,
2. Satellites in synchronous orbit that require stable position and function or that rotate through temperature extremes.

The solution is extremely low TCR resistors.

FOIL TCR

Two predictable and opposing physical phenomena within the composite structure of the resistance alloy and its substrate are the key to the low TCR capability of Bulk Metal® Foil:

1. Resistivity of the resistive alloy changes directly with temperature. (Resistance of the foil increases when temperature increases.)
2. The coefficient of thermal expansion of the alloy and substrate are different resulting in a compressive stress on the resistive alloy when temperature increases. (Resistance of the foil decreases due to compression caused by the temperature increases.)

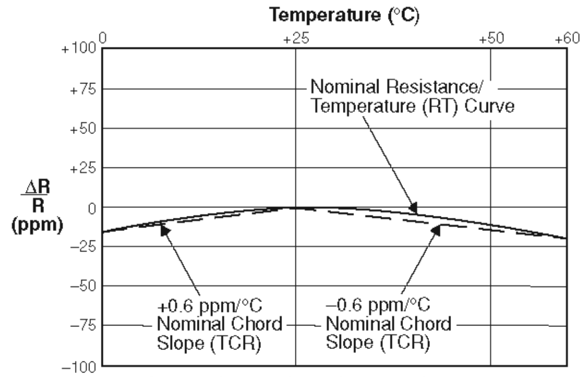
The Temperature Coefficient of Vishay Bulk Metal® Foil resistors is the result of matching the variation in resistivity of the alloy with temperature and variation of the resistance of the alloy with stress. These two effects occur simultaneously with changes in temperature. The result is an unusually low and predictable TCR.

Due to Vishay's 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!

NOMINAL TCR

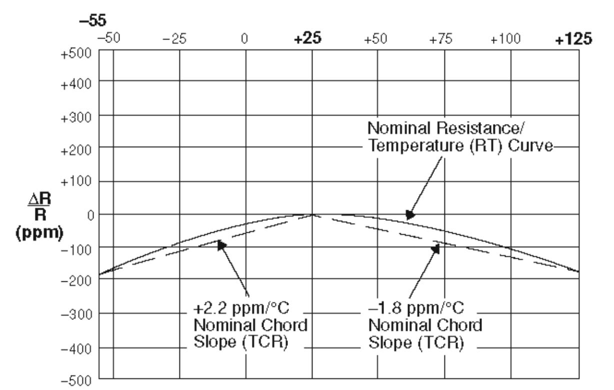
Vishay Nominal TCR is defined as the chord slopes of the relative change of resistance/temperature (RT) curve, expressed in ppm/°C (parts per million). Slopes are defined from 0°C to + 25°C and + 25°C to + 60°C ("Instrument" Range, see Figure 1); and from – 55°C to + 25°C and + 25°C to + 125°C ("Military" Range, see Figure 2). These specified temperatures and the defined nominal TCR chord slopes apply to all resistance values including low value resistors down to 1 ohm. Note, however, that without four terminals and Kelvin connection in low values, allowance for lead resistance and associated TCR may have to be made. All resistance and TCR measurements are made by the factory at a gage point 1/2" from the standoffs. See Figure 3 for increased TCR spread in low values and Figure 4 for the maximum spread and distribution in higher values. Figures 5 and 6 display the complete scope of performance in both instrument and military temperature ranges.

FIGURE 1 - VISHAY S102C SERIES NOMINAL TCR (0°C TO +60°C)



0°C / +25°C / +60°C are the test points with +25°C as the reference temperature

FIGURE 2 - VISHAY S102C SERIES NOMINAL TCR (-55°C TO +125°C)



–55°C / +25°C / +125°C are the test points with +25°C as the reference temperature

If we compare this performance to that of conventional metal film resistors with TCR both positive and negative within a resistance value (± 25 ppm/°C) or to that of conventional wirewounds with positive TCRs in some values and negative TCRs in others (± 10 ppm/°C) we see that foil provides consistent chord slopes for all values and lots. See Figure 2. This is a major improvement in TCR over anything else available. Use foil resistors for extremely low TCR requirements.

EXTREMELY LOW TEMPERATURE COEFFICIENT OF RESISTANCE (TCR) Continued

STANDARD TCR SPREAD FROM NOMINAL

Vishay Standard TCR Spread from Nominal is defined as a designer's reference which represents that at least 92% of the units, and 82% of the lots supplied by Vishay will be within the stated band centered on the nominal curve.

This definition of the Vishay Standard TCR Spread from Nominal applies to all resistance values. For values below 80 Ohms see Figure 3.

