



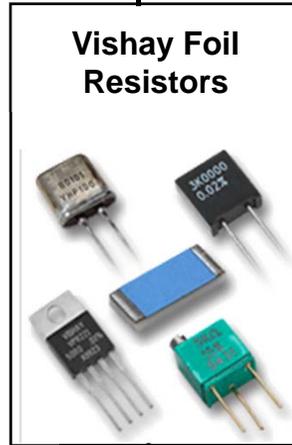
Precision Resistors

There is more to resistor precision than meets the eye



Where the World Goes
for Precision Measurement and Control

Vishay Precision Group



The World Today

- There are many challenges for electronic equipment:
 - Avionics: More Electric Aircraft (MEA) , high reliability, high temperature operation, long term stability
 - Energy: precision analogue measurement for inertial guidance, precision current sensing, high temperature operation, long term stability
 - Instrumentation – high precision analogue measurement

The World Today

- There are many challenges for electronic equipment:
 - Medical – precision current measurement, precision analogue measurement
 - Space – established reliability, long term stability, wide temperature range
 - Telecommunications – precision current measurement, precision analogue measurement

Vishay Foil Resistors

- Enable many of these applications by providing:
 - Excellent long term stability with power & temperature
 - Established reliability (ER)
 - High temperature operation to +240 °C
 - Tight tolerance to 0.0005%
 - Any value within the range at no extra cost - can be quickly made to any 6-digit resistance value
 - No minimum order quantity (MOQ)
 - No product obsolescence
 - Products for specific application e.g. current sensing
 - Tailored products to meet customers specifications

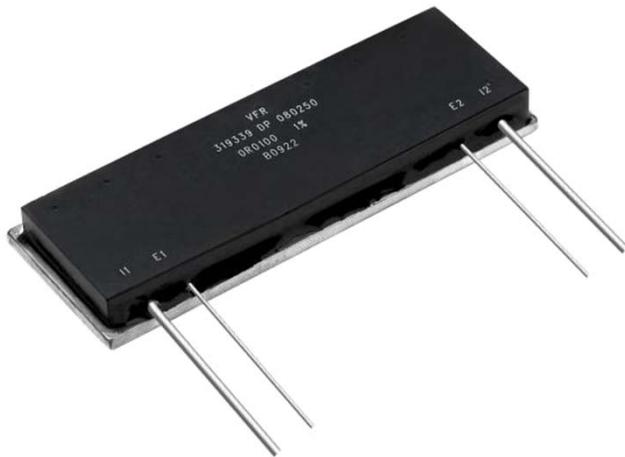
Typical Applications

- Audio amplifiers
- Bridge networks
- Current sensing
- Differential amplifiers
- Electron microscopes
- Force balance scales
- Gyro navigation controls
- High-precision amplifiers
- Measurement systems
- Motor speed controls
- Pressure sensors
- Telecommunications
- Temperature Measurement
- Standards and Decade Boxes
- Switching power supplies
- Weighing Scales



Bulk Metal[®] Foil Resistors in Precision Instrumentation

*New Generation of Current sensor (Custom designed)
is used in high end Voltage/current calibrator ; value:
10m Ω , TCR <1 ppm/ $^{\circ}$ C*



Wheatstone Bridge Circuitry

- Precision resistors have two basic uses in standard strain gage circuits: shunt calibration of strain-measuring instruments and bridge completion.

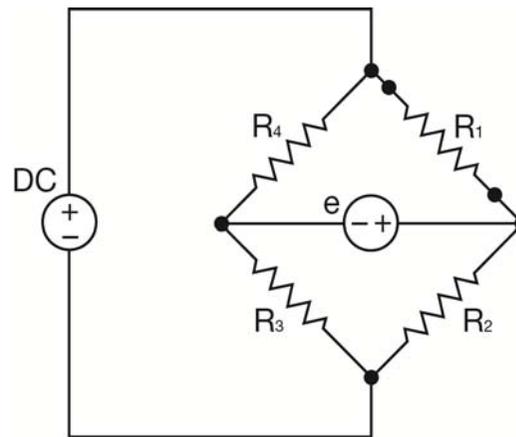
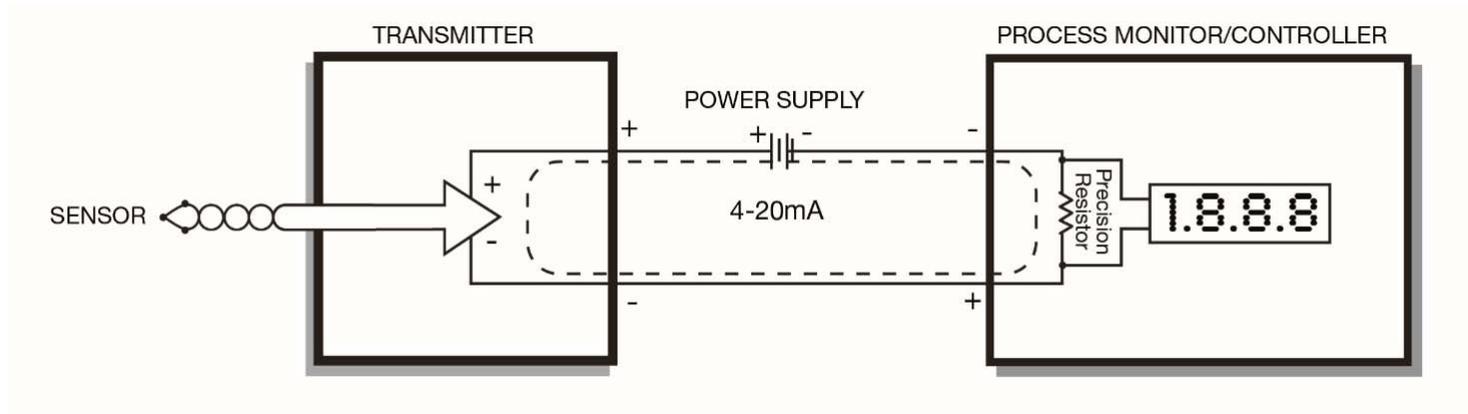


Figure 1: Basic Wheatstone Bridge Circuit Diagram

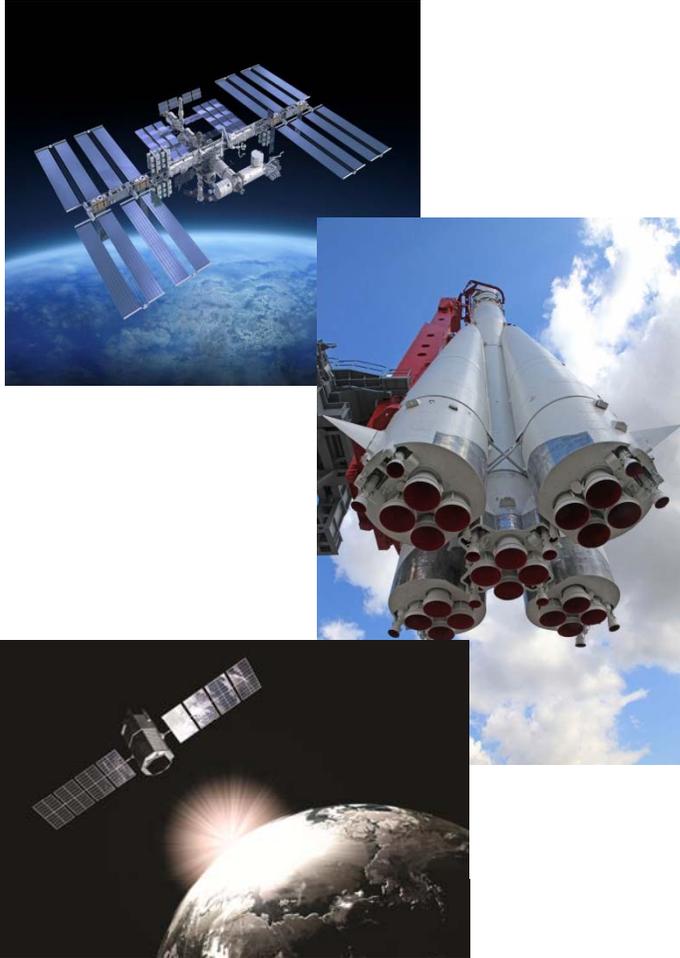
<http://www.vishaypg.com/doc?49677> (APPS107)

