VISHAY PRECISION GROUP

Applications at a Glance

From: Vishay Foil Resistors
March 21, 2012
ARTICLE# 104

Author: Yuval Hernik
Tel: +972-54-3000-191
E-mail: Yuval.Hernik@vishaypg.com

What Do Alternative Energy, Precision Resistors, and MacGyver Have in Common?

Alternative energy has been around for many millennia. It was even around when we were kids. Many of us in fact remember watching MacGyver use a magnifying glass to harness energy from the sun. This would start a fire and enable his escape from whatever predicament he'd gotten into that week.

"Alternative energy" is an envelope term that refers to any source of usable energy intended to replace conventional fuel sources such as coal, petroleum, and natural gas. "Renewable energy," a subset of alternative energy, is sometimes viewed as the best alternative to fossil fuels. Its name is intended to remind us that fossil fuels are limited and will eventually be exhausted or unavailable due to political issues. Renewable energy sources—such as the sun and wind—will continue. But just like fossil fuels, the production of solar, wind, geothermal energy, and other renewable resources requires a full complement of electronic controls, and these controls require high-precision resistors in several key circuit locations.

While energy surrounds all of us in all aspects of our daily life, the ability to harness and use it constructively, and as economically as possible, is the challenge before mankind. In many cases, in fact, the trade-off between efficiency, cost and pollution depends on a small passive component, the resistor, that many times doesn't get the appropriate attention. As we all know, 'renewable energy' is about electricity and the building block is always the resistor.

Today, Vishay Foil Resistors (VFR) offers various resistors for alternative energy and smart grid applications. Long ago we recognized the long-term trend toward decreasing reliance on conventional fuels and began developing high-precision resistors suited for a number of challenging alternative energy applications that have the effect of reducing carbon emissions and promoting the use of renewable energy. More than once, circuit designers have found that the gating factor in their success in developing such applications was, in fact, the resistor—or put another way, the main challenge was finding resistors with sufficient reliability, long-term stability, and immunity from ESD (Electrostatic Discharge).

The analog circuitry used in alternative energy applications is almost by definition operating under severe environmental, thermal, and mechanical conditions. Yet unlike many “industrial” applications, the picture is further complicated by tough regulatory restrictions and high consumer expectations. Additionally, the equipment must withstand extended frequent service by many users, professionals and novices alike. Designing and manufacturing equipment for this environment involves extreme challenges, and ones that until a few years ago seemed to be unachievable. All of this has an impact on the design of the analog circuits and obviously the role and expectations of the precision resistors.

Vishay Foil Resistors (VFR) is a leader in developing environmentally-friendly precision resistors for alternative energy projects that will help ensure man's progress and security for decades to come, including the Z- Foil technology introduced by our founder Dr. Felix Zandman a few years ago.

VFR’s highly reliable components are suitable for the harshest applications in such diverse fields as wind power, solar energy, smart grid, metering and other renewable energy applications.

VFR offers a broad portfolio of resistors to fulfill the requirements of alternative energy development, production and delivery. Some of the highlights include:

- **SMRxDZ** series with flexible terminations—special SMD parts that resist board stresses
- **VSMP** series, available in 0603 and larger sizes—low-noise resistors protected against ESD upwards of 25 kV (Z-Foil)
- **FRSM** series, excel over all previous stability standards for precision resistors with an order of magnitude improvement in temperature stability, load-life stability, and moisture resistance
- **VCS1625** series—current-sensing resistors with Kelvin connections, used throughout the smart grid, in smart meters, in solar inverters, and in wind energy inverters
- **Z201**, based on Z-Foil technology—through-hole devices for inrush current environments where SMDs aren’t suitable
- **CSM** series—SMD precision current sense resistors with 4-terminals for accurate voltage sensing in DC/DC converters

Ten Alternative Energy Precision Resistor Case Studies

The rapidly growing alternative energy market is driving improvements in power-efficient circuit design and energy storage solutions. VFR products for solar and wind turbine power systems provide the high reliability and long life required by solar energy cells and panels, smart meters, solar and wind inverter circuits, wind turbine braking circuits, hybrid electric vehicles, and more. In the remainder of this document we present some real-life examples of how precision resistors are being used in alternative energy applications such as these.