MAXIMUM TCR SPREAD FROM NOMINAL

Vishay Maximum TCR Spread is defined as the 3 σ (sigma) limit of a normal Gaussian distribution (99.73% of a production lot), which is within a band centered on the nominal curve. See Figure 4. This Vishay Maximum TCR Spread is no greater than ± 2.3 ppm/°C or ± 2.5 ppm/°C depending on temperature range and series (see graphs).

This definition of the Vishay Maximum TCR Spread from Nominal applies to all resistance values. For values below 80 Ohms see Figure 3.

FIGURE 3 - VISHAY TCR SPREAD FOR LOW-VALUE RESISTORS*

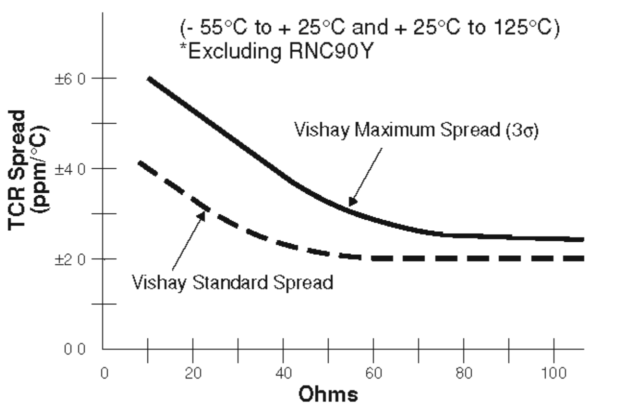


FIGURE 5 - VISHAY S102C SERIES TCR SPREAD FROM NOMINAL (0°C TO +60°C)

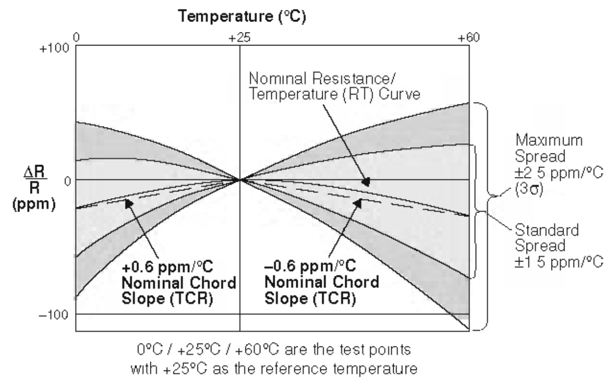


FIGURE 4 - NOMINAL DISTRIBUTION OF TCR (+25°C TO +125°C)

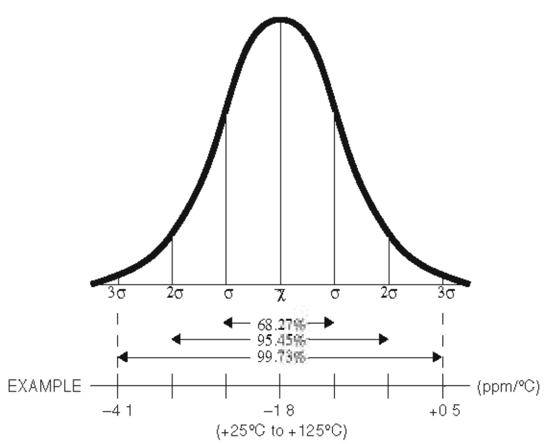
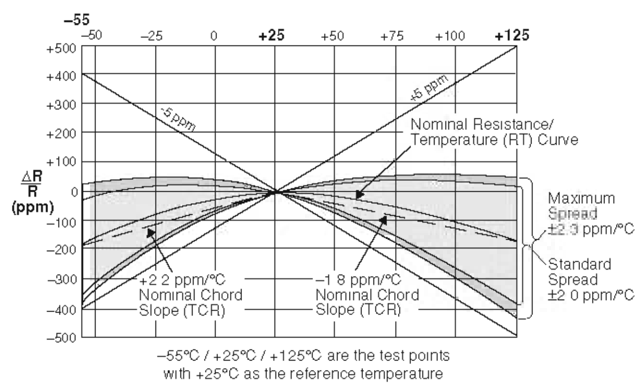


FIGURE 6 - VISHAY S102C SERIES TCR SPREAD FROM NOMINAL (-55°C TO +125°C)



EXTREMELY LOW TEMPERATURE COEFFICIENT OF RESISTANCE (TCR) Continued

IMPROVED TCR IN FOIL RESISTORS

Foil technology has advanced through the years and TCR improvements have been achieved. Alloys have been developed that give positive hyperbolic response to temperature. Figures 7 and 8 show this new response. The Vishay S102K resistor has a response to temperature nearly half that of the S102C and positive on the hot side (S102C is negative on the hot side).