4-20 mA Current Loop



<http://www.vishaypg.com/doc?49676> (APPS106)

Bulk Metal[®] Foil Resistors In Aerospace Application



Space Level Resistor per EEE –INST-002 that been used :

- **CSM Series (current sensors)**
- **VSMP Series (warp around SMD)**
- **SMR series (Molded SMD)**
- **PRND (Custom Designed Hermetically Sealed Networks)**



lithium-ion (Li-ion) battery

- With Need for more power and less weight Li-ion batteries are now used in Aircraft and Space applications.
- For control in charging and power management Current Sense Resistors Improve the Flexibility, Longevity, and Safety of Li-ion Batteries

For Case studies go to:

<http://www.vishaypg.com/doc?49678> (PPS108)

Calibrate RTD and Thermistors Measurements

- Bulk Metal® Foil resistors can be trimmed to unique resistance values for use in simulating RTD measurements at precisely defined temperatures. These ultra-low TCR resistors are nearly immune to drift over temperature and time, making them the ideal reference to check against RTD under any operating condition or after any lapse of time. VFR can produce unique resistance values in only a few days and with relatively little cost due to a convenient calibration factor built into every resistor.

Bulk Metal[®] Foil Resistors in military & in telecom undersea cables

52 units of S106D (S-Series) is used in undersea repeater station.

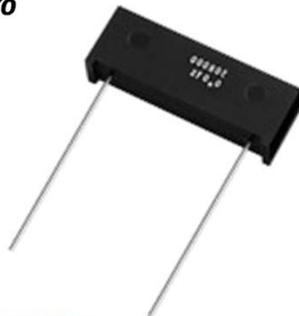
These are used to amplify the signal at various positions along the cable.

High Voltage divider 15KV.

Resistance value 50M

ratio 10000:1

Accuracy 0.0025%



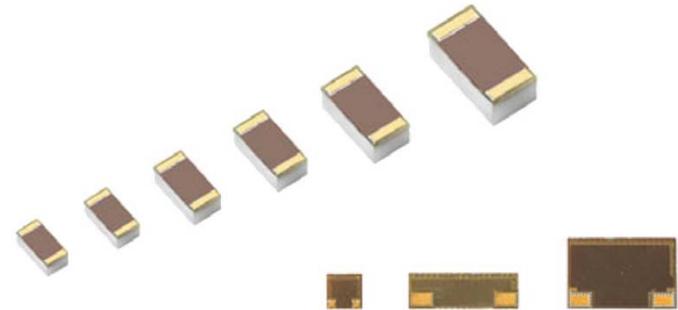
VCS1625Z (Kelvin Connections) is used for advanced helmet mounted display and sighting system that provides heads up display and accurate line of sight to the pilot and co-pilot.



Bulk Metal[®] Foil Resistors for High Temperature Application (Down hole)



HTHG series is used for measurement inside of a drilling tool, and withstand temperature up to +240°C



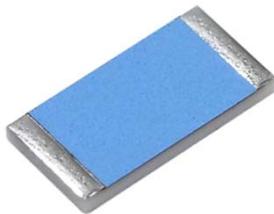
Advanced Medical

- **Example:**
 - End Product – Intravascular Cooling System.
 - The intravascular cooling system treats patient hypothermia with a metalized heat-exchange catheter that adjusts the temperature of the blood.
 - The Vishay Foil Resistors Solution: VSMP Series

<http://www.vishaypg.com/doc?63224> (APPS102)

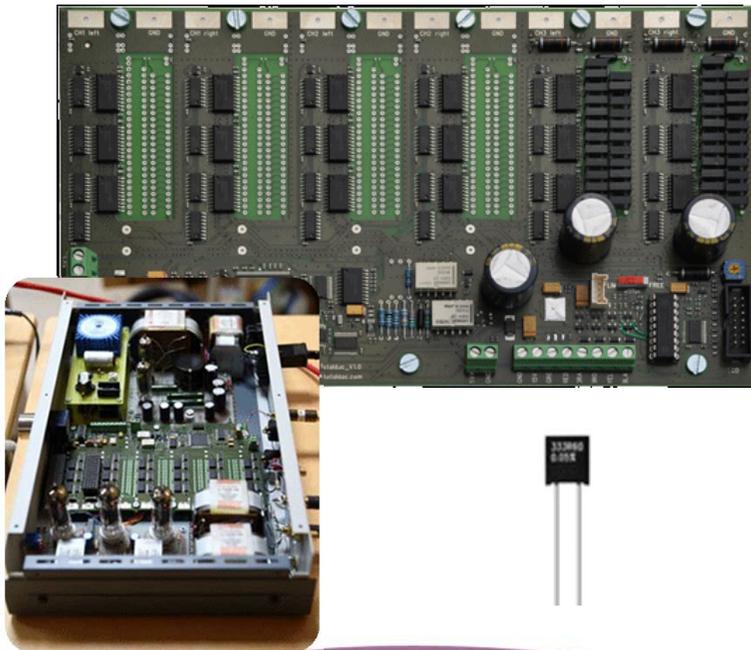
Bulk Metal[®] Foil Resistors in Precision Scales

*VFCP2512 are used as current sense resistors
in the new series of high performance
laboratory scales*



Bulk Metal[®] Foil Resistors in Audio Applications

96 units of S102C are used in high end sounding audio multi-channel digital-to-analog converter .



VSA101 is used in high end audio electronics line stage amplifier which required very low noise and low distortion electronic components.



Alternative Energy and Smart Grids

- **End Product** – System including motor control, power supply and PT-100 calibration unit.

<http://www.vishaypg.com/doc?49674> (APPS104)



There is More to Resistor Precision than Meets the Eye

- Resistors from different technologies may appear similar on the surface, and may often have similar published specifications (Initial TCR, Initial Tolerance, Load life stability, Noise, ESD, etc).
- However, each is made of a different resistive material and produced differently. Resistance material, design and processing variations strongly influence electrical performance, leading to different behaviours after installation.
- Resistor stability should be judged by real-life performance under load and temperature through short-term and long term exposure to different electrical and mechanical stresses

The Ideal Resistor

- When current passes through a resistor it generates heat and the thermal response induces relative mechanical changes (stresses) due to differential thermal expansions in the different materials comprising the resistor.
- Ambient temperature changes have a similar effect.
- Therefore the ideal resistor would employ materials and designs that minimize manufacturing stresses for a precise thermo-mechanical balance to eliminate the need to compensate for the effects of heat and stress during use.

