Applications at a Glance

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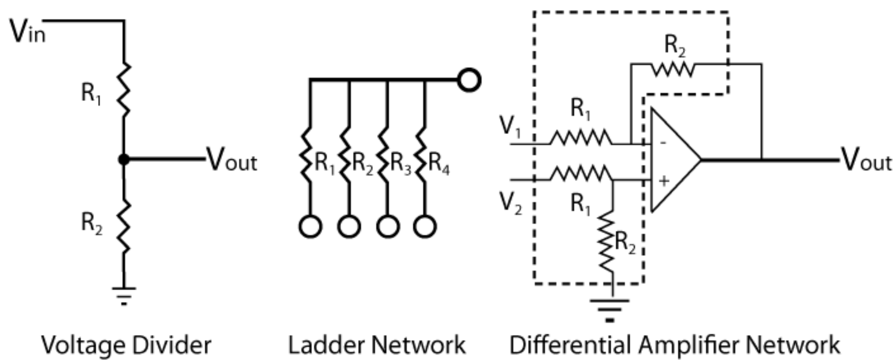
Discrete Resistors vs. Networks: Making the Right Choice

Analog circuits can be produced with improved performance and reliability by integrating resistance dividers and networks into common packages instead of selecting discrete resistors. As a matter of practical application, the low TCRs, tight ratio tolerances, and excellent load-life stability necessary for peak performance are achieved to a greater degree in matched pairs, networks, and resistor arrays than with discrete resistors. However, engineers that have not kept up with advances in resistor technology are not getting the best performance from their amplifiers and other IC circuits. As a result, some must now perform re-designs because of component obsolescence. The following discussion traces the modern developments of various resistor technologies through to the highest precision resistor technology available, compares their relative performance, and presents some practical applications for which only the highest precision products are suitable.

Figure 1: Typical precision resistor applications



Purpose of this article:

1. To explain the present limitation on existing precision resistor technologies and the advantages of selecting specialized dividers and networks
2. To introduce a new advance in precision resistor networks
3. To illustrate the practical application of tight tracking to achieve good ratio stability
4. To provide examples of real application solutions for technical dilemmas

Introduction

For years, there were only two methods of producing relatively low TCR resistors: winding a nickel chromium (NiCr) alloy wire onto a bobbin, or using a unique deposition process with additional screening to maneuver the TCR curve for lower TCR above +25ºC (though increasing the TCR at temperatures below +25ºC). In those days, not so long ago, every meter maker had a shunt winding operation and most precision instrument makers had a "bobbin room" to produce their own wirewound resistors. The advent of MIL-PRF (55182, 55342, etc.) supported a trend toward procurement from recognized industry sources, and most importantly, "qualified and reliable sources."

Resistors further evolved in the mid '60s when the first generation of cold-rolled foil (invented by Dr. Felix Zandman) took over many of drawn wire's precision duties. The reasons were clear and included better performance and reliability in almost every area: low TCR over a wide temperature range (-55ºC to >+175ºC), low inductance, low capacitance, low thermal EMF, low voltage coefficient, low current noise, and other environmental ∆Rs that compound into a lower total error budget (TEB) than previous technologies.

Furthermore, the size – particularly the board space required – was significantly better than wire or metal film. The main market force, however, was repeatability. One thickness of foil rather than many diameters of wire made TCR control simpler, and the planar construction permitted a new order of stability along with the lowest current noise. Tight tolerances and long-term stability became meaningful and common. Products made in one year now behaved like products made in any other year because the manufacturer did not "run out of that spool of wire."

While wirewounds were yielding to Bulk Metal® Foil on higher precision requirements, evolution struck again from the less demanding side. Metal film resistor makers were putting away their evaporators and installing sputtering equipment and other updated techniques that provided them with better control, particularly of TCR. The late 1990s saw more and more thin film resistors with precision performances being installed where previously only wirewounds would have been considered. However, they were still subject to long-term stability issues.

But the movement from wire to Bulk Metal Foil, or to precision thin film, did not signal the end of all wire, nor should it be assumed that evolution is finished, especially in regards to high-power applications. The Foil technology that was developed by Dr. Zandman still provides the best resistor at a relatively low long-term complete-application cost vs. low purchase price per unit. Precision thin film resistors have a low purchase price per unit but they still have some stability limitations and ESD sensitivity, so their long-term application cost can be higher due to drifts, failures, and system re-calibrations.

The Foil resistor is also a preferred choice for design engineers who need to know that the resistors in their designs will not become obsolete before the end of their own product's life cycle. All of the regular advances in Foil technology are based on the fundamental physics of the foil on ceramic technology. Advances in foil composition, adhesives, etch processes, calibration procedures, encapsulation, etc. continue in the same form, fit, and function as those products already in customers' systems. Advances in technology give engineers the opportunity to upgrade existing systems without a re-design, while providing new levels of performance for new systems using the same boards.