More recently a method of achieving virtually zero TCR has been developed. The Vishay Thermotropic™ resistor VHP100 has little or no response to temperature so a window definition has been devised to characterize the performance. For TCRs < 1ppm/°C over the military range (– 55°C to + 125°C, and for TCR < 0.5ppm/°C over the metrology range (+ 15°C to + 45°C), see Figure 9 and turn to page 15 for a more complete description of Vishay's VHP100 Thermotropic™ resistors.

The Vishay Nominal TCR for the S102C is + 2.2ppm/°C (– 55°C to + 25°C) and – 1.8ppm/°C (+ 25°C to + 125°C) for all resistance values including low value resistors. However, as the resistance value decreases below 80 Ohms, the Standard TCR Spread from Nominal starts to increase; the same is true for the Vishay Maximum TCR Spread from Nominal except that it starts to increase for resistance values below 80 Ohms. (On special order Vishay will produce low value resistors, below 80 Ohms, with a TCR spread from nominal of ± 1.5ppm/°C or better.)

TCR TRACKING OF FOIL RESISTORS ON A COMMON SUBSTRATE

When two or more resistors share a common substrate, their TCR track very closely: tracking of 0.1 ppm/°C is achievable.

EXAMPLE (SEE FIGURE 3)

At 10 Ohms, the nominal TCR is + 2.2ppm/°C (– 55°C to + 25°C) with a maximum TCR Spread from Nominal of ± 6ppm/°C, or the TCR of the resistor will be between:

– 3.8ppm/°C and + 8.2ppm/°C

(+ 2.2 – 6.0 = – 3.8ppm/°C; + 2.2 + 6.0 = + 8.2ppm/°C)

At 10 Ohms, the standard TCR Spread from Nominal will be ± 4.0ppm/°C or, a TCR range of:

– 1.8ppm/°C to + 6.2ppm/°C

(+ 2.2 – 4.0 = – 1 .8ppm/°C; + 2.2 + 4.0 = + 6.2ppm/°C)

Figure 3 shows that above 80 Ohms, the Vishay standard TCR Spread from Nominal is ± 2.0ppm/°C, and above 80Ω the Vishay maximum TCR Spread from Nominal is ± 2.3ppm/°C.

On special order, much better TCR's can be obtained for low value resistors.

FIGURE 7 - VISHAY S102K SERIES MAX. SPREAD FROM NOMINAL (0°C TO +60°C)

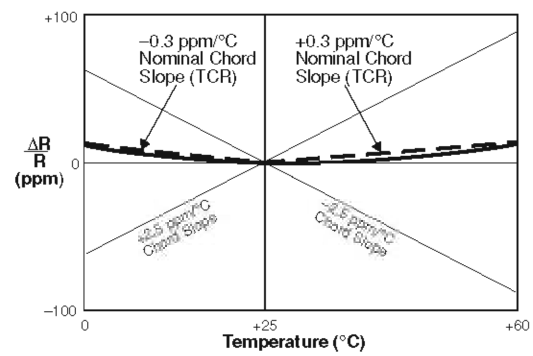


FIGURE 8 - VISHAY S102K SERIES MAX. SPREAD FROM NOMINAL (-55°C TO +125°C)

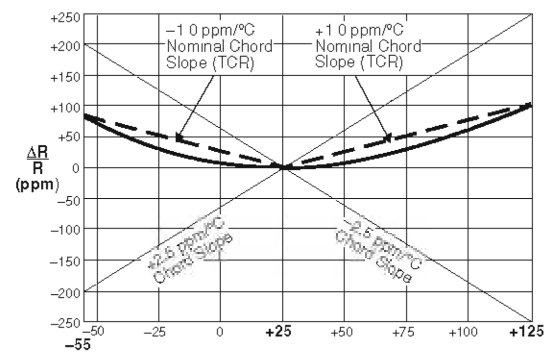
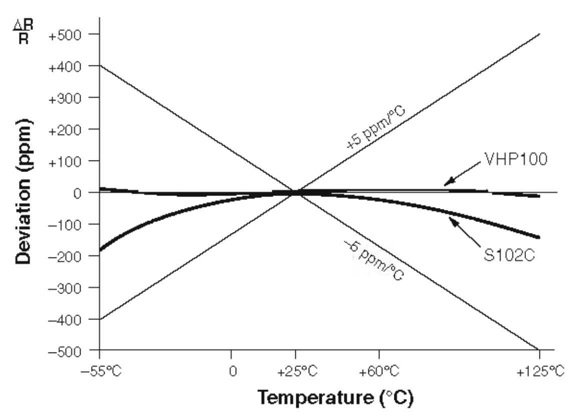