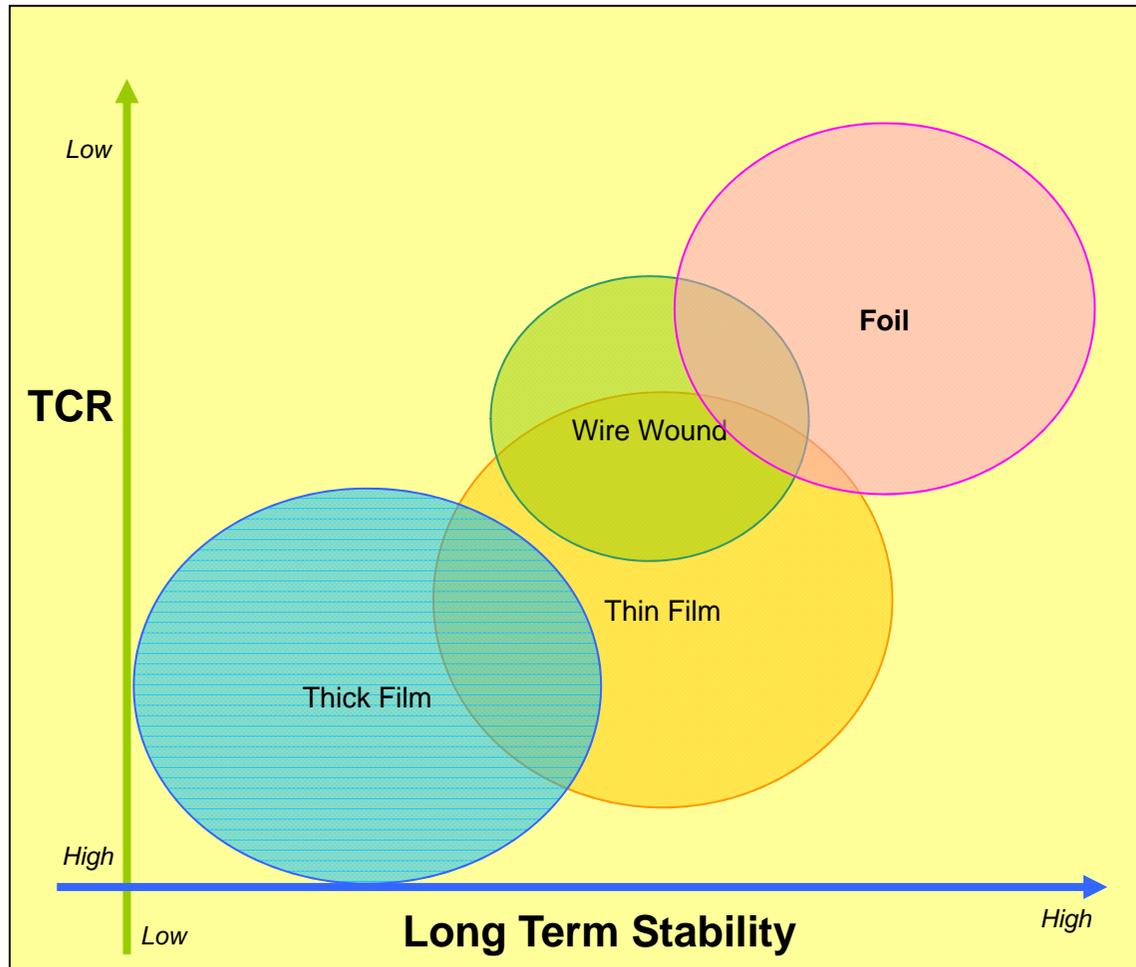
The Foil Resistor

- Foil technology deliberately introduces a controlled stress in the construction of the resistor therefore ensuring that the characteristics of the resistor are predictable and controlled. This applies from resistor to resistor and batch to batch.

Factors affecting resistor performance

- 1. Temperature coefficient of Resistance (TCR)
 - Changes due to ambient temperature
- 2. Power Coefficient of Resistance (PCR)
 - Changes due to power
- 3. Stability
 - Change due to soldering process (permanent)
 - Humidity (reversible)
 - Load Life (irreversible)
- 4. Other factors: ESD, Thermal EMF, Thermal Stabilization

Comparison of Resistor Technologies



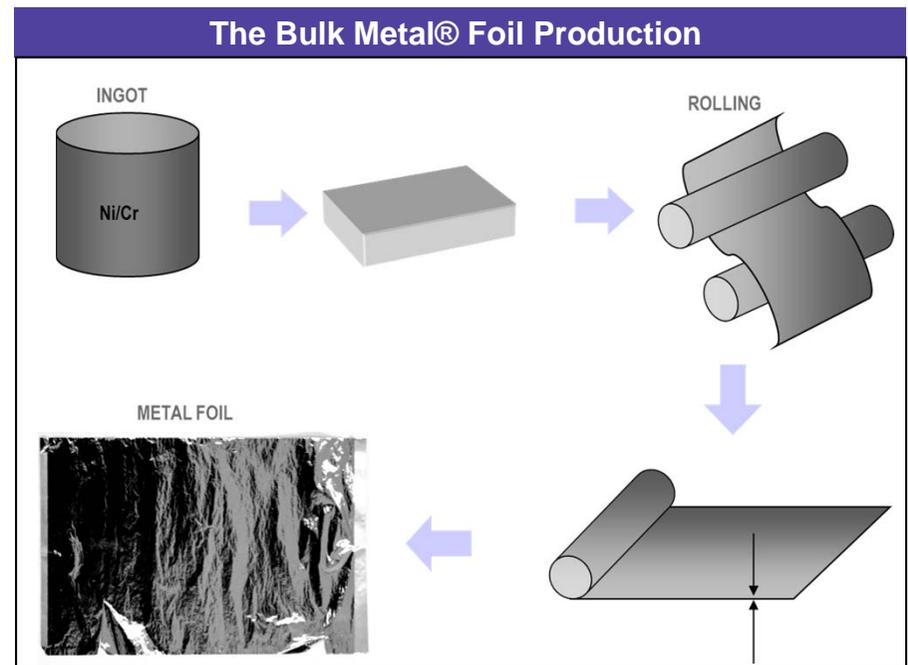
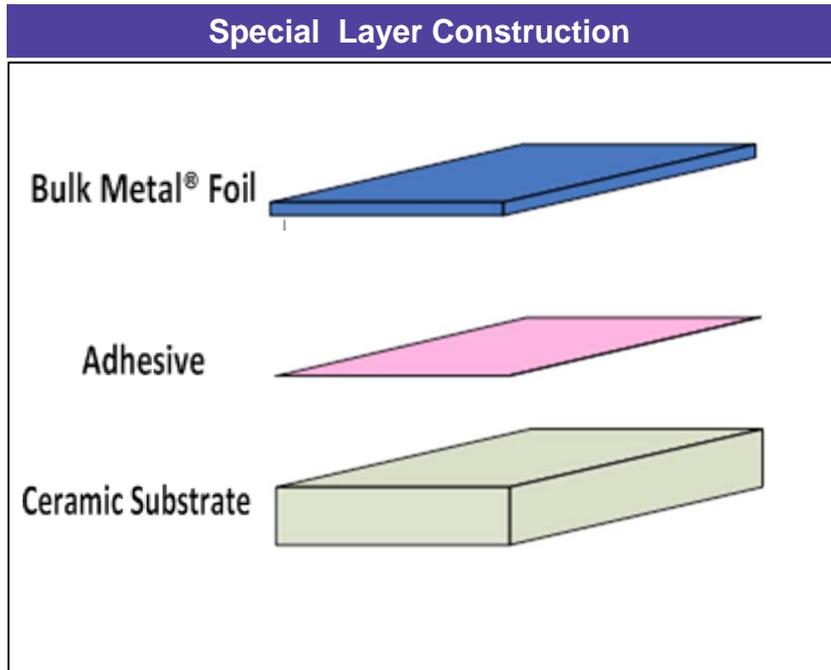
Comparison of Resistor Technologies

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) 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