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 0.001%	<0.05%	0.005% (50 ppm) 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) 0.15% (1500 ppm)	2500	>few minutes	-20
Precision Thick Film	±50 ppm/°C	From 0.5%	<5%	0.5% (5000 ppm) 2% (20,000 ppm)	2000	>few minutes	+20
Wirewound	±3 ppm/°C	From 0.005%	<0.5%	0.05% (500 ppm) 0.15% (1500 ppm)	25,000	>few minutes	-35

Figure 2: Comparison of popular precision resistor technologies
Note: Thermal stabilization time = nominal value achieved within 10 ppm of steady state value

Present Techniques and Limitations

Precision resistors are most often used in combination where they are expected to maintain a stable resistance, or more particularly, to maintain a stable resistance ratio.

The method of combining for ratio might be:

1. Matched sets: The resistor manufacturer matches a group of resistors for resistance values and/or TCR and bags them as a set. The risk here is the mixing of one set with another at assembly or the loss of one resistor, rendering the entire set unusable. There is also the risk of ESD damage to one or more resistors during handling or assembly, changing the tolerance of one of the set and rendering the entire set unusable.

2. Select at Test (SAT): On the factory floor, the value of the resistor is identified by the appropriate bin of resistors. The risk here is that any one empty bin prevents shipment of the unit and/or a large inventory of unused resistors remains at the end of the contract. This also limits the performance capability of the circuit because the bins are not matched for tolerance or TCR, and the ratios can be no better than whatever the random match and TCR is among the selected resistors.

3. Half tolerance: The designer specifies a tolerance that is half the ratio allowance, thereby assuring adequate matching of all resistors without selection or set control. The risk in this case is eliminated;

however, the total cost could be a concern and the total error budget might have to be increased due to performance inconsistencies, since there is no assurance of similarity among the resistors used. This is particularly true through temperature changes, because there is no matching of individual TCRs.

4. Encapsulated network: The resistor manufacturer combines discrete resistors in the specified combination, and either packages or molds them together with the specified pin-outs. Factory floor risk is minimal, but installation can be slow while size and cost are both increased.

5. Chip and wire: The resistor manufacturer selects and combines chips of the appropriate resistance values in hermetic or non-hermetic packages. Interconnections in the hermetic packages are made with one-mil gold wire. Individual resistor chips are trimmed to tolerance and/or matched and the completed assembly is in a plastic or hermetic enclosure. These devices allow for resistance variation from circuit to circuit without the non-recurring engineering cost (NRE) of specialized networks when used in high volume. When using foil chips, the very low absolute TCR of ALL Foil resistors assures excellent TCR tracking, even among randomly selected chips.

6. Single-substrate network: The thin film resistor manufacturer deposits the complete device on a substrate, attaches leads, laser trims to value, and encapsulates. The resistors share the heat during the unequal self heating, but they were made from the same resistive layer, and therefore we expect that they have the same TCR. But this is not always the case. As a consequence, they will not always move in the same direction with time, but they do respond more uniformly than individually produced and later selectively combined resistors. Foil chips, however, will always move together in the same direction. On a single substrate, they will behave even more uniformly and with tighter TCR tracking than individual chips (as low as 0.1 ppm/ºC). In quantity, this represents the most cost-effective way of producing high-performance resistor networks. Regardless of the technology employed, however, singe-substrate networks require masking and up-front costs (NRE) plus extended delivery time for the first article.

These single-substrate networks have traditionally been classified as either thick film or thin film. By far, the largest usage of resistor networks is thick film, but lower TCR and tighter tolerances are obtained with thin film or Foil. Unfortunately, devices under the classification of thin film are made by any of the following processes: Chromium cobalt vacuum deposited on glass; evaporation of NiCr onto glazed ceramic; sputtering of NiCr onto ceramic; deposition of NiCr on silicone; deposition of Ta/Ni on silicone; sputtering of combined layers of TaN and NiCr onto ceramic; sputtering of Ta/Ni onto ceramic; SiCr on Ceramic and Cermet (SiCr oxide), ion beam deposition; and ion implantation.

It should be apparent that not all of these methods can lead to exactly the same parameters, and in critical applications we should go beyond “thin film” in categorizing a specified device. If not, we end up with divergent performance results applied to the same drawing.

