ULTRA-HIGH PRECISION Z FOIL CURRENT SENSE RESISTORS FOR SPACE APPLICATIONS

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VPG Foil Resistors has introduced industry-exclusive ultra-high precision current sense resistors. These components incorporate a unique design consisting of VPG's own proprietary Bulk Metal Z Foil resistive technology, along with a four-terminal Kelvin connection design, for precision current sensing and temperature stability.

The unique Bulk Metal® Foil resistor technology is universally recognized for its long-term consistency and reliability, which makes it the ideal resistive solution for space applications. This technology is highlighted by an advanced manufacturing technique of balancing thermo-mechanical forces between a Bulk Metal Foil alloy and an engineered ceramic substrate resulting in unparalleled low Temperature Coefficient of Resistance (TCR), long-term stability, non-inductance, ESD insensitivity, low capacitance, fast thermal stabilization, and low noise. When this resistive element is combined with a 4 terminal Kelvin connection configuration, the result is an outstanding Z Foil current sense resistor which generates a highly precise voltage directly proportional to measured current levels for efficient control and precise measurements.

Screening and testing in accordance with NASA Goddard EEE-INST-002 guidelines are consistently used as a baseline to develop and ensure a high level of reliability. We also provide the option to order our Z Foil current sense resistors screened and tested per EEE-INST-002 (Tables 2A and 3A, Film/Foil, Level 1) and per MIL standards in which they are submitted to our post-manufacturing operations (group A & B tests) and to our Environmental Test Lab. Finally, a Quality Conformance Inspection report may accompany the shipment per customer request. This option offers design engineers a reliable set of data for the anticipation of actual resistor performance within an intended installation among other considered parameters.

Models CSM3637F and VCS1625Z are surface mount chip resistor designed with 4 pads for Kelvin connection. Utilizing Bulk Metal Foil as the resistance element, these current sense resistors provide enhanced characteristic capabilities resulting in superior performance when compared with other resistor technologies. The unique combination of Z Foil technology along with the designed 4 pads configuration results in significant reduction of the component’s sensitivity to applied power changes such as power coefficient of resistance (PCR) and thermal resistance.

Technology Background

Current sensing calls for a variety of solutions based on application requirements. Current sensing is best achieved with a Kelvin connection, which removes the unwanted influences of lead resistance and lead sensitivity to temperature. Other requirements, such as high stability and short thermal stabilization time when the power changes, may dictate a special resistor design. High-precision resistors used for current sensing are usually low ohmic value devices requiring four terminal connections. Two terminals, called "current terminals," are connected to conduct electrical current through the resistor, while voltage drop VS is measured on the other two terminals, called "sense" or "voltage drop" terminals. According to Ohm's law, the sensed voltage drop VS divided by the known resistance RS gives the sensed current IS. The accuracy of measurement depends on the stability of ohmic resistance RS between the nodes, i.e. the points of connection of the sense leads. Since the voltage leads feed into an ―infinite resistance circuit, there is no current flowing through the voltage terminals and, therefore, no IR drop in the voltage sense leads. Thus, the four-terminal system eliminates the voltage-drop errors originated in the leads when the voltage terminations are connected close to the resistance element (excluding significant portions of the leads that carry the current).

This arrangement, called a "Kelvin connection", reduces, especially for low ohmic resistance values, a measurement error due to the resistance of the lead wires and the solder joints as the sensing is performed inside the resistor, in or close to the active resistive element.

Of the commonly used methods of measuring the magnitude of electrical current, this current sensing resistor method provides the most precise measurement. According to Ohm's law, V = IR, the voltage drop measured across a resistor is proportional to the current flowing through the resistor. With the known value of the resistance R, the voltage drop sensed on the resistor indicates the intensity of the current flowing through it.