The original Bulk Metal[®] Foil Technology

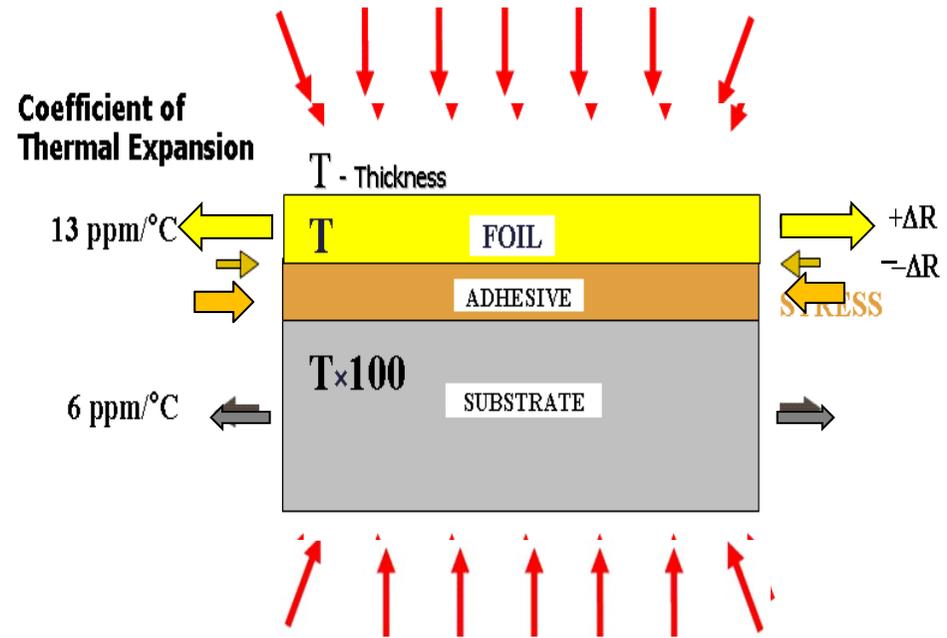
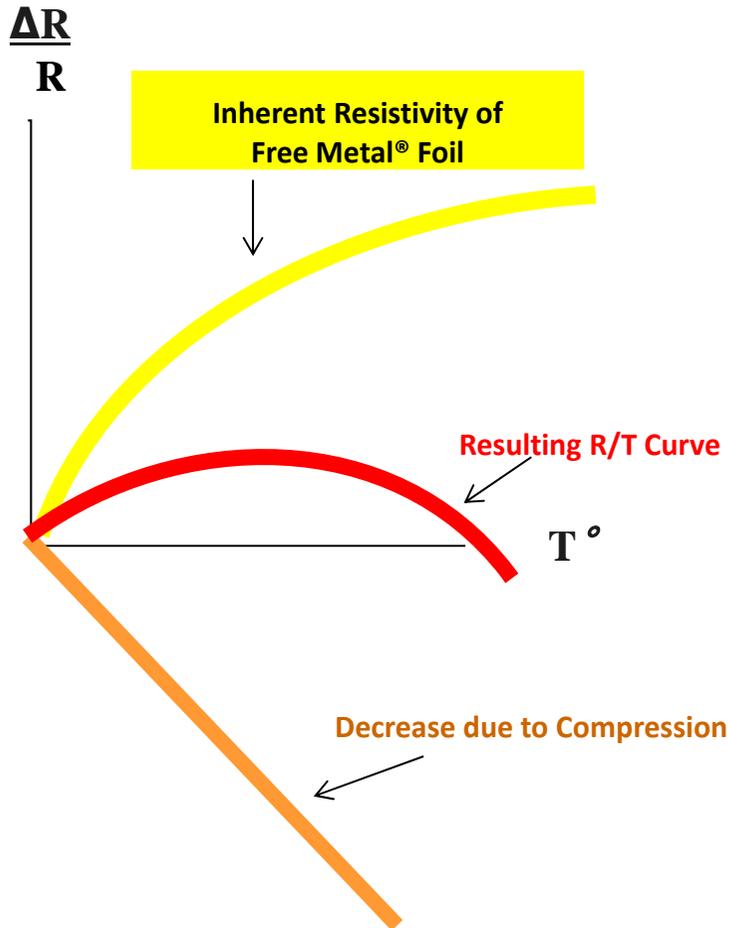
Company's Key Technology

- The Bulk Metal[®] Foil resistor is based on a special concept where a proprietary bulk metal cold-rolled Foil is cemented to a ceramic substrate.



Company's Key Technology

TCR and PCR



Bulk Metal[®] Foil Resistor

Silicone Rubber Encapsulation
 Provides a cushioning layer that isolates the resistive element from external stresses.

One Piece Transfer Molded Case
 Affords maximum protection against all environmental conditions.

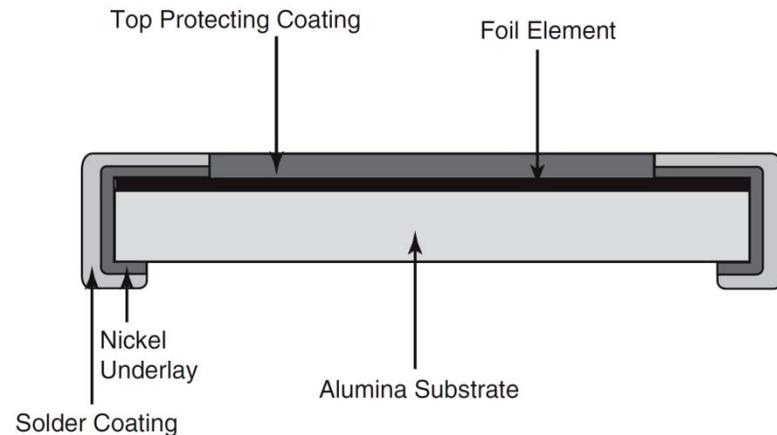
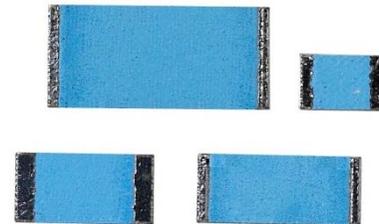
Bulk Metal[®] Foil
 Etched resistive element.

Polymerized Moisture Protection Layer

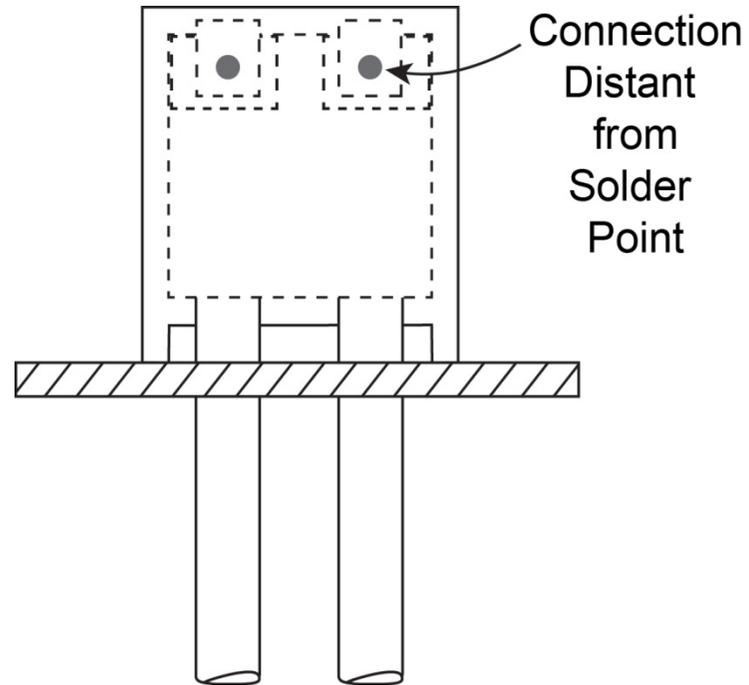
Molded Standoffs
 Allow easy PC board cleaning.