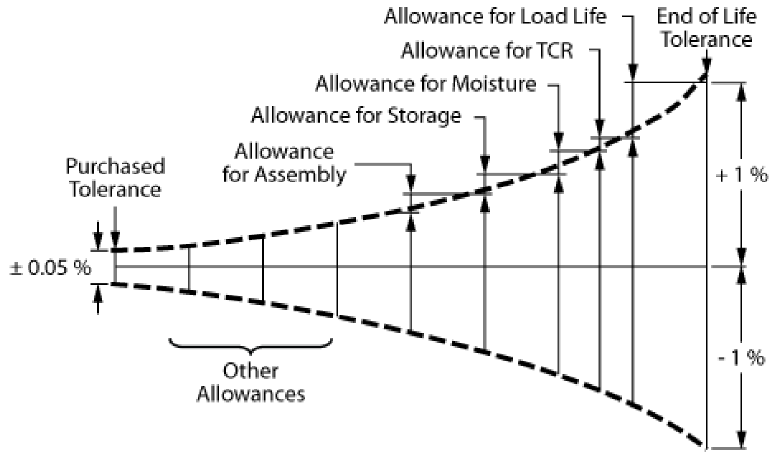


Figure 3: TEB = total error budget There are several factors taken into account in the total error budget of a resistor network. It may need to be increased due to performance inconsistencies between resistors

Widening the Gap in Ideal Precision Resistor Networks

The gap between prior thin film networks and the new generation of Bulk Metal Foil networks applies primarily to absolute TCR, stability, and value range and/or cost. Precision thin film resistor networks are limited to 10 ppm/°C absolute TCR (in some cases a 5 ppm/°C absolute TCR can be achieved with screening) and TCR tracking to 2 ppm/°C. A technology that would deliver <2 ppm/°C absolute TCR consistently over a value range from 100 Ω would substantially widen the performance gap.

The new state-of-the-art Z and Z1-Foil networks presented here do exactly that. Through a proprietary cold-rolled method of foil production and employing the principles of “constant sheet resistivity” and “variable real estate,” performance is optimized such that absolute TCR of <2 ppm/°C is possible regardless of the resistance value. Additional benefits include very low current noise levels, very low thermal EMF, fast thermal stabilization, ESD immunity, and a very high stability through thermal and mechanical stresses.

Tracking of Resistors With Temperature and Other Factors Affecting Ratio Stability

Two resistors in the same network can be at different temperatures due to proximity to external heat sources, or due to differential self-heating from uneven power dissipation. For example, we can look at circuit elements consisting of an operational amplifier and two resistors. If the amplification ratio is 10:1 at room temperature, what will it be when the equipment is turned on and the temperature of one resistor increases by 60°C, but the second by only 6°C? To answer this, we need to know the temperature of the two resistors and what kind of resistors they are.

The changes in ratio resulting from the model could well be amplified again and again depending on the circuitry. How important is a shift of one part per million (ppm)? The practical application and importance of choosing a fundamentally low absolute TCR resistor pair to maintain ratio stability is clear. The degree of demand may vary, but it is easy to visualize military requirements as far more demanding than those of commercial applications.

Turning to some other factors that may cause ratio changes, a precision voltage divider might require a voltage divider R1=10-ohms to R2=9990-ohms (Total resistance R=10,000.) Even if we do not expect large temperature swings in the application of this equipment, a difference of about 0.5°C from one lead or termination to another is not unlikely. That 0.5 °C difference will result in a thermal EMF error superimposed on the output voltage. The effect of this is clear in the following example. Suppose this divider had a 5V input with a 5mV output. If the 0.5°C were in the 10 ohm resistor leads, a typical Thermal EMF of 8 µV/°C would change the output by 4 µV, or an error of 0.08% of the expected 5mV output. New foil resistors have a thermal EMF of <0.1uV/°C which would result in an output change of only 0.05µV, or an error of only 0.001%, 80 times less than the typical resistor. Whatever system might be fed this divider's output would start off with 80 times more error using typical resistors instead of foil resistors. Where the typical divider (for an OpAmp, for example) requires ratio matches of 0.005% to 0.01%, the Thermal EMF error would amount to 10 times the design ratio using a typical resistor vs only one-tenth the design ratio using a foil resistor.

For circuits that require stability over time and temperature, under varying power and through environmental changes, design engineers can improve their circuit stability by choosing resistors and networks with proven histories of reliable performance in similar applications. Various MIL specifications and available QPL data may be considered to show that resistance networks offer several advantages as compared to discrete components, and are available using commonly available technology.

