# Vishay Dale Electronics
# High Reliability Current Sense

Presented by:

**Bryan Yarborough**

Product Marketing Engineer

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# Introduction

Bryan Yarborough is a Product Marketing Engineer for Vishay Dale Electronics for more than 10 years and is responsible for technical customer engagement and product marketing for Power Metal Strip® current sense resistors (≤ 1 ohm).

**<u>Previous Experience and Training</u>**:
Served as a Nuclear Operator in the U.S. Navy for 6 years, where I trained in electrical and mechanical engineering for integrated operation of nuclear systems. After the Navy, I earned a Bachelor's in Computer Science and Mathematics, followed by an MBA. I worked for 6 yrs as an Applications Engineer at Saft America, focusing on manufacturing and product development for primary and rechargeable lithium batteries. I also worked as Applications Engineer at IRC, for 7 years with data analysis and product marketing for multiple resistor technology types.


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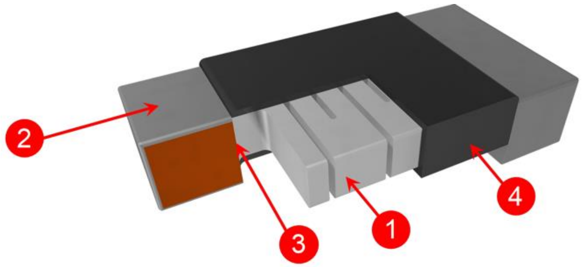
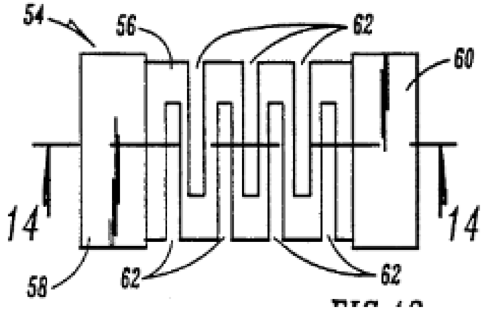
# Introduction (Dale & WSL)


Dale Electronics began 1951
Producing wirewound resistors

WSL patented in 1994




1. Resistive Element
2. Copper terminal with solderable finish
3. Terminal to Element weld
4. High temperature encapsulent

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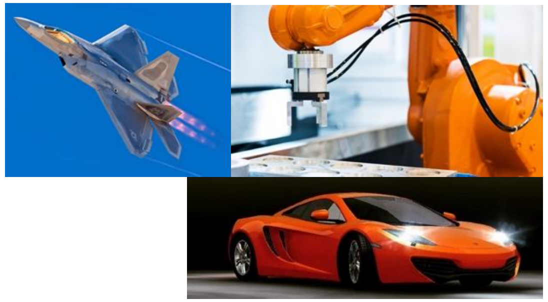
# Power Metal Strip® - WSLx Product Family



## Market Segments

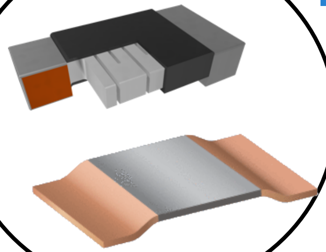
- Automotive, Military, Industrial
- High Reliability & Safety

## Applications

- Current Sense
- Power Conversion
- Motor Drive

## Highlights

- Low Resistance
- Wide range of footprints
- High pulse capability
- Robust all metal welded construction
- Flexibility with Laser trim construction



## Features

- MIL-PRF-32773 Ambient Temp Derated
- MIL-PRF-32783 Terminal Temp Derated
- Automotive Grade
- Tight tolerance (down to 0.1%)
- Wide Resistance range 1 to 0.0001 ohm
- High Current (380 Amps)
- Low TCR (down to 35 ppm/°C)

## Our Advantages

- Patented Power Metal Strip in 1994
- Multiple manufacturing locations
- Own source of Electron Beam welding
- Detailed technical data available

  ww2bresistors@Vishay.com

  Joule Wizard

Joule Wizard

Power Metal Strip @ Vishay.com

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1. Introduction
2. **Specification Hierarchy**
3. Construction & Thermal Resistance
4. Qualification data