Ceramic Substrate

Paddle Leads with Welded Terminations— No Ribbons
 Only two welds, both remote from the lead-to-case point-of-entry, the best arrangement for maximum reliability. Excellent moisture resistance, high temperature, and load life capabilities, low Thermal EMF

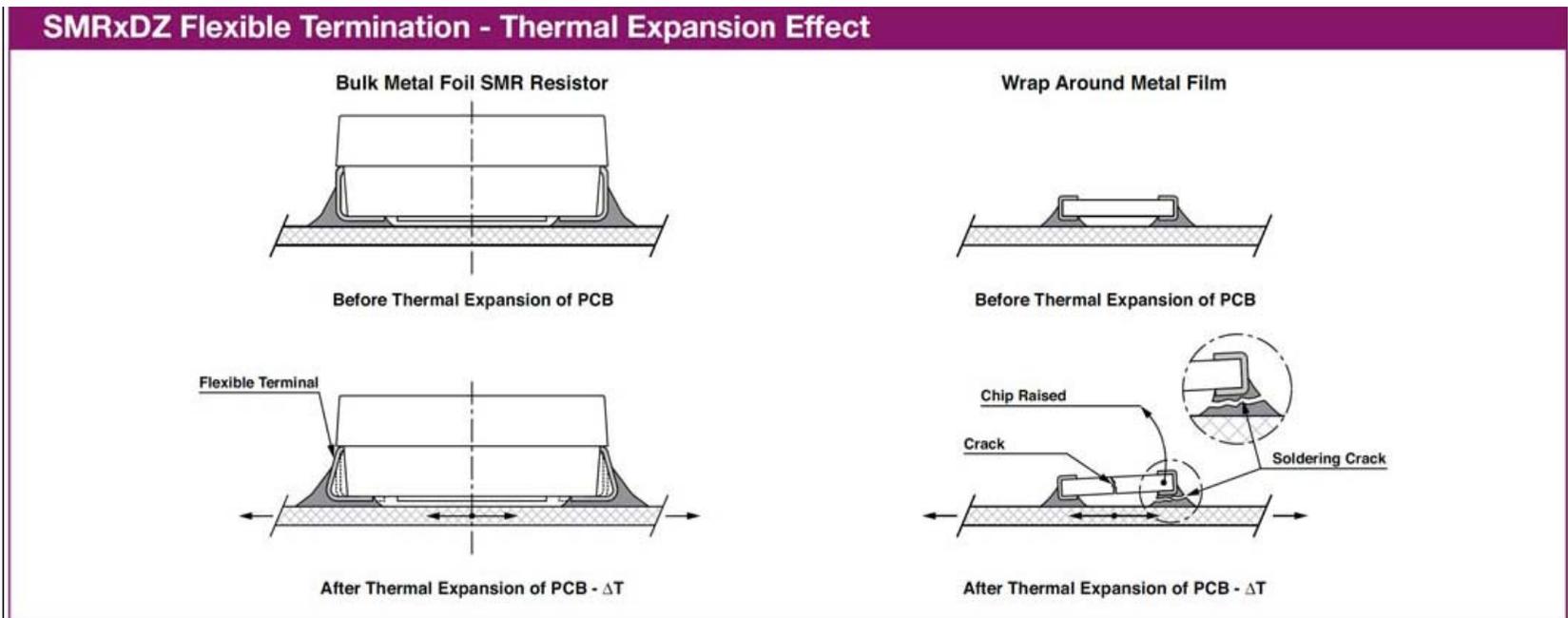


Through- Hole



Flexible Terminations

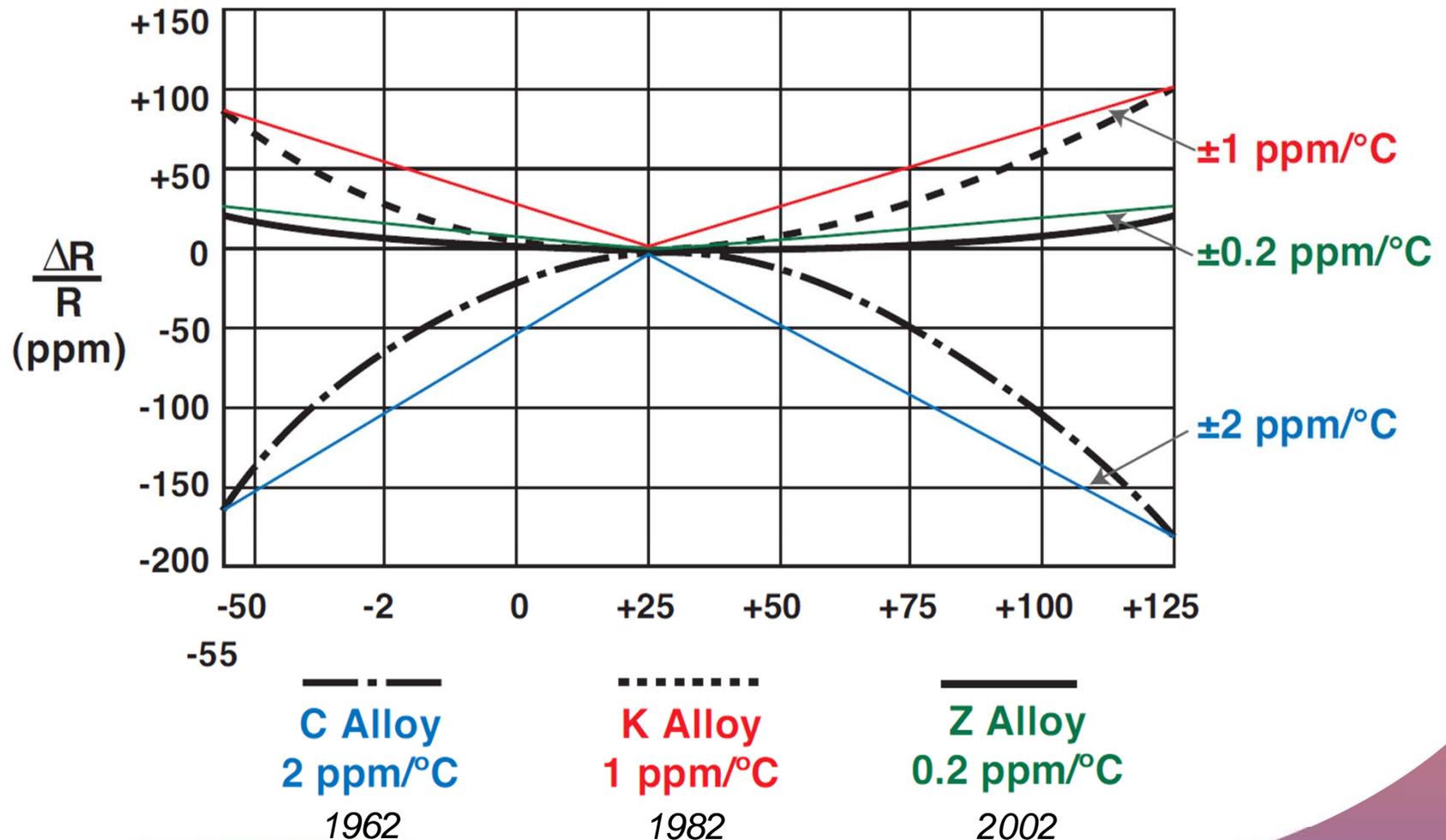
- Chip sizes of 1206 and larger occasionally delaminate from the printed circuit board or develop cracks. This is due to stresses introduced into the chip by handling of the PC board and stress due to thermal shock. VFR's SMRxDZ, a chip in molded package



SMR3D

- **Important:**
 - Thermal stresses can occur due to changes in ambient temperature or internal heat generation in the resistor itself.
 - Whatever the cause, stress cycling due to thermal phenomena can cause material fatigue and cracks: The SMR series eliminates the problems of cracked substrates and board delamination by providing flexible terminations for strain relief, thereby increasing reliability

The Foil Development Over the Years



Capacitance and Inductance

- In spiraled and wirewound resistors, the Capacitance and Inductance are created by the loops and spaces formed by the spirals or turns of wire (Fig A)
- In planar resistors such as the Bulk Metal® Foil resistors, the geometry of the lines of the resistor patterns is intentionally designed to counteract these reactances.
- Figure B shows a typical serpentine pattern of a planar resistor. Opposing current directions in adjacent lines reduces mutual inductance while geometry-related inter-line capacitances in series reduces overall capacitance.
- Both inductance and capacitance produce reactance proportional to the operating frequency and it changes the effective resistance and the phase between the current and voltage in the circuit.