The stability of a resistor depends primarily on its temperature, which is affected by temperature coefficient of resistance (TCR) and power TCR (ΔR due to self-heating). These performance characteristics are particularly important in alternative energy market instrumentation and equipment, where Bulk Metal Foil resistors deliver proven reliability and stable performance, even when exposed to unstable levels of temperature and humidity or other harsh environmental conditions. Other important design considerations in alternative energy and smart grid equipment include providing immunity to single-event upsets in electronics, such as radiation, and damage caused by electrostatic discharge (ESD).

#1 End Products – Mass flow controller, battery current control and analyzers that detect gases and measure gas concentrations based on proprietary technology of laser-based photo-acoustics.

Customer Challenge:
In the customer's system, the accurate measurement of the flow of liquids depends on the sensors and associated electronics used to measure it. The resistors must provide the needed high accuracy and stability over a wide temperature range. In choosing new components for the design, the project engineer also sought to improve the performance of an existing amplifier unit.

The Vishay Foil Resistors Solution
VSMP series ultra-high precision Z-Foil wraparound surface-mount chip resistors: Offered in six chip sizes from 0603 to 2512, the VSMP series features a wide resistance range from 5 Ω to 125 kΩ. Within this range, any "as required" value (e.g. 1.2345 kΩ vs. 1 kΩ) can be supplied at no extra cost or delivery time

- Available in case sizes 0603 through 2512 and 2018
- The circuit uses the VSMP0603 (2.0 kΩ), VSMP0603 (5.11 kΩ), VSMP1206 (15.0 kΩ), and VSMP2512 (90.9 kΩ) resistors
- Absolute tolerance: 0.01%
- Enables temperature measurement and control to within 0.05°C
- Temperature coefficient of resistance (TCR): 0.05 ppm/°C typical (0°C to +60°C)
- Electrostatic discharge (ESD) at least to 25 kV
- Resistance patterns are photo-etched into the element to permit the trimming of resistance values to very tight tolerances as low as 0.01%.
- Thermal stabilization time <1 s (nominal value achieved within 10 ppm of steady state value)
- Load-life stability: to ±0.005% (50 ppm) at 70°C, 2,000 hours at rated power
- Current noise of 0.010 µVrms/V of applied voltage (<-40 dB)
- voltage coefficient of <0.1 ppm/V
- Available in matched sets upon request
- Datasheet: http://www.vishaypg.com/foil-resistors/list/product-63060/

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

Customer Schematic/Specifications

The customer manufactures motor-driven power supply and calibration units in wind and solar equipment that was developed in Arizona. These systems require component technologies with a history of high reliability, since they are exposed to harsh environments and are located in remote locations where access and repair can be very expensive. As part of the same project, the design engineer wanted to build a multiplexed ADC for temperature-measuring PT-100 temperature sensors with an integrated calibration resistor in order to measure temperatures with high accuracy and temperature resolution.

One of the PCBs in this project was to be mounted into a small dip (metal tube), so an SMD was required. Working conditions are -10°C to +50°C and low working power. The complete sensor tube would then be aged during the manufacturing process with 160 temperature cycles of +60°C/−20°C to stabilize the PT-100. After each cycle, a calibration of the sensor would be performed at the triple-point of water and gallium to monitor the progress of stabilization.

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

Required specifications:

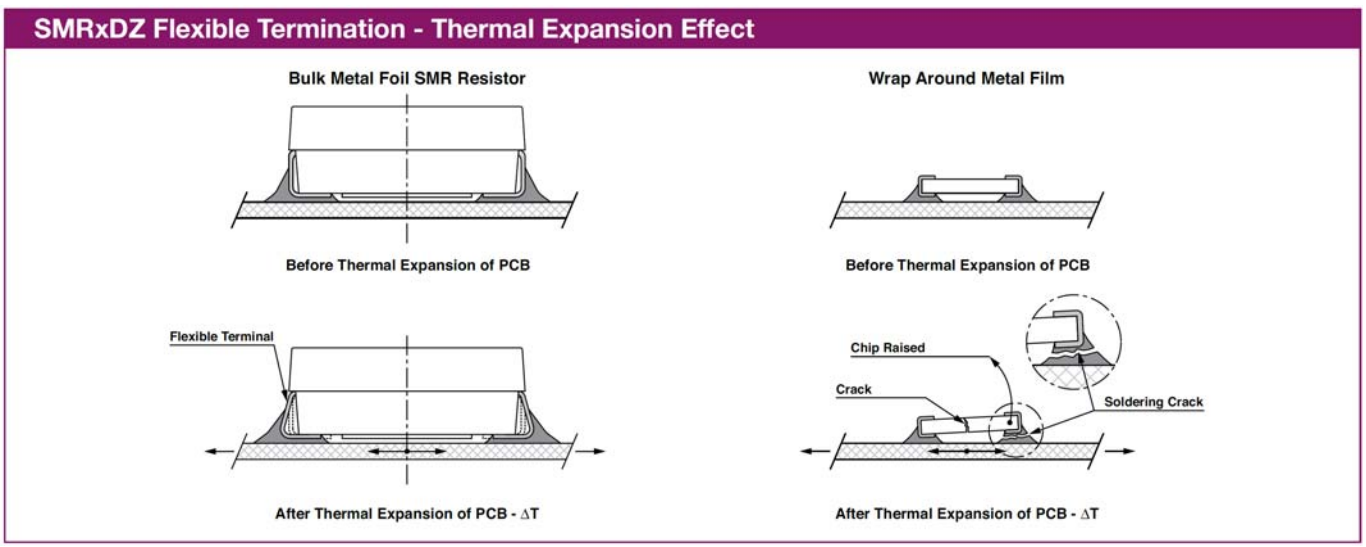
- Flexible terminations to ensure minimal stress transference
- Resistance values: 350 Ω , 120 Ω and 1 KΩ
- Absolute tolerance: 0.02%
- Working power: <200 mW
- Absolute TCR: <3 ppm/°C maximum (-10°C to +50°C)
- End-of-life tolerance: <0.1% maximum
- Improved load-life stability: <0.05% for 2000 hours under rated power
- Low inductance and capacitance
- Fast response time

The Vishay Foil Resistors Solution

SMR3DZ: This Z-Foil ultra-high-precision wrap-around chip resistor provides improved load-life stability and flexible terminations to ensure minimal stress transference from the PCB due to load-induced temperature gradients and a difference in thermal coefficient of expansions (TCE)

- TCR: 2 ppm/°C maximum (-10°C to +50°C)
- Power TCR : 5 ppm at rated power
- Tight 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%
- Current noise of 0.010 µVrms/V of applied voltage (<-40 dB)
- Voltage coefficient of <0.1 ppm/V
- Thermal stabilization time of < 1 s (nominal value achieved within 10 ppm of steady state value)
- Thermal EMF of 0.05 µV/°C
- Datasheet: http://www.vishaypg.com/foil-resistors/list/product-63118/

The Bulk Metal Foil resistor has documented more precise load-life stability than any MIL-qualified resistor. This is because the resistor's element is a bulk metal alloy that has been applied to a substrate with a unique process that results in a stress-free adhesion. The adhesion is maintained throughout the manufacturing process, including termination welding, encapsulation, marking, and curing. It then maintains adhesion integrity through all environmental and application stresses.



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

Foil resistors with flexible terminations are the most stable resistors, and thus require the least error allowance. The lower in-service error allowance means that more error allowance can be transferred to active devices – resulting in lower costs – or applied to the Foil resistors themselves, allowing for looser initial tolerances than would be required for other resistor technologies

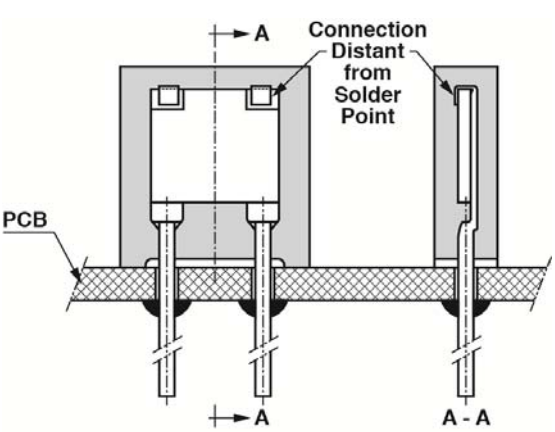
#3 End Product – High accuracy energy monitoring instruments, involving high-voltage pulse handling and PT-100 calibration.