Assuming an ideal current sense resistor that doesn't change its resistance value when there is a change in the magnitude of the current or a change in environmental conditions, like the ambient temperature or self heating, the measured voltage drop will yield a precise value of the current: I = V/R. But with a real-life resistor, such as a metal film resistor or a Manganin bar, a change in current intensity (and in the dissipated power) will cause a change in the resistor's value which will involve a thermal transient period taking a few seconds or longer to stabilize. Even when stabilized, there is a change of resistance due to the resistor's inherent TCR responding to the temperature increase, which is caused by the resistor's change in self heating due to change in power dissipation.

Therefore, the key to a fast and precise measurement of current is the use of a real life current sensing resistor which approaches, as closely as possible, an ideal resistor. That is, a resistor that is not influenced by changes in the magnitude of the current flowing through it nor by changes in ambient temperature or any other environmental condition.

Real-life resistors exhibit two temporary changes from their room-temperature values:

1. When they are cooled or heated by a changing ambient temperature, and
2. By self-heating due to the power they have to dissipate (Joule effect)

When a high precision is required, these two effects induce a change in the resistive element's temperature, ΔT_a due to ambient and ΔT_{sh} due to self-heating, both of which must be considered.

The ambient temperature changes slowly and all parts of a resistor follow uniformly the change of the ambient temperature, but the effect of the dissipated power is different. The temperature of the resistive element — the active part of the resistor — will change rapidly with the change of the intensity of current. The power it has to dissipate will change proportionally to the square of the current and a rapid increase in current will cause a sudden increase in the temperature of the resistive element and in the heat that must be dissipated to the ambient air. A rapid decrease in current will take longer to register the current change because the heat build-up takes longer to dissipate through the physical encapsulants. These two effects of resistance changes are quantified by TCR – Temperature Coefficient of Resistance and by PCR – Power Coefficient of Resistance (called also ”Power TCR”). It should be noted that industry-standard testing to define TCR measures the resistance values after the ***inactive*** resistors have stabilized for a considerable time at precisely regulated ambient temperatures. This method ignores the effects of ***dynamic*** temperature changes within the resistor as a result of actual resistor operation.

Bulk Metal Foil Stability

Bulk Metal Foil resistors built on the revolutionary Z Foil Technology are characterized by an absolute temperature coefficient of resistance (TCR) of ± 0.2 ppm/°C (–55°C to +125°C, +25°C ref.) typical. The lower the absolute TCR, the better a resistor can maintain its precise value despite ambient temperature variations and self-heating when power is applied.

A specific Bulk Metal Foil alloy with known and controllable properties (Ni/Cr with additives) is cemented to a special ceramic substrate, resulting in a thermo-mechanical balance of forces. A resistive pattern is then photo-etched in the Bulk Metal 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.

Resistors with extremely low absolute TCR keep temperature-induced changes to a minimum. Two predictable and opposing physical phenomena within the composite structure of the resistive alloy and its substrate are the keys to the low absolute TCR capability of a Bulk Metal Foil resistor:

- Resistivity of the resistive alloy changes directly with temperature in free air (resistance of the foil increases when temperature increases)

- The coefficient of thermal expansion (CTE) of the alloy and the substrate to which the foil alloy is cemented 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 two opposing effects occur simultaneously, resulting in an unusually low, predictable, repeatable, and controllable TCR. Due to the design of the Bulk Metal Foil resistor, 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 shows the typical TCR characteristics of 3 foil alloys used to produce Bulk Metal Foil resistors. The original C Foil alloy exhibited a negative parabolic response to temperature with a positive chord slope on the cold side and a negative chord slope on the hot side. Next was the K Foil alloy, which produced an opposite parabolic response with temperature with a negative chord slope on the cold side and a positive chord slope on the hot side. In addition, it provided a TCR approximately one half that of the C Foil alloy.