Fig A- Capacitance and Inductance in a Wound or Spiraled Resistor

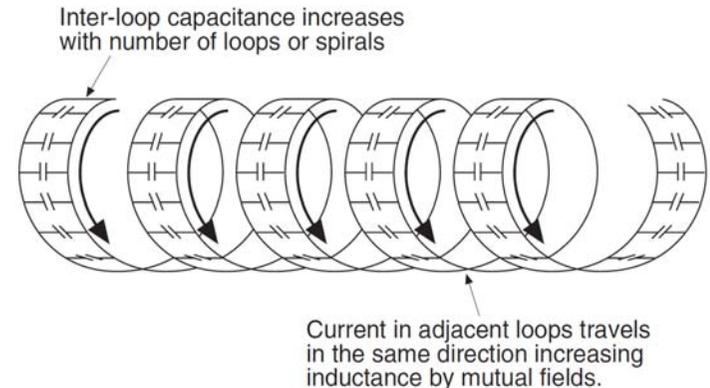
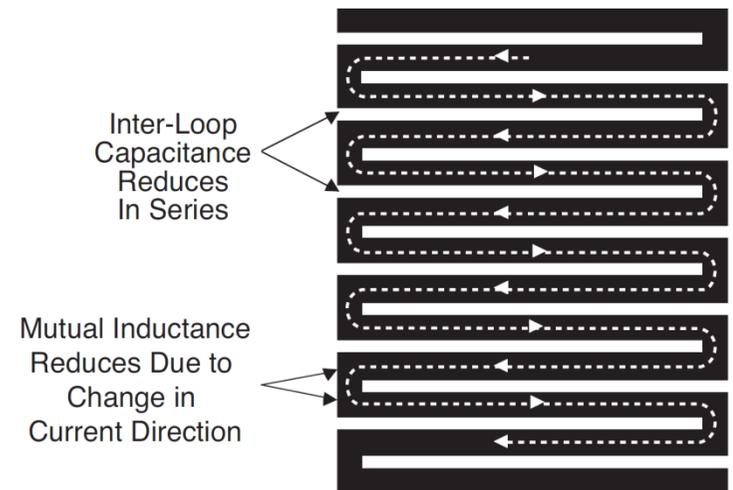
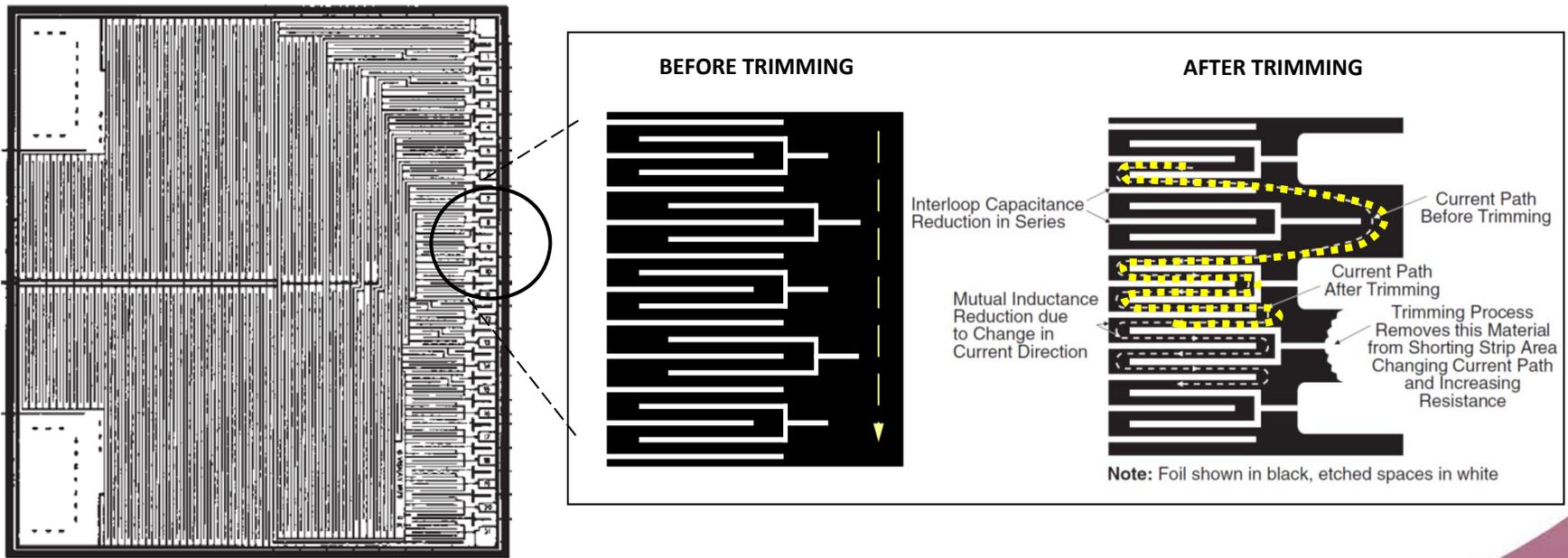


Fig B- Bulk Metal® Foil Planar Design



Unique Trimming Method

- The Bulk Metal® Foil is photo etched into a resistive pattern (no mechanical stress introduced). Later, it is laser (or manually) adjusted to any desired value and tolerance.
- Because the resistive metal used is not drawn, wound or mechanically stressed in any way during manufacturing process, the Bulk Metal Foil resistor maintains all its design, physical and electrical characteristics while winding of wire, or sputtering of Thin Films, or thick film glazing do not.



Trimming

Laser Trimming



Manual Trimming



Vishay Foil Resistors are not restricted to standard values, specific “as-required” values can be supplied at no extra cost or delivery (e.g., 100.1234Ω vs 100Ω)

Key Features

Vishay Foil Resistors Features

Metal Bulk Foil Unique Features

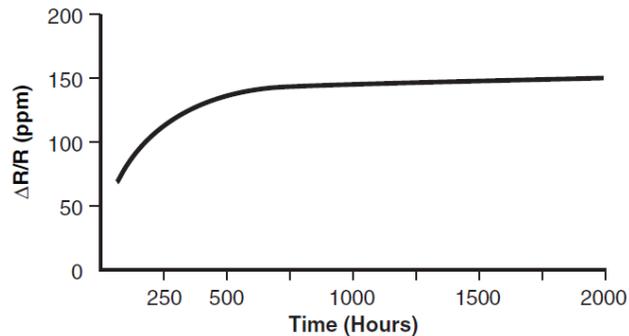
- Temperature Coefficient of resistance absolute and tracking: from 0.2ppm/°C
- Resistance Tolerance absolute and match: from 0.001% (10ppm)
- Load Life stability: from 0.002% after 2000h at rated power
- Power TCR (PCR): from 5ppm at rated power with Z-Foil resistors
- End of Life Tolerance (Total error budget): <0.05%
- Shelf Life stability : 2ppm for at least 6 years
- No minimum order quantity
- Products are available on short lead times from our local precision centers

Inherent Characteristics of Foil Resistors

- Vishay Foil Resistors are not restricted to standard values, specific “as-required” values can be supplied at no extra cost or delivery (e.g., 100.1234Ω vs 100Ω)
- Electrostatic discharge (ESD): at least to 25 kV
- Rise time: 1 ns, effectively no ringing
- Thermal stabilization time < 1sec (within 10 ppm of steady state value)
- Non-inductive, non-capacitive design
- Voltage Coefficient: 0.1ppm/V
- Current noise: 0.010μVRMS/V of applied voltage (<- 40dB)
- Thermal EMF: <0.1 μV/°C