FIGURE 9 - VHP 100 COMPARED TO S102C



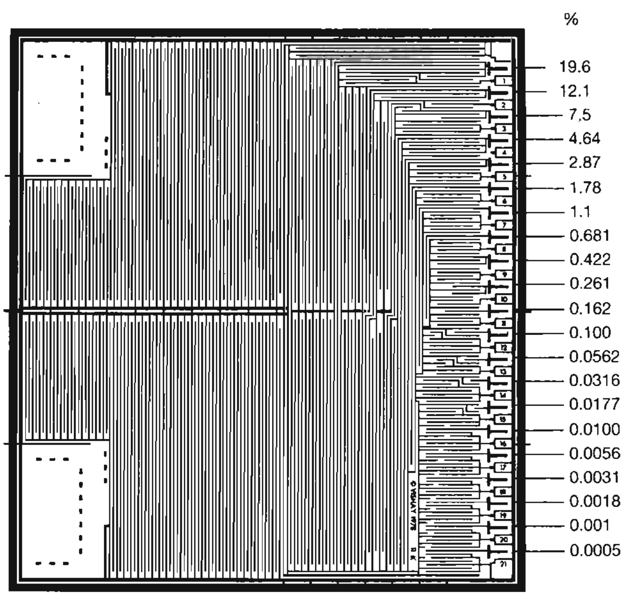
REASON 2

TIGHT RESISTANCE TOLERANCE

Why do users employ tight tolerance resistors? A system or a device or one particular circuit element must perform for a specified period of time and at the end of that service period it must still be performing within specification. During its useful life it may have been subjected to some hostile service conditions and it is no longer within purchased tolerance. One reason for specifying a tighter purchased tolerance than the end of life error budget tolerance is to allow room for service shifts. Another reason is that the error budget is more economically applied to resistors than to most other components.

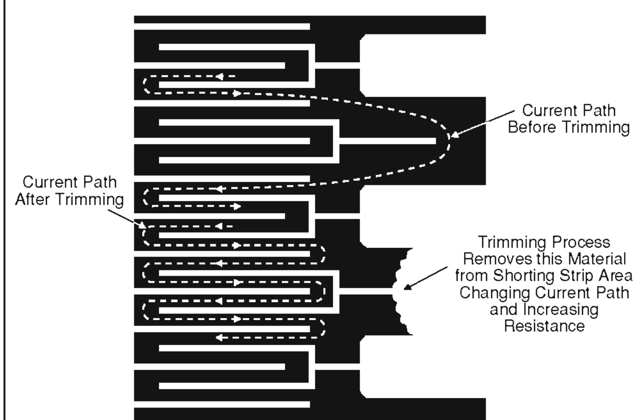
The accuracy of Bulk Metal® Foil resistors can be made as precise as 0.001% by selectively trimming various adjusting points that have been designed into the photoetched pattern of the resistive element. See Figure 10. They provide predictable step increases in resistance to the desired tolerance level. Trimming the pattern at one of these adjusting points will force the current to seek another longer path, thus raising the resistance value of the element by a specific percentage. In the fine adjust areas, trimming affects the final resistance value by smaller and smaller amounts down to 0.001% and finally 0.0005% (5ppm). This is the trimming resolution. See Figure 11

FIGURE 10 - VISHAY S102C RESISTOR ELEMENT



NOTE: Foil shown in white, etched spaces in black.

FIGURE 11 - TRIMMING TO VALUES (CONCEPTUAL ILLUSTRATION)



NOTE: Foil shown in black, etched spaces in white.

REASON 3

EXCELLENT LOAD-LIFE STABILITY

Why are designers concerned about stability with applied load? Load Life stability is the characteristic most relied upon to demonstrate a resistor's long term reliability. Military testing requirements to 10,000 hours with limits on the amount of shift and the number of failures results in a failure rate demonstration. Precision Bulk Metal® Foil resistors have the tightest allowable limits. Whether military or not, the load life stability of foil resistors is unparalleled and long term serviceability is assured.

The reason foil resistors are so stable has to do with the materials of construction (Bulk Metal® Foil and high alumina substrate). For example, the S102C resistor is rated at 0.3W at 125°C with an allowable ΔR of 150ppm. (See Figures 12 and 13 for the demonstrated behavior). Conversely, the ΔR is reduced by decreasing the applied power which lowers the element temperature rise in Vishay resistors. Figure 12 shows the drift due to load life testing at <u>rated</u> power and Figure 13 shows the drift due to load life testing at <u>reduced</u> power. Reducing the ambient temperature has a marked effect on load life results and Figure 14 shows the drift due to rated power at different ambient temperatures. The combination of lower power and ambient temperature is shown in Figure 15.