Customer Schematic/Specifications

The amplifier in the design will require very stable resistors for the biasing circuit

The Vishay Foil Resistors Solution

S-Series High Precision Bulk Metal® Foil Resistors



- Temperature coefficient of resistance (TCR): ±2 ppm/°C typical (-55°C to +125C°C, +25C° ref)
- Tolerance: ±0.005% (50 ppm)
- Total Error Budget (TEB) < 0.05%
- Resistance range: 0.5 Ω to > 1 MΩ
- Load-life stability: (at 70C°C for 2000 h at rated power): ±0.005% (50 ppm)
- Rated power: 0.3 W to 1 W at +125°C (depending on size)
- Rise time <1 ns (without ringing)
- Non hot spot design
- Matched sets are available per request (TCR tracking: to 0.5 ppm/°C)
- Datasheet: http://www.vishaypg.com/foil-resistors/list/product-63001/

The newly advanced structural design of the S series resistors employs a pre-planned stress compensation that never exceeds Hooke's constant for the materials. Therefore, the resistors maintain their molecular-level structural integrity and assure resistance stability throughout the load-life and application environments of the resistor – holding resistance change to less than 0.05 % throughout the planned life of the equipment. The devices are designed with a coating and molding compound that provides moisture proofing and mechanical damping, as well as a path for heat dissipation

#4 End Product – A system with a new-generation power supply DC/DC converter and modular data acquisition system

Customer Schematic/Specifications

The design engineer needed a current sense resistor to accurately measure the current output and also provide current sense at a precision voltage divider at each measuring channel.

The Vishay Foil Resistors Solution

VCS1625Z (Z-Foil) and VCS1625- High Precision Current Sensing Resistors
VCS1625ZP and VCS1625P – higher power to 1W

- Temperature coefficient of resistance (TCR): (Z-Foil)
  ±0.05 ppm/°C typical (0C°C to +60°C)
  ±0.2 ppm/°C typical (-55°C to +125°C , +25°C ref)
- Tolerance: to ±0.1% (0.01% and 0.05% are available)
- Resistance range: 0.01 Ω to 10.0 Ω with specific “as required” values within this range (e.g. 1.234 Ω vs. 1 Ω) available at no additional cost or delivery time
- Load life stability: (at 70°C for 2000 h, rated power): ±0.02%
- Rise time of 1.0 ns, with effectively no ringing
- Short time overload of <0.005% (50 ppm)
- Current noise of 0.010 µVrms/V of applied voltage (<-40 dB)
- The VCS1625 series is offered with tin/lead or lead (Pb)-free gold or tin termination options, and with additional temperature treatments (PMO) to extend the operating temperature from +150 °C to well above +200 °C
- Datasheet: http://www.vishaypg.com/foil-resistors/list/product-63094/

#5 End Product – System including differential amplifier in analog-to-digital converter (ADC) and wind/temperature detection sensors.

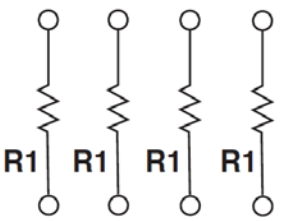
Customer Schematic/Specifications

The ADC requires very stable voltages which will be provided by two resistor sets of voltage dividers. Excellent tracking and long term stability are critical.