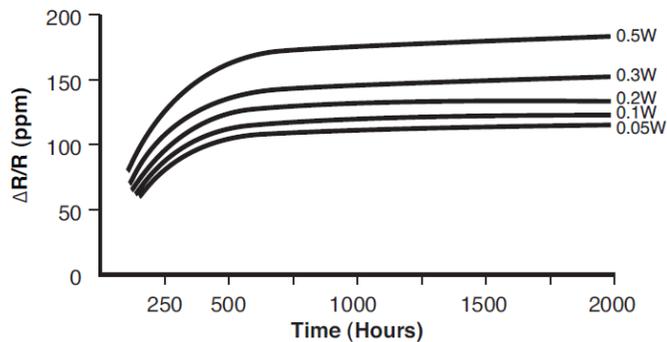
LOAD LIFE STABILITY

Relative Resistance Change ($\Delta R/R$) as a Function of Time, Load 0.3W, +125°C Ambient

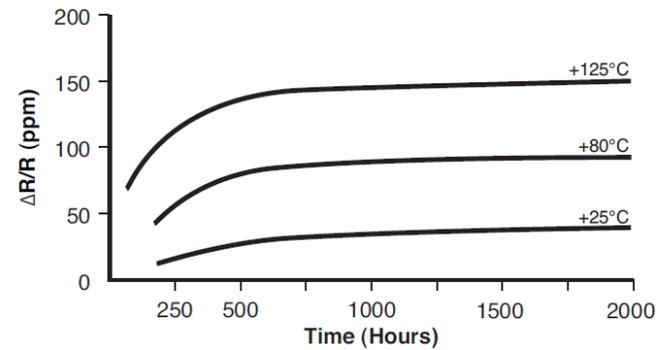


Resistor Technology	Load Life Stability	Test Conditions		
		Time	Power	Temperature
Precision Thin Film	500- 1500 ppm	2000 hrs	Rated Power (e.g. 0.3W)	+125°C
Bulk Metal® Foil	150 ppm			

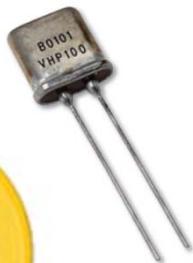
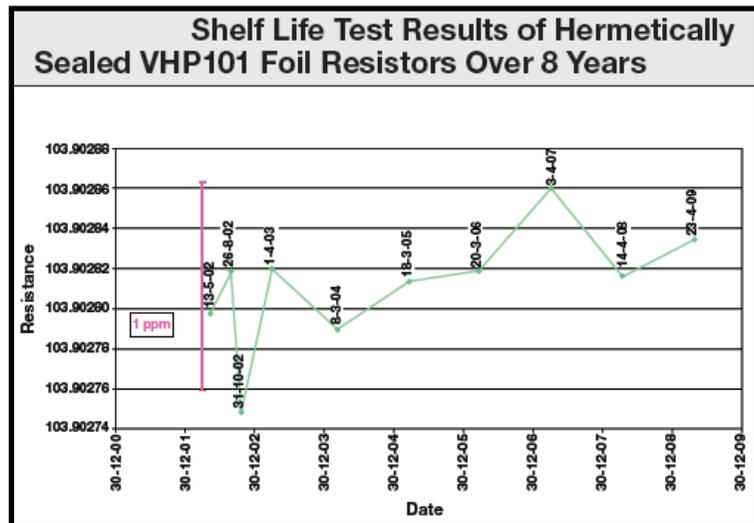
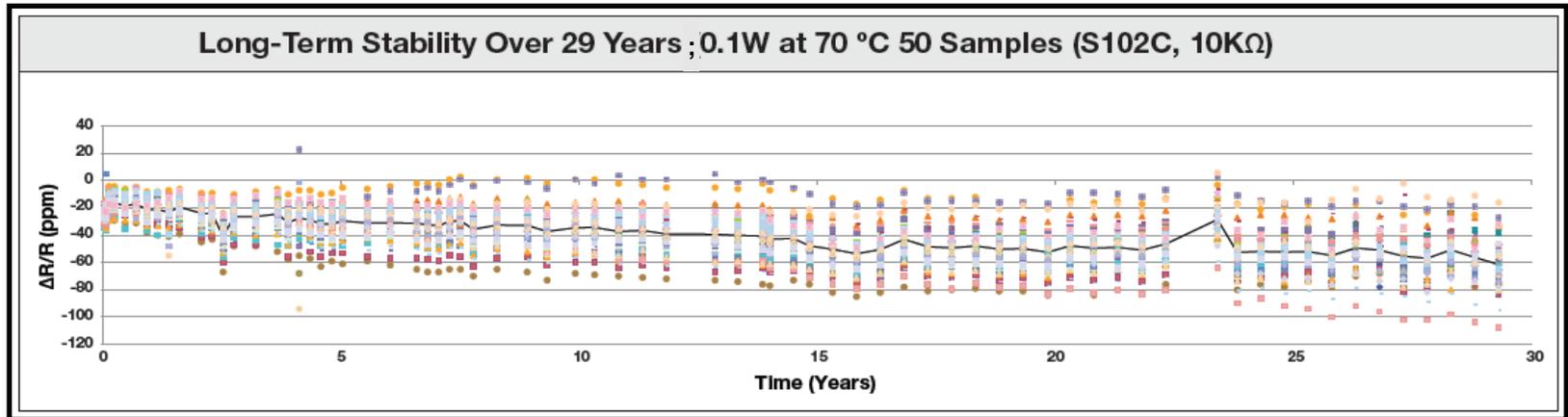
($\Delta R/R$) = F (Time), Loads 0.05 to 0.5W, +125°C Ambient



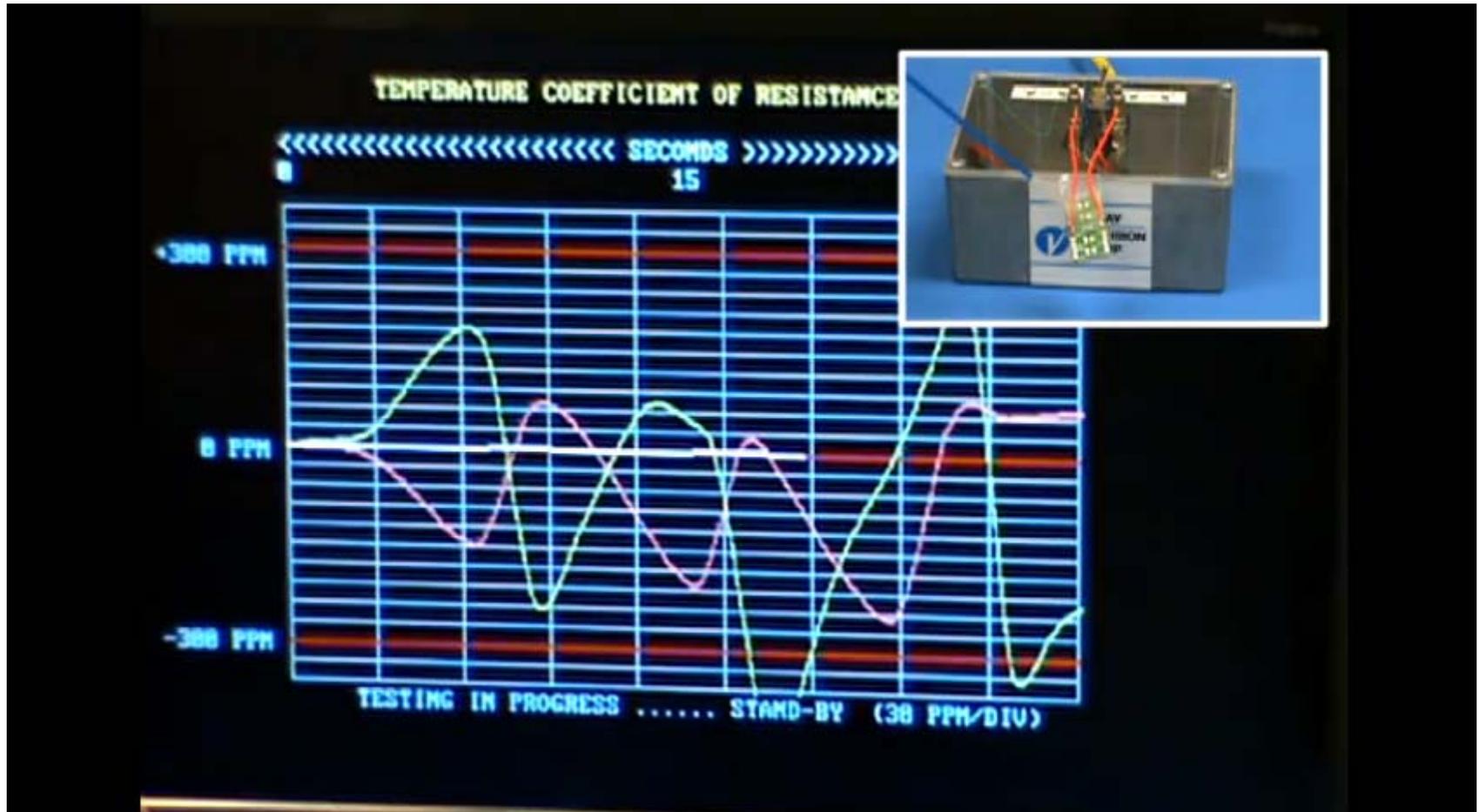
$\Delta R/R$ = F (Time), Loads 0.03W, Different Ambient Temperatures