FIGURE 12 - RELATIVE RESISTANCE CHANGE (ΔR/R) AS A FUNCTION OF TIME, LOAD 0.3 W, +125°C AMBIENT

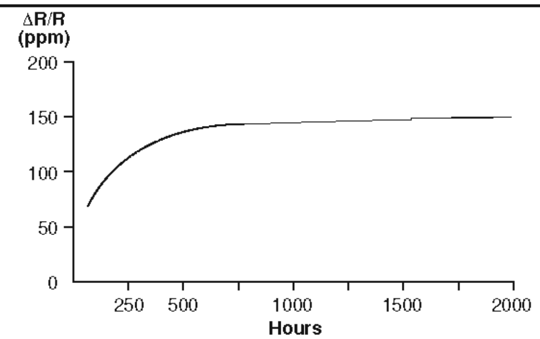


FIGURE 13 - ΔR/R = F (TIME), LOADS 0.05 TO 0.5 W, +125°C AMBIENT

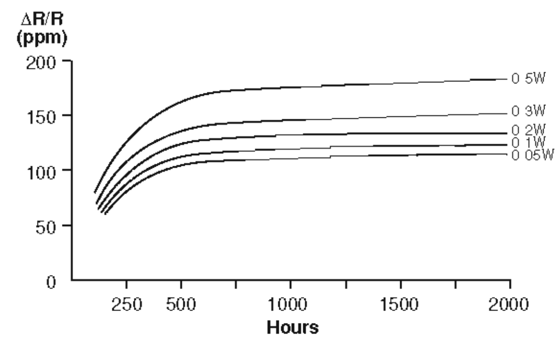


FIGURE 14 - ΔR/R = F (TIME), LOAD 0.3W, DIFFERENT AMBIENT TEMPERATURES

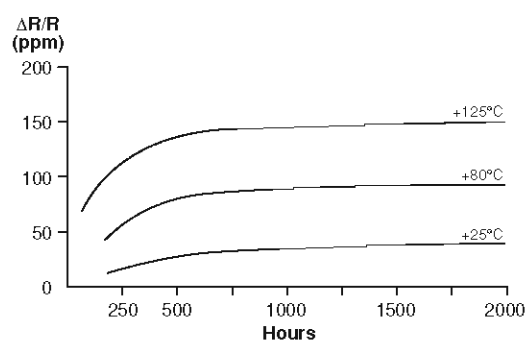
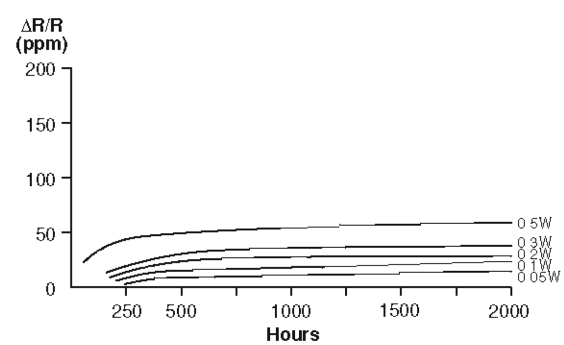


FIGURE 15 - ΔR/R = F (TIME), LOADS 0.05 TO 0.5 W, +25°C AMBIENT



EXCELLENT LOAD-LIFE STABILITY Continued

The two parameters which must be mentioned together, power rating and ambient temperature, can be joined into one single parameter for a given style of resistor. If the steady state temperature rise can be established, it can be added to the ambient temperature, and the sum will represent the combined (load induced + ambient) temperature. For instance the Vishay S102C resistor has a temperature rise of 9°C per 0.1W of applied power. It leads to the following sample calculations:

If T = 75°C, P = 0.2 Watts, and t = 2,000 hrs.;

Then self heating = 9°C x 2 = 18°C.

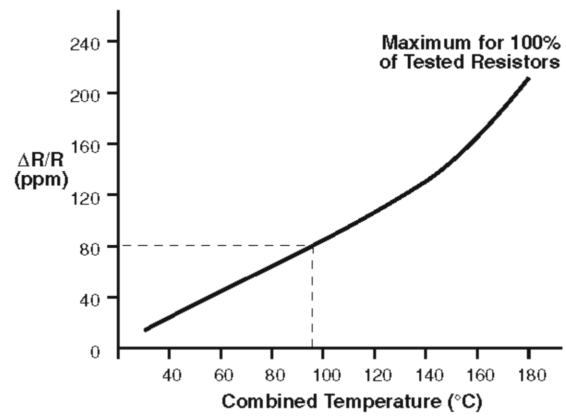
18°C rise + 75°C ambient = 93°C total.

$\frac{\Delta R}{R}$ max = 80ppm from the curve of Figure 16.

Figure 16 shows, for a given duration of load life test, how the drift increases with the level of the applied combined temperature. As explained above, the combined temperature comprises the effect of power induced temperature rise and the ambient temperature. The curve shows maximum drift.