# High Reliability: Performance Pyramid

Price / Performance

**Space**
- Extended Group A and/or C
- Highest Reliability Levels (e.g., Weibull D)

**MIL Spec**
- QPL; MIL-PRF; EPPL
- Established Reliability

**DLA (DSCC) Drawings**
- Customer / Supplier Sponsored
- SnPb finish

**Source Control Drawings (SCD)**
- Project or Application Specific Screening
- Special testing available

**AEC-Q200+**
- 2 kHr / 2 kcycle
- Higher robustness margin

**Automotive / Standard AECQ200**
- AEC-Q200 (1 kHr / 1 kcycles)
- Standard Automotive

**Industrial/Commercial Grade**
- Broadest Range
- Leading Edge Designs

Product Breadth

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# Reliability (Upscreen & SCD's) – Power Metal Strip®

- Frequently referenced Mil Specs
  - M55342 (Thick & Thin film chip resistor)
  - M32159 (Resistor fixed film chip)
  - M39007 (Through-hole wirewound)
  - M49465 (Metal element, low resistance)
- Frequent Exceptions to above Mil Spec
  - Resistor Element technology
    - all metal welded construction
    - Extremely low resistance range down to 0.0001 Ω
    - High current capability, up to 380 Amps
  - Mounting methods (through hole vs SMD)
  - Manufacturing process methods (Pre-conditioning; in process due to destructive testing)
  - Construction style (uncoated vs coated; example solderability test method)

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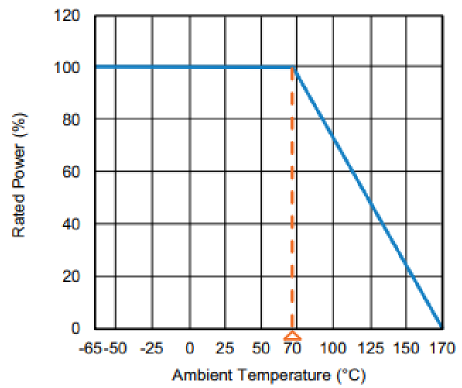
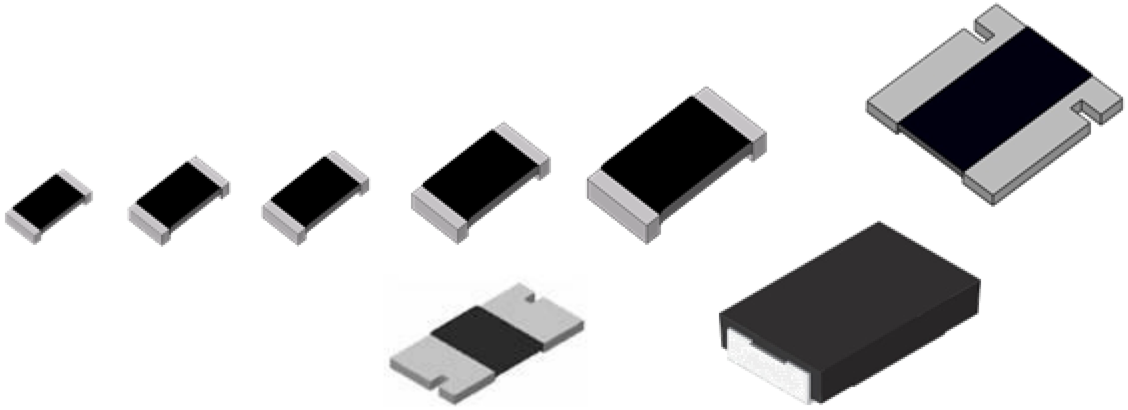
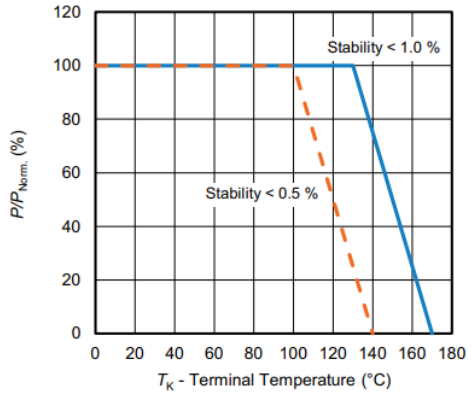
# Mil Spec for Metal Strip Current Sense