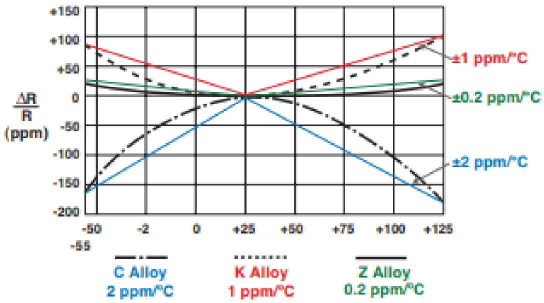

Fig. 1. Typical resistance versus temperature curve and its chord slopes (TCR) of Bulk Metal Foil alloys in temp. MIL range

The Z foil alloys have a similar parabolic response to the K Foil alloy but produce TCR characteristics an order of magnitude better than C Foil and five times better than the K Foil. Using this technology, extremely low TCR resistors, which exhibit virtually zero response to temperature changes, have been developed and made possible. These technological developments have resulted in a major improvement in TCR characteristics compared to what was available before, and what is available in any other resistor technology. Traditional passive current sensors and shunts generate heat under power, which changes their resistance, and thus their voltage output. The Bulk Metal Z Foil low absolute TCR reduces errors due to temperature changes, thus reducing a major source of uncertainty in current measurement.

As stipulated by the Joule effect, when current flows through a resistance, there will be an associated generation of heat. Therefore, the TCR alone does not provide the actual resistance change for a precision resistor. Hence, another metric is introduced to incorporate this inherent characteristic—the power coefficient of resistance (PCR). PCR is expressed in parts per million per Watt (ppm/W) or in ppm at rated power. In the case of Bulk Metal Z Foil resistors, the PCR is 5 ppm typical at rated power.

Load-life stability is one of the most relied upon characteristics to demonstrate a resistor's long-term reliability. Bulk Metal Foil resistors are constructed by balancing thermo-mechanical forces between a Bulk Metal Foil alloy and an engineered ceramic substrate resulting in unparalleled inherent long-term stability. Figure 2 displays the average drift due to load life testing at rated power of Bulk Metal Foil current sense surface mount resistors. Typical current sensing resistors offer a load-life stability of $\geq$ 1% through a 2000 h workload. The improved resistance stability of the Bulk Metal Foil current sense makes it ideal for tightened-stability voltage division and precision current sensing applications in switching linear power supplies, power amplifiers, measurement instrumentation, bridge networks, and medical and test equipment.

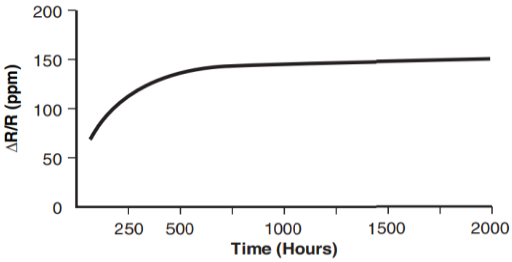

Fig. 2. Relative resistance change (ΔR/R) as a function of time, resistor model CSM3637F, load 3W, +70°C

Screening and Testing in Accordance with NASA Goddard EEE-INST-002

The avionics, military and space (AMS) industry differs from other industries in one essential requirement – its need for continuous reliability. Projects are often mission-critical and every component must perform flawlessly for long periods. For space applications, we have employed a testing pattern developed by NASA in compliance with the EEE-INST-002 guidelines (Tables 2A and 3A Film/Foil, Level 1). These are constantly used as a baseline to develop and ensure a high level of reliability. By subjecting Bulk Metal Foil resistors to the mentioned sequence of tests, the confidence level of a part to perform in a critical space application is improved. Finally, a Quality Conformance Inspection report detailing all test data collected during Environmental Test Laboratory accompanies each desired item.

Figures 3 and 4 show the screening/testing method employed for Bulk Metal Foil surface mount current sense resistors.