FIGURE 16 - MAXIMUM RESISTANCE SHIFTS AFTER 2,000 HRS. OF LOAD LIFE TEST UNDER THERMAL STRESSES*

*Combined temperature– ambient and temperature rise due to applied power.



This information is based on product taken off the line without any screen testing or burn in. Further drift reduction is available by factory burn in. Consult Applications Engineering for this and other screening tests that are available.

REASON 4

HIGH SPEED

The equivalent circuit of a resistor, as shown in Figure 17, combines a resistor in series with an inductance and in parallel with a capacitance. Resistors can perform like an R/C circuit or filter or inductor depending on their geometry. In spiraled and wirewound resistors these reactances are created by the loops and spaces formed by the spirals or turns of wire. Figure 18 shows how the capacitance and inductance increase as the resistance value increases due to continually increasing the number of spirals or turns.

In planar resistors such as the Vishay Bulk Metal® Foil resistors, the geometry of the lines of the resistor patterns are intentionally designed to counteract these reactances. Figure 19 shows a typical serpentine pattern of a planar resistor. The opposing directions of current prevents the build-up of mutual inductance and reduces the capacitive effects by placing the inter-conductor capacitances in series.

In pulse applications, these reactive distortions result in a poor replication of the input. Figure 20 shows the current response to a voltage pulse comparing a fast Bulk Metal® Foil resistor to a slower wirewound. Here a pulse width of one nanosecond would have been completely missed by the wirewound resistor while the foil resistor achieves full replication in the time allotted.

In frequency applications these reactive distortions also cause changes in apparent resistance (impedance) with changes in frequency. Figure 21 shows a family of curves relating the AC resistance to the DC resistance in Bulk Metal® Foil resistors. Very good response is seen in the 100ohm range out to 100 MHz and all values have good response out to 1MHz. The performance curves for other types of resistors can be expected to show considerably more distortion (particularly wirewounds).

FIGURE 17 - THE EQUIVALENT CIRCUIT OF A RESISTOR

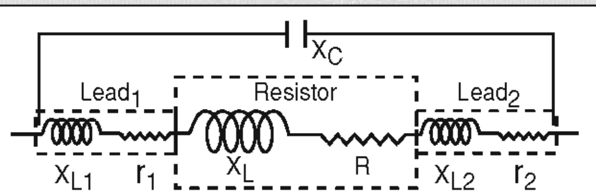


FIGURE 18 - CAPACITANCE AND INDUCTANCE IN A WOUND OR SPIRALED RESISTOR

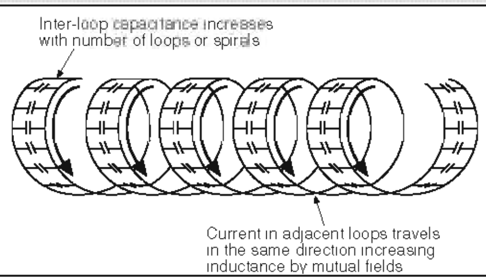


FIGURE 19 - BULK METAL® FOIL PLANAR DESIGN

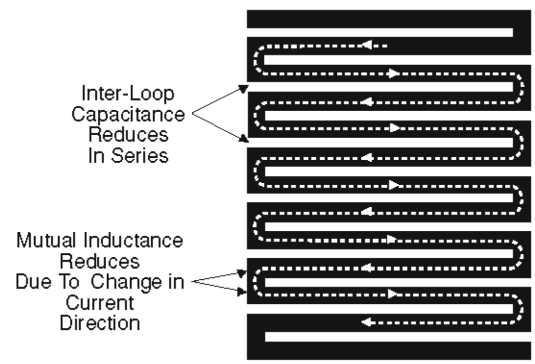


FIGURE 20 - COMPARISON OF RESPONSE TO A PULSE

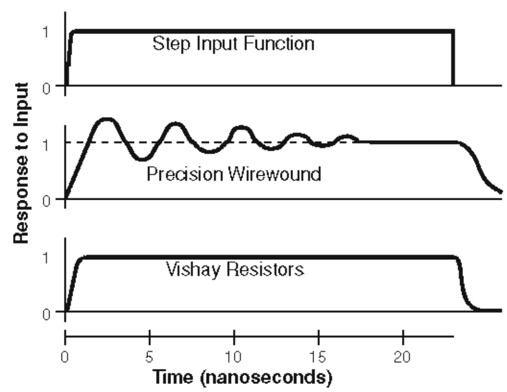
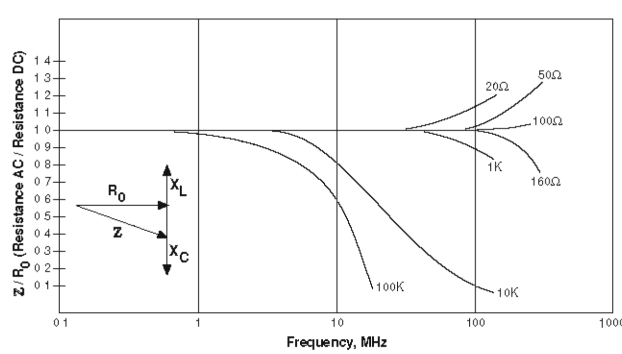