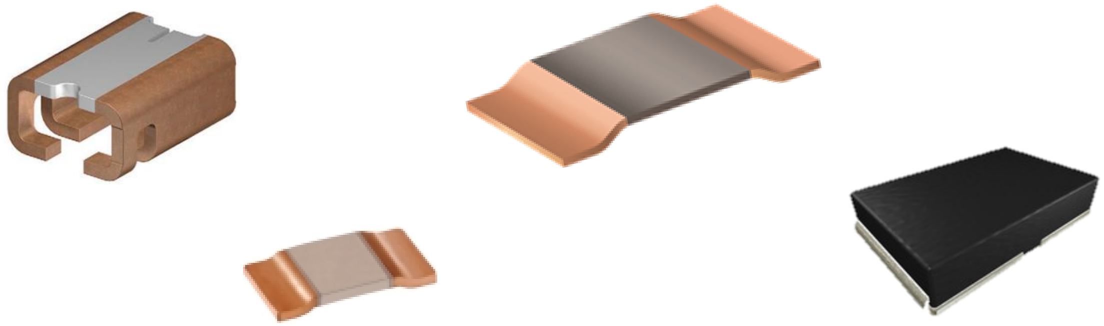
- Commercial, Military, Space level
- MIL-PRF-32773 : *Ambient* Derating



- MIL-PRF-32783 : *Terminal Temperature* Derating





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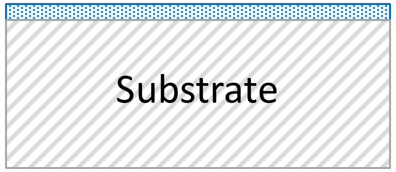
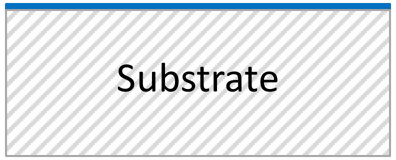
# Current Sense Technology Overview

Comparison of relative cross-section of
resistor element technologies for a 2512 size

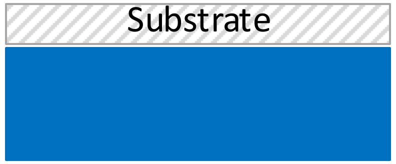
Power Metal Strip
0.0089”




Thick Film
0.000 8”

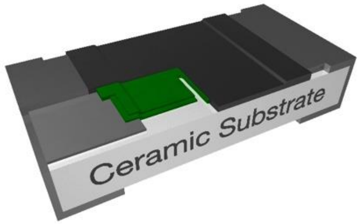


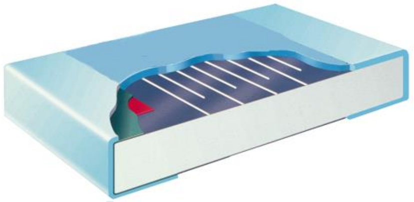

Commercial Thin Film
0.000 25”

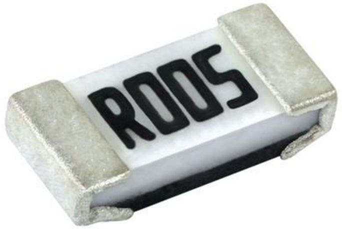



Foil
Up to 0.007”