The Vishay Foil Resistors Solution

SMNZ (Z-Foil) 4 Resistor Surface Mount Network Dual-In-Line Molded Package

- Temperature Coefficient of Resistance (TCR): Absolute: ±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
- Resistance tolerance match: ±0.01%
- Resistance range: 100 Ω to 10 KΩ (per resistor)
- Power TCR (PCR) tracking: 5 ppm at rated power
- Load life stability: 0.005% (50 ppm), 0.1 W at 2000 h, 70°C
- Datasheet: http://www.vishaypg.com/foil-resistors/list/product-6311



Up to 4 different values R1, R2, R3, R4

#6 End Product – System including a high-temperature pressure sensor unit for control at desert solar stations and thermoelectric charging systems based on solar panel conditions.

Customer Schematic/Specifications

For the above projects the engineers needed four temperature-controlling high-stability resistors. These would be used in temperature-measuring bridges together with specially manufactured temperature sensors; the design team required sets of four different resistors with very tight TCR tracking and high long term stability of the ratio (less power, ambient temperature 19°C to 25°C). The engineer had shifted from PT-1000 (used in earlier designs) to NTC for this application, to improve performance.

The Vishay Foil Resistors Solution

FRSM Z-1 Foil Ultra High Precision Wrap-around Chip Resistors (0603-2512) : The devices' solid element alloy is matched to the substrate, forming a single entity with balanced resistance versus temperature characteristics for an unusually low and predictable TCR over a wide temperature range from -55 °C to more than +175 °C

- 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.)
- Load-life stability:
  - ±0.0025% at 70 °C, 2,000 hours at rated power
  - ±0.005% at 70 °C, 10,000 hours at rated power
- Thermal stabilization time <1 s (nominal value achieved within 10 ppm of steady state value)
- Electrostatic discharge (ESD) at least to 25 kV
- Short-time overload: 0.005%
- Rise time: 1 ns with effectively no ringing
- Current noise: 0.010 μV_{RMS}/V of applied voltage (< - 40 dB)
- Non inductive: 0.08 µH
- Voltage coefficient of <0.1 ppm/V
- Noise-free and provide ESD protection to of 25 kV or more for increased reliability
- Current noise of 0.010 µVrms/V of applied voltage (<-40 dB)

- These new benchmark levels of performance provide design engineers with the tools to build circuits not previously achievable, while reducing costs in the most critical circuits by eliminating the need for corrective circuitry.
- Datasheet: http://www.vishaypg.com/foil-resistors/list/product-63209/

#7 End Products – A system with a measurement instrument using entirely surface-mount components. The resistance temperature detector (RTD) circuit, which is part of it, requires high stability matching resistors

Customer Schematic/Specifications

RTDs are sensors used to measure temperature by correlating the resistance of the RTD element with temperature. Bulk Metal Foil resistors, with their very high stability, are used as a reference to compare to the resistance value of the RTD.

The Vishay Foil Resistors Solution

DSMZ High Precision Z-Foil Surface Mount Voltage Divider

- Temperature coefficient of resistance (TCR):
  Absolute: ±0.05 ppm/°C typical (0°C to +60°C)
  Tracking: 0.1 ppm/°C typical
- Tolerance match: to 0.01%
- Resistance ratio stability: 0.005% (70°C for 2000 h at rated power)
- Resistance values: 100 Ω to 10 KΩ per resistor
- Power rating (at +70°C):0.1 W (entire package), 0.05 W (each resistor)
- Datasheet: http://www.vishaypg.com/foil-resistors/list/product-63121/

#8 End Product – A solar instrument requiring a high stability precision trimming potentiometer to set the operating parameters. Tolerance match to 0.01% needed.

Customer Schematic/Specifications

- Trimming potentiometer with a resistance value of 5 kΩ and 10 kΩ
- The engineer had refused previously to use trimmers because he was not satisfied with the real and reputed stability and reliability limitations of cermet trimmers
- The customer replaced cermet with Bulk Metal Foil technology for better adjustability (less time to adjust) and improved linearity
- The engineer had to solve problems related to the , variability of resistance change vs lead-screw rotation, long setting time, and shock/vibration effects on the trimmer value