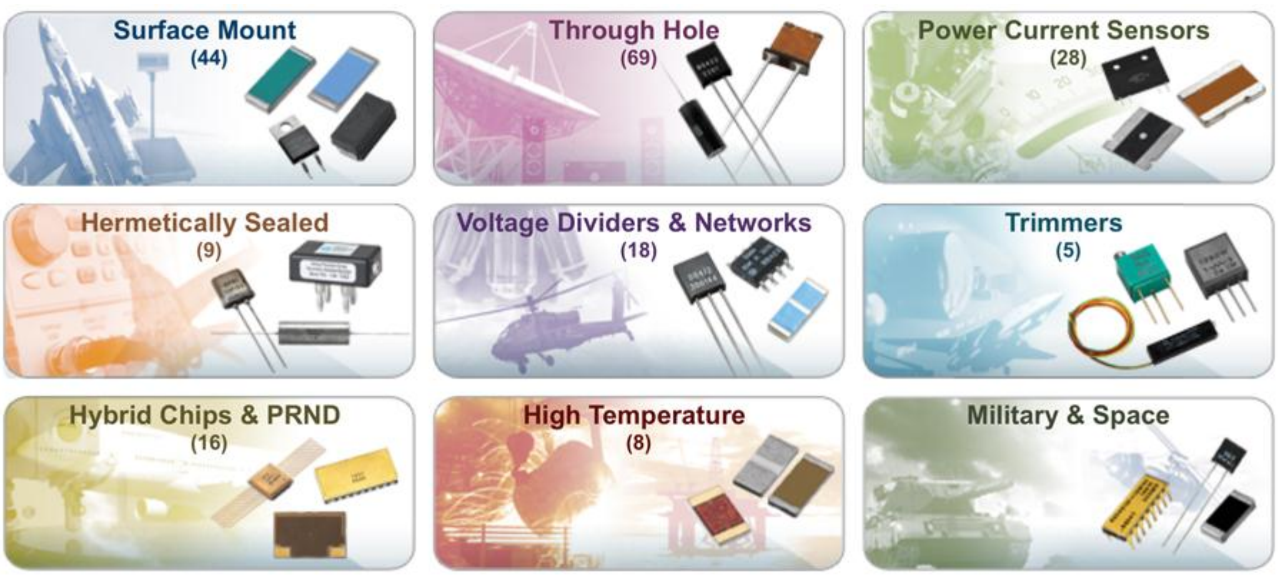


Figure 4: Different resistors configurations (refer to www.foilresistors.com)

Critical Applications for Resistor Networks

Cryogenic Applications

Resistor networks in cryogenic applications require structural integrity capable of withstanding extreme thermal cycling without damage or detriment to performance. VFR resistors have been used as heaters of small-mass samples and as circuit elements at cryogenic temperatures. The cryogenic demo is available now on the VFR website at:
http://www.vishaypg.com/foil-resistors/videos/?video=29

Electrostatic Discharge (ESD)

The effects of ESD can be categorized into three types of damage:

- Parametric failure - Occurs when the ESD event alters one or more device parameters (resistance in the case of resistors), causing it to shift from its required tolerance.
- Catastrophic damage - Occurs when the ESD event causes the device to immediately stop functioning.
- Latent damage - Occurs when the ESD event causes moderate damage to the device, which is not noticeable, as the device appears to be functioning correctly. However, the load life of the device has been dramatically reduced, and further degradation caused by operating stresses may cause the device to fail during service.

Bulk Metal Foil resistors withstand high ESD spikes when compared to thin film and thick film, as demonstrated in a new video on the VFR website at
http://www.vishaypg.com/foil-resistors/videos/?video=3

High Temperature

Resistors are the passive building blocks of an electrical circuit. They may be used for dropping the voltage, buffering the surge when the circuit is turned on, providing feedback in a monitoring loop, sensing current flow, etc. When the application requires stability over time and load, initial accuracy, minimal change with temperature for more than 200°C, resistance to moisture, and a number of other characteristics that will be described, only the new generation of VFR resistors has the attributes needed. Recently, there has been considerable growth in the demand for precise, stable, and reliable resistors that can operate in harsh environments, and especially at high temperatures to +220°C. Many analog circuits for industrial, military, aerospace, alternative energy, down-hole, oil well, and automotive applications require passive components such as resistors to have a minimal drift from their initial values, particularly when operating above +175°C and in humid environments. In these applications, the most important factor is the end of life tolerance (which is part of the stability) and to a lesser extent, the initial tolerance.

The new VFR resistors provide stabilities well under the maximum allowable drift required by customers' specifications through thousands of hours of operation under harsh conditions, such as the extreme temperatures and radiation-rich environments of down-hole oil well logging applications in the frigid arctic, under the sea, or in deep space. All Bulk Metal Foil resistors receive stabilization processing, such as repetitive short term power overloads, to assure reliable service through the unpredictable stresses of extreme operation

EEE-INST-002

For applications that require a high level of reliability, MIL-style testing consisting of electrical and environmental stresses are added to the production process of the resistors in order to screen out and identify any parts or lots that exhibit variations in their performances. The level of testing that is required for specific applications depends on how critical the circuit is to the overall objective of the project. The testing of the parts may vary depending on the requirements of the specification; however, the tests are usually separated into groups, some of which undergo screening tests performed on 100% of a production lot, while other lots undergo destructive tests that are performed on a sample of units from within a specific lot in order to guarantee the performance of the rest.