Vishay Foil Resistors' Unique Stability



TCR Demo



<http://www.vishaypg.com/foil-resistors/videos/?video=10>

Power Coefficient Demo (PCR)



<http://www.vishaypg.com/foil-resistors/videos/?video=7>

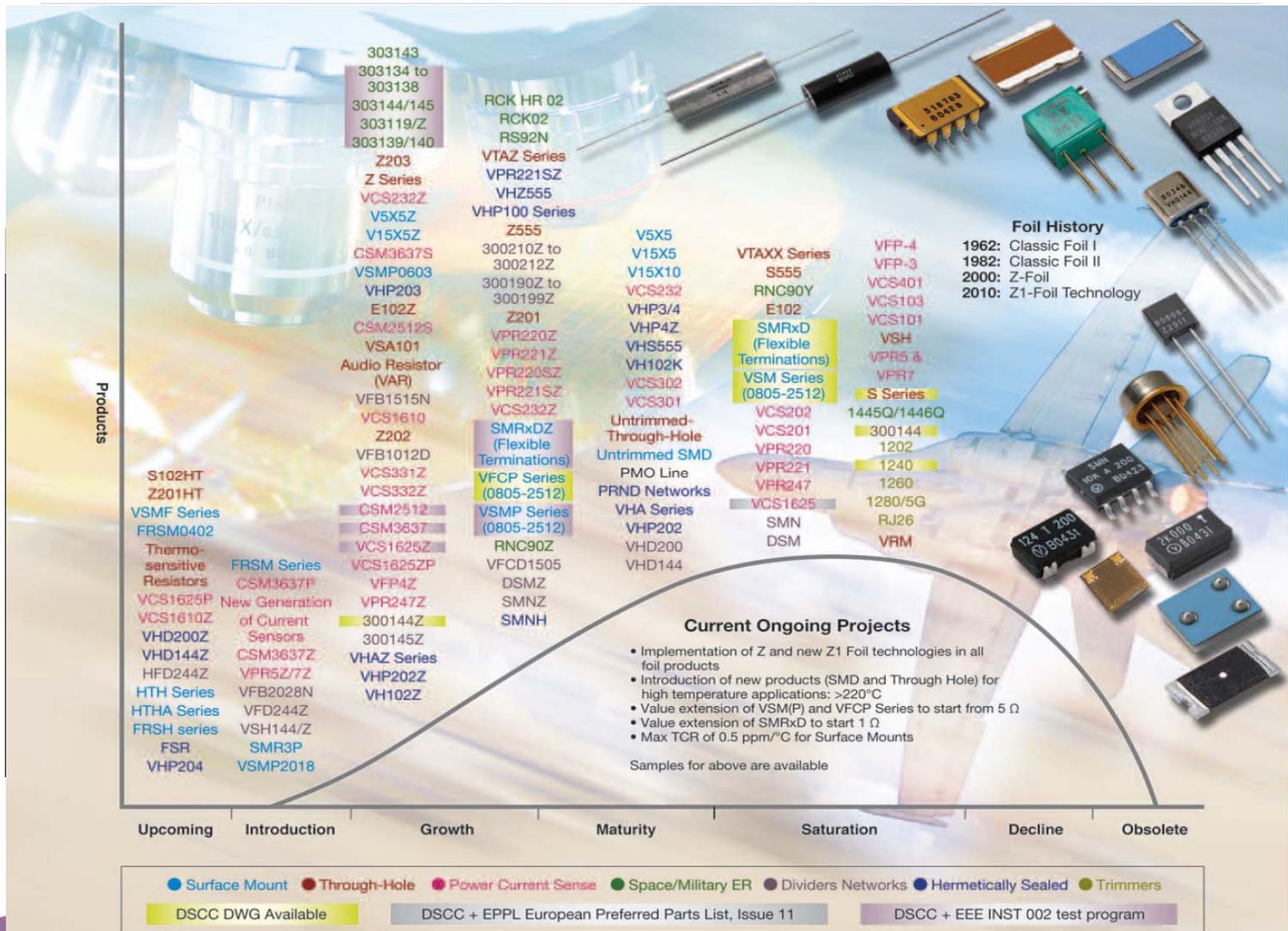
Products

Bulk Metal[®] Foil Resistor Categories



<http://www.vishayfoilresistors.com>

Product Life Cycle



Obsolescence, Counterfeiting and COTS: understanding the consequences

It is critically important for designers, component engineers, and designers to know their component manufacturers, their product commitments, their integrity, their reputation, the specific details of their products, the design and test links of their commercial products to their reliability-documented products, and to never, ever allow any unapproved links in the supply chain. Faced with the continuing concentrated ingenuity of the counterfeiting entities, everyone must protect themselves and the industry, in general, with scrupulously unrelenting vigilance and supply-chain control.

Why can't counterfeits duplicate the performance of Bulk Metal[®] Foil resistors?

- The physics of the Bulk Metal resistor are fairly simple to describe but the realization of a foil resistor requires advanced expertise in multiple disciplines such as metallurgy; high-temperature adhesives; very fine line photolithography; fine etching and chemical passivation; conductor path design to minimize inductance, capacitance, excess noise and hot spots (points of high current density); stress analysis and its thermal components; strain-relieving encapsulants or terminations; and reliability-enhancing in-process and post manufacturing operations (PMO).

<http://www.vishaypg.com/doc?63509> (FACTS118)

Tailored Solutions

Tailored Solutions

- The Foil resistors can be provided even with better specification than written in the standard datasheets. There are specific cases where some parameters can be maximized/ Improved beyond the standard performances to suit the customer requirements.
- Examples of such parameters are:
 - Total Error Budget (TEB) or End Of Life (EOL)
 - Long term stability
 - Ultra precision
 - Matched resistors
 - Resistance Value
 - Tolerance - Absolute and matched
 - TCR - Absolute and tracking



For more information please contact Application Engineering department:
foil@vishaypg.com

The End