Uncoated WSL





Greater Resistor Element **mass** = Pulse Capability

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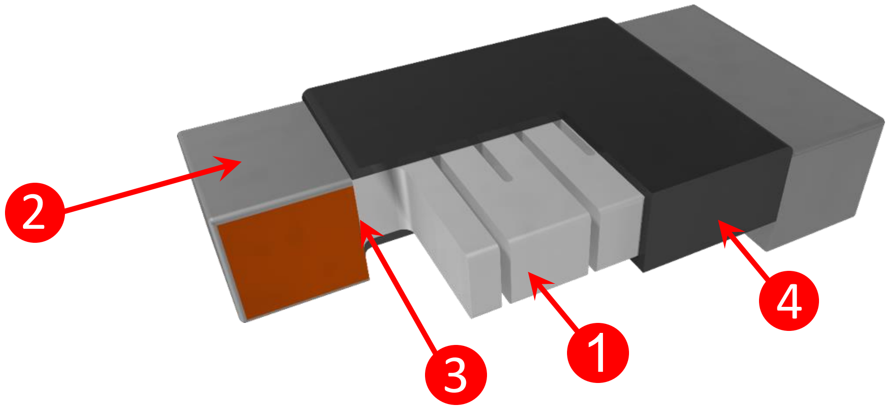
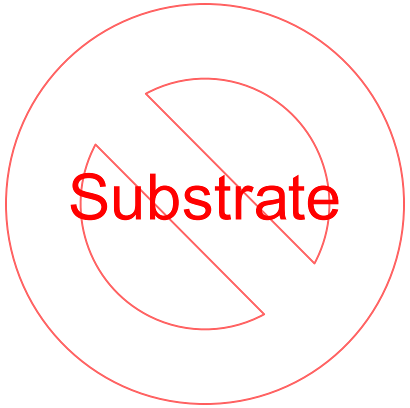
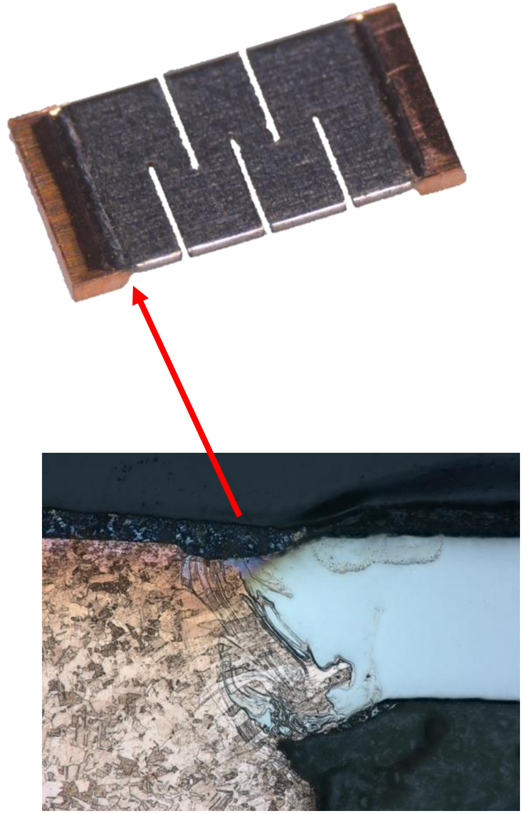
# Power Metal Strip® - Construction