For applications used in space projects, a more specific and relevant testing pattern that was developed by NASA may be used as a basis. The EEE-INST-002 guidelines – or Instruction for EEE Parts Selection, Screening, Qualification, and Derating – are used as a basis for the development of several specifications which use Foil resistors. By subjecting the resistors to the mentioned sequence of tests, the confidence level of a part to perform in a critical space application is improved. NASA developed the EEE-INST-002 guidelines to be flexible enough to accept any technology and part type, to which VFR has responded with five specifications suitable for these types of critical projects.

Some military applications require either less stringent tests, or a part which is not qualified to a QPL specification. The Defense Supply Center of Columbus also maintains several up-screening plans oriented around products with high demand that have not been QPL qualified. These specifications, known as DSCC specs, consist of a 100% screening test, known as Group A testing, and also a destructive series of tests known as Group B testing. DSCC specifications are easily recognized by engineers, distributors, and QA organizations, and come in a wide variety of part types.

VFR now offers new custom hermetically sealed precision resistor network devices (PRND) with screen/test flow in compliance with EEE-INST-002 (Tables 2A and 3A, Film/Foil, Level 1) and MIL-PRF-83401.

Eight Precision Resistor Networks Case Studies

#1 End Products
Analog-to-digital convertor (ADC), precision voltage reference, precision voltage source

Customer Schematic/Specifications
The engineers had used a thin film divider and the resistance drifts with temperature contributed to errors in circuits that experience significant ambient temperature changes. It was expected that the ratio would remain constant if two resistors shifted the same amount (in percent) and in the same direction when the temperature changed – but that didn't happen.

Requirements
- Excellent load-life stability for >3000 hours with tight TCR tracking
- Resistance values: 1 kΩ/1 kΩ and 1 kΩ/2 kΩ
- Absolute and match initial tolerance: from 0.01%
- Working power: 100 mW
- Absolute TCR: <2 ppm/°C (working temperature: -10°C to +50°C)

- TCR tracking <1 ppm/°C (-10°C to +50°C)
- End-of-life tolerance: <0.2% (total error budget)
- Improved load-life stability match: <0.05% for 2000 hours under rated power
- Low inductance and capacitance, as well as low current noise
- Fast response time

The Vishay Foil Resistors Solution

300144Z 1 kΩ/1 kΩ and 300144Z 1 kΩ/2 kΩ

- TCR: 2 ppm/°C maximum (-10°C to +50°C)
- TCR tracking: <0.5 ppm/°C
- Power TCR tracking: 5 ppm at rated power
- Tight absolute and matching tolerance: 0.01%
- Load-life stability: ±0.005% (50 ppm), 2000 hours at working power
- Rise time: <1 ns (without ringing)
- End-of-life tolerance: <0.1% (total error budget)
- Electrostatic discharge (ESD): up to 25 000 V
- Voltage coefficient: <0.1 ppm/V
- Current noise: 0.010 µVRMS/V of applied voltage (<-40 dB)
- Thermal stabilization time: <1 s (nominal value achieved within 10 ppm of steady state value)
- Datasheet: **http://www.vishaypg.com/ppg?63115**

#2 End Products

Laboratory voltage calibration standards: Zener diode reference voltage multiplier, amplifier gain adjust, and data acquisition system

Customer Schematic/Specifications

The customer wants to perform further tests, especially the drift under load, over a longer time period since their thin film divider doesn't reach thermal stabilization after two minutes. Exceptionally good load-life and environmental exposure stability are also required.

The Vishay Foil Resistors Solution

VHD200Z (Z-Foil technology) plus post-manufacturing stabilization (PMO)

- The VHD200Z is hermetically sealed and oil filled, providing additional moisture protection and allowing considerable improvement in ratio match stability and TCR tracking
- TCR: 2 ppm/°C maximum (+18°C to +45°C)
- Power TCR: 5 ppm at rated power
- Tight tolerance: 0.005% (50 ppm)
- Load-life stability ratio: ±0.005%, 2000 hours at working power
- Rise time: <1 ns (without ringing)
- Devices with hermetic enclosures are more reliable and provide better long-term performance than molded resistors. Moisture and oxygen both pass through plastic or epoxy, and both contribute to long-term degradation of resistive elements
- Datasheet: **http://www.vishaypg.com/ppg?63036**