The Vishay Foil Resistors Solution

1240X Ultra High Precision Trimming Potentiometers

- 1/4" square, RJ26 style, with 5/10 kΩ resistance and 5% tolerance
- Temperature coefficient of resistance (TCR):
  ±10 ppm/°C (-55°C to +150°C, ref. at +25°C); through the wiper: ±25 ppm/°C
- A smooth and unidirectional resistance change with lead screw adjustment
- Load-life stability: 0.1% typical ΔR, 1.0% maximum ΔR under full rated power at +85°C for 10,000 hours

- Settability: 0.05% typical; 0.1% maximum in less than 20 seconds
- Setting stability: 0.1% typical; 0.5% maximum
- Power rating: 0.25 W at +85°C
- Resistance range: 5 Ω to 10 kΩ
- Resistance tolerance: ±5%, ±10%
- "O"-ring prevents ingress of fluids during any board cleaning operation
- Electrostatic discharge (ESD) at least to 25,000 V
- Datasheet: http://www.vishaypg.com/foil-resistors/list/product-63053/

#9 End Products – System with pulsed current driver circuit and current output board

Customer schematic/Specifications

The circuit is a trans-conductance amplifier using two resistors in parallel for an equivalent value of 0R005 ohm. The maximum pulse current for the pair is 200 A with a 2% duty cycle. Pulse rise time is 10 ms and fall time is 7 ms. The design engineers were also looking for a range of resistors to be used for high-precision current sensing of the charge and discharge of batteries. One of the most important parameters was the TCR: the engineer wanted resistance to be as close as possible to constant over a small range of temperatures, for both positive and negative currents.

The resistors would be stored in an environmental chamber nominally held at 28°C (±0.5°C maximum) and running at essentially constant current; the designer required the ability to measure very small fluctuations in this current, hence the need for low TCR. The actual temperature fluctuations would be small and mostly driven by heating of the resistor when current is running through it. The system would rely on air flow to maintain temperature.

- Measure applied currents to monitor the equipment
- Ohmic value: 0.005 Ω and 0.1 Ω
- Ambient temperature: -40°C to 85°C
- Absolute tolerance <0.25%
- Absolute TCR: <15 ppm/°C maximum
- Maximum current 11A over 100ms, 0.5Hz repeating rate for the current output board and maximum pulse current for pair of CSM is 200 A with a 2% duty cycle
- Continuous power 100mW (1A)

The Vishay Foil Resistors Solution

CSM Series - Ultra-high-precision Bulk Metal Foil current-sensing, surface-mount resistor

- Compact SMD size
- TCR: 15 ppm/°C Maximum (option to use “Z” version for 5 ppm/°C)
- Power rating: to 5 W (“P” version)
- Load-life stability to ±0.2% (at 70°C, 2,000 hours at rated power)
- Tight tolerance: 0.2%
- Low thermal EMF: <3 µV/°C (DC offset error, significant for low values)
- Proprietary processing technique produces extremely low resistance values with improved stability
- Datasheet: http://www.vishaypg.com/foil-resistors/search/?query=CSM

#10 End Product – Solar data logging systems – two-channel precision data logger

Customer schematic/Specifications

Low noise and temperature-stable dividers were required for the input amplifiers in the signal conditioning module to improve the temperature stability. Equally important to the system were long-term stability and reliability.

The Vishay Foil Resistors Solution

VFCD1505 1K / 1K 0.01% Ratio Match Network

- 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
- Resistance range: 1 kΩ to 10 kΩ
- Foil resistors are not restricted to standard values or ratios, specific “as required” values or ratios may be supplied at no extra cost or delivery (e.g. 2K234/5K456)
- Power coefficient tracking: ”ΔR due to self-heating” 5 ppm at rated power
- Short time overload: ± 0.005 %
- Tolerance: absolute and resistance ratio: to 0.01%
- Noise-free and provide ESD protection to of 25 kV or more for increased reliability
- Load life stability (0.1 W at 70 °C, 2000 h)
  - Absolute: 0.01%
  - Ratio: 0.005%
- Datasheet: http://www.vishaypg.com/foil-resistors/list/product-63109/

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/

Further information about other Vishay Foil Resistors products is available at www.vishayfoilresistors.com

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