FIGURE 21 - EFFECT OF OPERATION AT FREQUENCY



REASON 5

LOW NOISE

As measurement instrumentation and circuitry become more demanding, noise or unwanted signals, superimposed upon the fundamental signal become troublesome. Measurement instrumentation based on low level signal inputs and high gain amplification cannot tolerate microvolt level background noise when the signal being measured is itself in the microvolt range. Although audio circuitry, when signal purity is of utmost concern, is the most obvious use of noise free components, other industries and technologies are equally concerned with this characteristic.

Resistors, depending on construction, can be a source of noise. This unintended signal addition is measurable and independent of the presence of a fundamental signal. Figures 23 and 24 below illustrate the effects of resistor noise on a fundamental signal.

Resistors made of conductive particles in a non-conductive binder are the most likely to generate noise. In carbon composition and thick film resistors, conduction takes place at points of contact between the conductive particles within the binder matrix. Where these point to point contacts are made constitutes a high resistance conduction site which is the source for noise. These sites are sensitive to any distortion resulting from expansion mismatch, moisture swelling, mechanical strain and voltage input levels. The response to these outside influences is an unwanted signal as the current finds its way through the matrix. Figure 25 illustrates this current path.

Resistors made of metal alloys, such as the Vishay Bulk Metal® Foil resistor are the least likely to be noise sources. Here the conduction is across the inter-granular boundaries of the alloy. The inter-granular current path from one or more metal crystals to another involves multiple and long current paths through the boundaries reducing the chance for noise generation. Figure 26 illustrates this current path.

In addition, the photo lithography and fabrication techniques employed in the manufacture of Bulk Metal® Foil resistors results in more uniform current paths than found in some other resistor constructions. Spiraled resistors, for example, have more geometric variations that contribute to insertion of noise signals. Bulk Metal® Foil resistors have the lowest noise of any resistor technology, with the noise level being essentially immeasurable.

FIGURE 22 - SEGMENT OF A FUNDAMENTAL CURVE

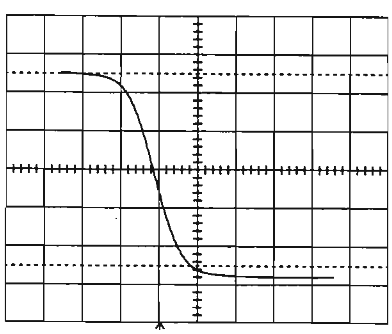


FIGURE 23 - SIGNAL WITH ADDED RESISTOR NOISE

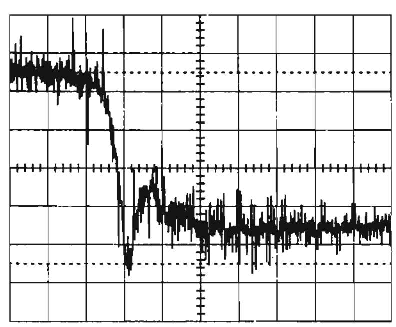
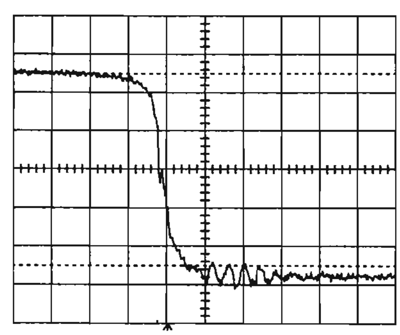
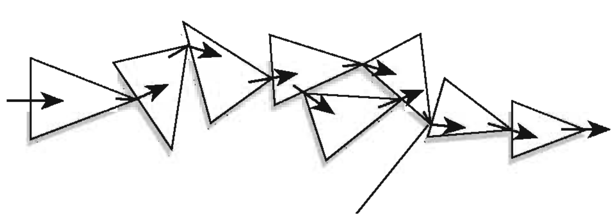


FIGURE 24 - SIGNAL WITH A "NOISE FREE" RESISTOR



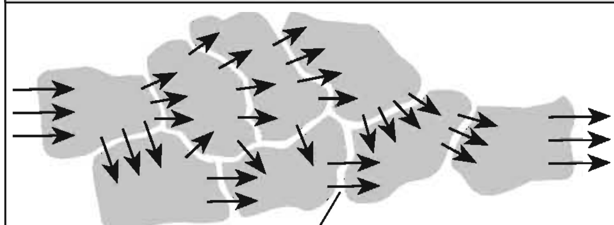
Courtesy of LeCroy

FIGURE 25 - THE CURRENT PATH IN A PARTICLE TO PARTICLE MATRIX



Noise generation is maximum when current flow is through point to point contacts as shown in a particle to particle matrix.