#3 End Products
Precision measurement and signal conditioning with temperatures above +200°C, and large ratio division (high temperature)

Customer Schematic/Specifications
In this project, equipment will be in an isolated location with minimum access. Once the resistors have been calibrated and installed, the equipment must operate on its own until the specified recalibration. In high-reliability applications such as this one, resistor networks must behave reliably and stable for long periods of time without any means of adjustment or recalibration. The load-life specification is examined to get an idea of how well components will maintain their ratios after applied power, temperature, and time. The application requires a divider network with high stability over temperature, in addition to great ratio matching. A precision resistor network with values of 9.76 kΩ, 12.1 kΩ, 7.68 kΩ, 5.11 kΩ, 2.74 kΩ, and 6.19 kΩ has been suggested. See the schematic below.

Requirements
- A real hermetic resistor network
- Resistance values: several
- Absolute tolerance: 0.01%
- Working power: 100 mW
- Absolute TCR: <3 ppm/°C (+25°C to +200°C)
- End-of-life tolerance: <0.1% (total error budget)
- Improved load-life stability ratio: <0.05% for 2000 hours under rated power
- Low inductance and capacitance
- Fast response time

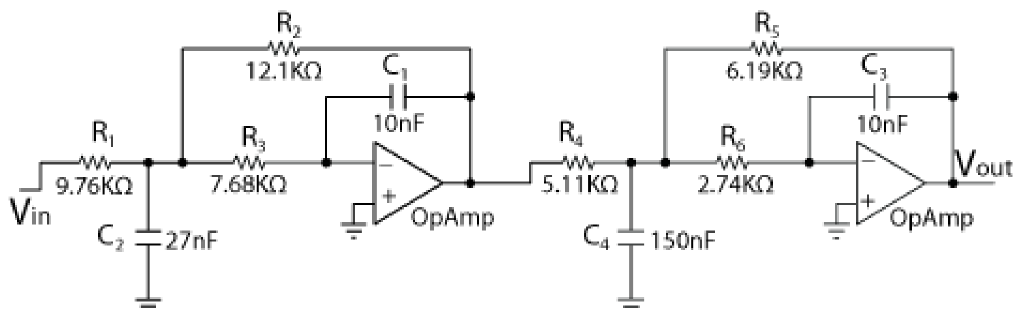


Figure 5: Precision measurement and signal conditioning

The Vishay Foil Resistors Solution
Precision Resistor Network Department (PRND)
- Absolute and tracking TCR: 2 ppm/°C maximum
- Power TCR : 5 ppm at rated power
- Resistance tolerance match: to ±0.005%
- Load-life stability ratio: 0.02% typical (rated power at 70°C, 2000 h)
- VFR resistors are not restricted to standard values; specific “as required” values can be supplied at no extra cost or delivery (e.g. 1.2345 kΩ vs. 1 kΩ)
- Thermal stabilization time: <1 s (nominal value achieved within 10 ppm of steady state value)

- Non-inductive, non-capacitive design
- Current noise: 0.010 µVRMS/V of applied voltage (<-40 dB)
- Voltage coefficient: 0.1 ppm/V
- Rise time: <1 ns (without ringing)
- End-of-life tolerance: <0.1%
- Datasheet: **http://www.vishaypg.com/ppg?63213**

Note: The combination of the ceramic package, which has the advantage of electrical isolation on the underside and high heat dissipation capability ("heat-sink effect"), together with the hermeticity and the location of the chips within the package help preserve uniform conditions inside it. The best long-term tracking stability for thermally coupled resistors is guaranteed by the mounting of the resistors in the same hermetically sealed package. This assembly ensures uniform environmental conditions for the resistors. The electrical specs in a hermetically sealed network hold their tight TCR ratio under the combined influences of temperature, load, and time.

#4 End Products

Current transformer (CT) power protection, amplifier section, and bridge completion network

Customer Schematic/Specifications

The customer wants to measure the current on each output of the CT, and also requires a voltage tap between the current sensing resistors, each leading to a 499 kΩ resistor to ground. This 5th tap is to keep the front end from going into saturation. The design consists of two SMR1DZ resistors with flexible terminations set up as current sense resistors, with the 5th tap between them now creating a divider. The customer chose Bulk Metal Foil because they required stability over temperature, time, and power.