EEE-INST-002 (Table 2A Film/Foil, Level 1) 100% Tests/Inspections	
RC Record	In tolerance
Thermal Shock	25× (–65°C to +150°C)
RC Record	ΔR = 0.1%
High Temperature Exposure	+170°C, 100 h, no power
RC Record	In tolerance ΔR = 0.2%
Final Inspection	5% PDA on ΔR, 10% PDA on out of tolerance
Visual Inspection	Magnification 30× to 60×
Mechanical Inspection	Dimensions, workmanship, 3 units sample size

Note

(1) Vishay Foil Resistors will perform a pre-cap visual inspection 100% in the production flow prior to overcoating

Fig. 3. Screening and testing flow in conformance with EEE-INST-002 Table 2A

EEE-INST-002 (Table 3A Film/Foil, Level 1) Destructive Tests – MIL-PRF-49465 and 55342		
Group 2	Sample size: 3(0)	
	Solderability	MIL-STD-202, method 208
Group 3	Sample size: 10(0) – mounted on FR4	
	TCR measurement per MIL-STD-202, method 304	±15 ppm/°C, R <100 mΩ; ±10 ppm/°C(3) R ≥100 mΩ (-55°C / +25°C / +125°C)
	Low temperature storage per MIL-PRF-49465	ΔR = 0.02% –55°C ±2°C, 24 h ±4 h ambient no load dwell for 2 h to 8 h at +25°C
	Low temperature operation per MIL-PRF-55342	ΔR = 0.02% –65°C ambient no load dwell for 1 h, rated power for 45 min no load dwell at +25°C for 24 h ±4 h
	Short time overload per MIL-STD-49465	ΔR = 0.05% 5 × rated power at +25°C for 5 s, not to exceed maximum current rating
Group 4	Sample size: 9(0) – mounted on FR4	
	Resistance to soldering heat	ΔR = 0.05% performed per MIL-PRF-55342 para. 4.8.8.1
	Moisture resistance per MIL-STD-202, method 106 (7a and 7b not required)	ΔR = 0.02% 240 h, no power
Group 5	Sample size: 9(0)	
	Shock per MIL-STD-202, method 213, condition I	ΔR = 0.05% 100G, 6 ms axes Z and Y, 10 shocks per axis
	Vibration per MIL-STD-202, method 204, condition D	ΔR = 0.05% 10 Hz to 2000 Hz, 20G 2 axes, 6 h per axis
Group 6	Sample size: 12(0) – mounted on FR4	
	Life test per MIL-PRF-49465	ΔR = 0.1% 2000 h, +70°C, rated power
Group 7B	Sample Size: 10(0) – mounted on FR4	
	Solder mounting integrity per MIL-PRF-55342	5 kg force, 30 s
Group 9	Sample size: 5(0) – mounted on FR4	
	High temperature exposure per MIL-PRF-49465	ΔR = 0.3% 1000 h, +170°C ±7°C, no power
Group 10[2]	Sample size: 4	Per ASTM E595

Notes

[1] Units selected randomly from lots which successfully passed the table 2A testing

[2] Optional, per customer request.

Measurement error allowed for ΔR limits: 0.0005 Ω.

Fig. 4. Screening and testing flow in conformance with EEE-INST-002 Table 3A

Z Foil Current Sense Surface Mount Resistors Performance Highlights

Resistor models VCS1625Z and CSM3637F:

Temperature coefficient of resistance (TCR): ±0.2 ppm/°C typical (–55°C to +125°C, +25°C ref.).

Load-life stability: ±0.05% (70°C, 2,000 h at rated power).

Power coefficient of resistance (PCR) “ΔR due to self heating 5”: ppm/W at rated power.

Resistance Range: any 6 digit value between 10 mΩ to 10 Ω.

Resistance tolerance: to 0.1%.

Power rating: up to 3W.

Electrostatic discharge (ESD): up to 25,000 V.

Test data report for EEE-INST-002 Table 2A (resistor type 303119Z(U) for model VCS1625Z; resistor type 303337(U) for model CSM3637F).

Quality conformance inspection (QCI) report for EEE-INST-002 Table 3A (resistor type 303119Z for model VCS1625Z; resistor type 303337 for model CSM3637F).