FIGURE 26 - THE CURRENT PATH IN A RESISTIVE ALLOY



Noise generation is minimal when current flow is through multiple paths as exists in Bulk Metal® Foil resistive alloy.

REASON 6

LOW THERMAL EMF

The thermoelectric effect, which is negligible in ordinary resistors, may become a significant source of drift or instability in high-precision resistors. Known as the seeback effect, it occurs when the following two conditions are present at the same time:

1. An electrical circuit is made from two different conducting materials (metals M1 and M2), which are soldered at their ends, A and B.
2. A temperature difference $T_2 - T_1$ exists between A and B.

When a junction is formed by two dissimilar metals, and is heated, a voltage is generated due to the different levels of molecular activity within these metals. This electromotive force, induced by temperature, is called Thermal EMF and is usually measured in microvolts. A useful purpose of this Thermal EMF is the measurement of temperature using a thermocouple and microvolt meter.

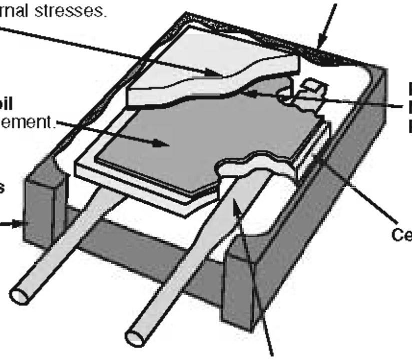
In resistors, this Thermal EMF is considered a parasitic effect interfering with pure resistance. It is often caused by the dissimilarity of the materials used in the resistor construction especially at the junction of the resistor element and the lead materials. The Thermal EMF performance of a resistor can be degraded by external temperature variations, dissymmetry of power distribution within the element, and the dissimilarity of the molecular activity of the metals involved.

A key feature of the Vishay Bulk Metal® Foil resistor is its 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 the element material. These design factors result in a very low Thermal EMF resistor.

FIGURE 27 - RUGGEDIZED CONSTRUCTION

The combination of ruggedized leads and molded case plus the highly efficient heat-transfer characteristics of the unique assembly and the ceramic substrate results in a high reliability resistor with excellent moisture resistance, high temperature and load-life capabilities. These also afford a very low thermal EMF.

Flattened "paddles" are wrapped around the resistance element structure and welded directly to the resistance alloy – thus there is only one weld per lead. The closely related thermal characteristics of the selected materials, combined with the unique "paddle" lead design, produce a resistor with extremely low thermal EMF.



REASON 7

NON-MEASURABLE VOLTAGE COEFFICIENT

As mentioned earlier in our section on resistor noise, resistors can change value due to applied voltage. The term used to describe the rate of change of resistance with changing voltage is known as voltage coefficient.

Resistors of different constructions have noticeably different voltage coefficients. In the extreme case the effect in a carbon composition resistor is so noticeable that the resistance value varies greatly as a function of the applied voltage.

Vishay Bulk Metal® Foil resistor elements are insensitive to voltage variation and the designer can count on foil resistors having the same resistance under varying circuit voltage level conditions. The inherent bulk property of the metal alloy provides a non-measurable voltage coefficient.

Texas Components Corporation

Conclusion

The seven reasons to specify Bulk Metal® Foil resistors are inherent in the design and are not a function of manufacturing variables or a selection process. This combination of parameters is not available in any other resistor technology. Bulk Metal® Foil technology resistors provide a unique, inherent combination of performance characteristics resulting in unmatched performance and high reliability satisfying the needs of today's expanding requirements.

Custom Resistive Solutions

Consider Bulk Metal® Foil Resistors for all of your low TCR needs. Orders may be placed for low TCR, tighter tolerances, and close TCR tracking of individual resistors and network combinations. Contact Texas Components to discuss your requirements for these and any other custom applications.

About Us

Established in 1980, Texas Components is a manufacturer of resistive component products, using Vishay supplied materials, which are crafted to the stringent technical specifications of Vishay resistors. Vishay franchises our assembly facility, and Vishay QA personnel assure the quality of the products of Texas Components through periodic product analysis and through procedure supervision.

Texas Components additionally uses these requisite skills to create resistive products for special applications, or to customer specifications, as well as DSCC specifications for high reliability applications. If you need reliability and quick turnaround, this is the place to order precision Bulk Metal® foil products.

All resistors, dividers, and networks manufactured by Texas Components are suitable for 200°C operation, or can be made so, if we have knowledge of the requirement.

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