The Vishay Foil Resistors Solution

Set of two SMR1DZs:
New Z-Foil ultra-high-precision wrap-around chip resistor for improved load-life stability and flexible terminations to ensure minimal stress transference from the PCB due to load-induced temperature gradients and differences in Coefficient of Thermal Expansion (CTE)

- Flexible terminations ensure minimal stress transference from the PCB due to differences in Coefficient of Thermal Expansion (CTE)
- TCR: <2 ppm/°C maximum (0°C to +60°C)
- Power TCR: 5 ppm at rated power
- Tight tolerance: 0.01%
- Load-life stability: ±0.005%, 2000 hours at working power
- Rise time: <1 ns (without ringing)
- End-of-life tolerance: <0.05% (total error budget)
- Datasheet: **http://www.vishaypg.com/ppg?63118**

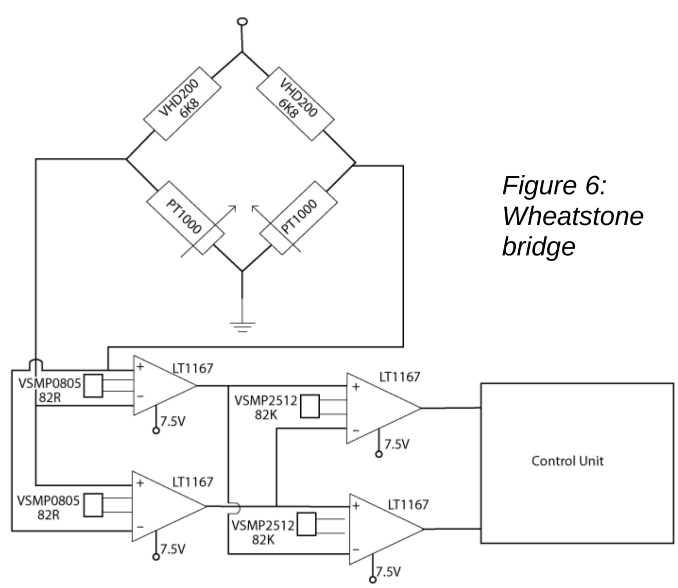


Figure 6: Wheatstone bridge

#5 End Products

Calibration of a Wheatstone bridge with two PT1000 sensors and VHD200 6.8 kΩ/6.8 kΩ resistors for measuring of temperature differences (differential signals will be amplified by four LT1167s controlled with a PD-Controller)

Customer Schematic/Specifications:

- Resistance values: 6.8 kΩ
- Absolute tolerance: 0.01%
- Working power: 200 mW
- Absolute TCR: <2 ppm/°C maximum
- End-of-life tolerance: <0.05%
- Improved load-life stability ratio: <0.05% for 2000 hours under rated power
- Low inductance and capacitance
- Fast response time <1 ns with effectively no ringing

The Vishay Foil Resistors Solution

VHD200

- VHD200 is hermetically-sealed and oil filled, providing additional moisture protection and allowing considerable improvement in ratio match stability and TCR tracking
- TCR: 2 ppm/°C maximum
- Power TCR: 5 ppm at rated power
- Tight tolerance: 0.01%
- Load-life stability: ±0.005%, 2000 hours at working power
- Rise time: <1 ns (without ringing)
- Devices with hermetic enclosures are more reliable and provide better long-term performance than molded resistors. Moisture and oxygen both pass through plastic or epoxy, and both contribute to long-term degradation of resistive elements
- Datasheet: **http://www.vishaypg.com/ppg?63036**

#6 End Products

A low-noise instrumentation amplifier and ADC

Customer Schematic/Specifications

- Customer needs a stable voltage divider 5 kΩ/1.998 kΩ with ratio tolerance of 0.05%
- Working power: 200 mW
- Absolute TCR: <2 ppm/°C (0°C to +60°C)
- End-of-life tolerance: <0.05%
- Improved load-life stability: <0.05% for 2000 hours under rated power
- Low inductance and capacitance
- Fast response time <1 ns with effectively no ringing

The Vishay Foil Resistors Solution

SMNZ

- Absolute temperature coefficient of resistance (TCR):
  ±0.05 ppm/°C typical (0°C to +60°C)
  ±0.2 ppm/°C typical (-55°C to +125°C, +25°C ref.)
- Tracking: 0.1 ppm/°C typical

- Tolerance match: 0.01%
- Power coefficient tracking (R2 -R1 due to self heating): 5 ppm at rated power
- Power rating at 70°C: 0.4 W (entire package)
- Each resistor: 0.1 W
- Ratio stability: 0.005% (0.1 W at 70°C, 2000 h)
- Large variety of resistance ratios
- Electrostatic discharge (ESD) up to 25,000 V
- Short time overload: 0.0025%
- Non-inductive, non-capacitive design
- Rise time: 1 ns (without ringing)
- Datasheet: **http://www.vishaypg.com/ppg?63117**

#7 End Product
Infrared radiometer

Customer Schematic/Specifications
- A highly stable resistor network for temperature measurement.
- 10 kΩ/10 kΩ divider with matched tolerance of 0.01%
- Very tight tracking vs. temperature (requires Foil resistors)
- Parts with screen/test lots in compliance with
  EEE-INST-002, (Tables 2A and 3A, Film/Foil, Level 1) and MIL-PRF-55182
- Working power: 200 mW
- Absolute TCR: <3 ppm/°C
- End-of-life tolerance: <0.05%
- Improved load-life stability: <0.01% for 2000 hours under rated power
- Low inductance and capacitance

The Vishay Foil Resistors Solution
VFD244Z Bulk Metal Foil ultra-high precision Z-Foil voltage divider Resistor
- Absolute temperature coefficient of resistance (TCR):
  ±0.05 ppm/°C typical (0°C to +60°C)
  ±0.2 ppm/°C typical (-55°C to +125°C, +25°C ref.)
- TCR tracking: 0.1 ppm/°C typical
- Tolerance: absolute and matching to 0.005% (50 ppm)
- Resistance range: 1 Ω to 100 kΩ per resistive element
- Power coefficient tracking (ΔR due to self heating): 5 ppm at rated power
- Power rating: up to 1 W at 70°C (for the entire package, divided proportionally between the two values)
- Load-life ratio stability: <0.005% (50 ppm) 1 W at 70°C for 2000 h
- Maximum working voltage: 350 V
- Electrostatic discharge (ESD) up to 25,000 V
- Rise time: 1 ns (effectively no ringing)
- Current noise: 0.010 µVRMS/V of applied voltage (<-40 dB)
- Thermal EMF: 0.05 µV/°C typical
- Voltage coefficient: < 0.1 ppm/V
- Thermal stabilization time: <1 s (nominal value achieved within 10 ppm of steady state value)
- Datasheet: **http://www.vishaypg.com/ppg?63176**

#8 End Product
Differential amplifier used with reference circuits where TCR tracking and long-term stability are required

Customer Schematic/Specifications
- 2 1 kΩ/2 kΩ dividers with very tight TCR tracking required (target <0.5 ppm/°C)
- Absolute tolerance: 0.01%
- Working power: 200 mW
- End-of-life tolerance: <0.05%
- Improved load-life stability: <0.05% for 2000 hours under rated power
- Fast response time <1 ns with effectively no ringing

The Vishay Foil Resistors Solution
Custom 2-, 3-, or 4-resistor networks (Z-Foil technology): ultra-high-precision Z-Foil voltage divider and network resistor

- Resistance range: 5 Ω to 100 kΩ (any ohmic value ratio is available within resistance range)
- Temperature coefficient of resistance (TCR):
  ±0.05 ppm/°C typical (0°C to +60°C, +25°C ref.)
  ±0.2 ppm/°C typical (0°C to +125°C,+25°C ref.)
- TCR Tracking from 0.1 ppm/°C
- Power coefficient (ΔR due to self heating): 5 ppm at rated power
- Resistance Tolerance: absolute and match to 0.005% (50 ppm)
- Resistance ratio stability: at 0.05 W at +25°C to 0.001%
- Electrostatic discharge (ESD) at least to 25 kV
- Power rating to +125°C: 0.3 W per element
- Thermal EMF: 0.05µV/°C
- Thermal stabilization time: <1 s (nominal value achieved within 10 ppm of steady state value)
- Current noise: 0.010 µVRMS/V of applied voltage (<-40 dB)
- Rise time: 1 ns without ringing
- Datasheet: **http://www.vishaypg.com/ppg?63114**

Conclusions:

1. There are significant performance differences among the families of products categorized as precision resistors.
2. A new state-of-the-art Foil resistor network technology is available from Vishay Foil Resistors that offers broad resistance ranges, ratio ranges, and low TCR.
3. Tight ratio stability is important in many applications and can only be maintained by good tracking of resistors with low absolute TCRs, as well as good TCR tracking.
4. Other factors such as thermal EMF at the termination junctions can induce ratio errors.

Samples and production quantities of the Foil resistors are available now, with lead times of five days for prototype samples and from two days to five weeks for standard orders at the catalogue houses (depending on their shelf availability). **http://www.vishaypg.com/foil-resistors/customers/catalog-house/**

In addition, Vishay maintains a number of Precision Centers around the world for exceptional support for customers' prototype developments and emergency situations. Precision Centers manufacture small

quantities of any value and tolerance in most VFR models in five days or less.
Check **http://www.vishaypg.com/foil-resistors/customers/precision-centers/** for the Precision Center nearest you.

Further information about other Vishay Foil Resistors products is available at www.vishayfoilresistors.com
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For more information about this product group, please contact us at: Foil@vishaypg.com