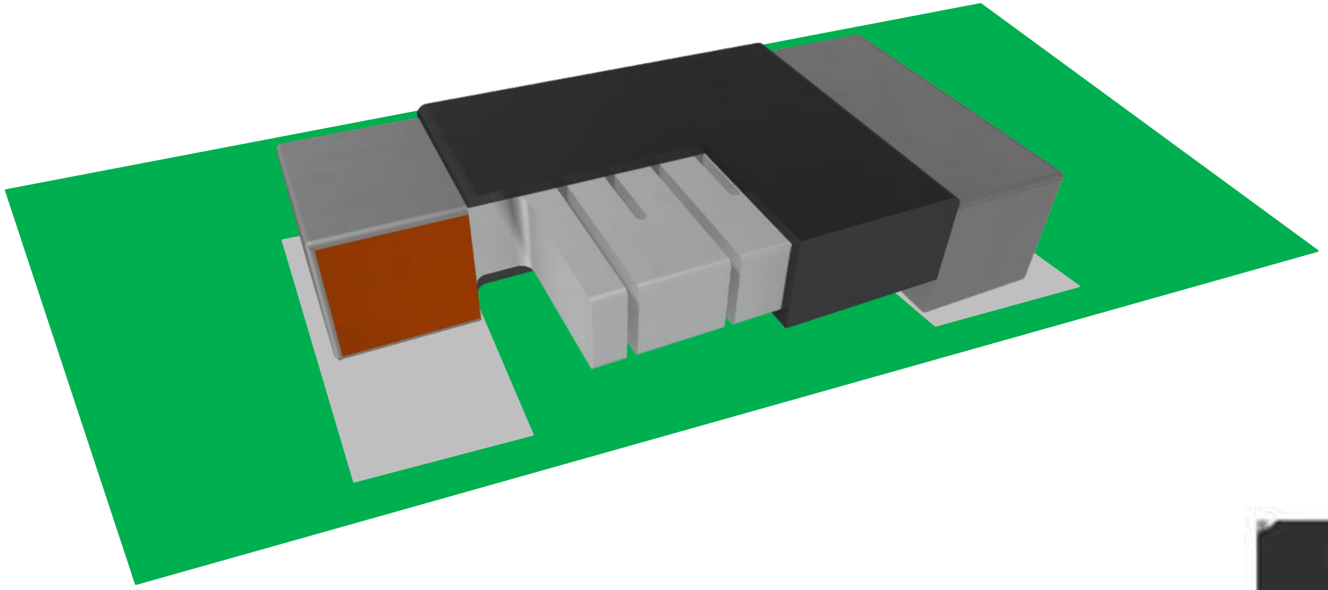


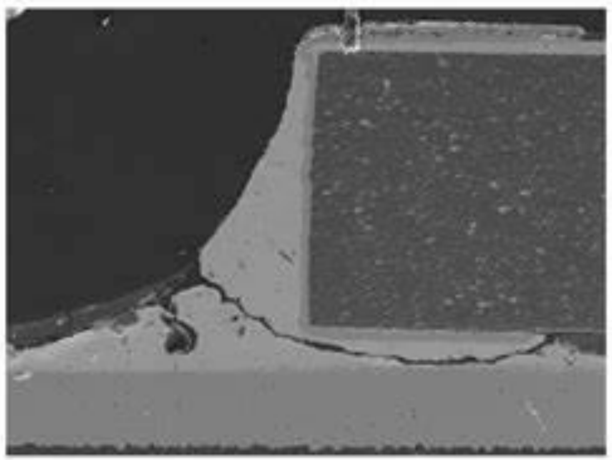



1. Resistive Element
2. Copper terminal with solderable finish
3. Terminal to Element weld
4. High temperature encapsulant

# Power Metal Strip® - WSL Construction & CTE Mismatch

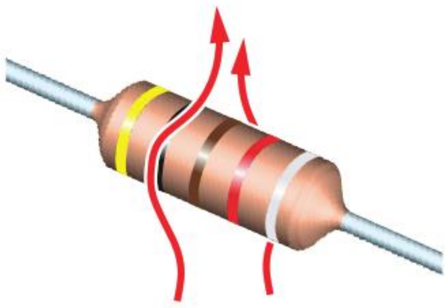




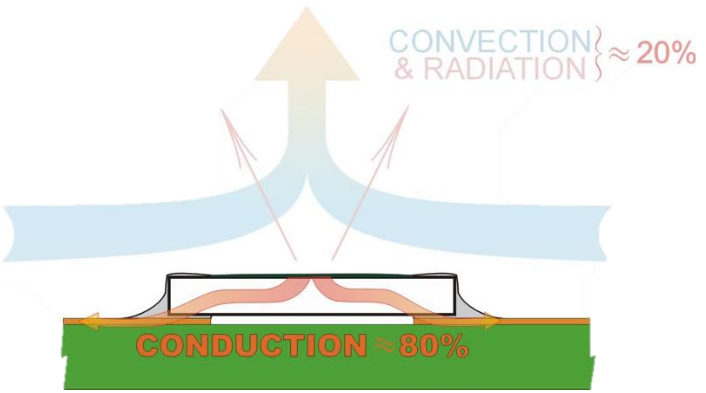
**<u>CTE Values</u>**

1. FR4 pcb 15 ppm/°C
2. Ceramic 5 ppm/°C (high mismatch)
3. WSL 13 ppm/°C (low mismatch)

# Why 2 separate Mil specs? (Heat Transfer Modes)



Ambient Power Rating

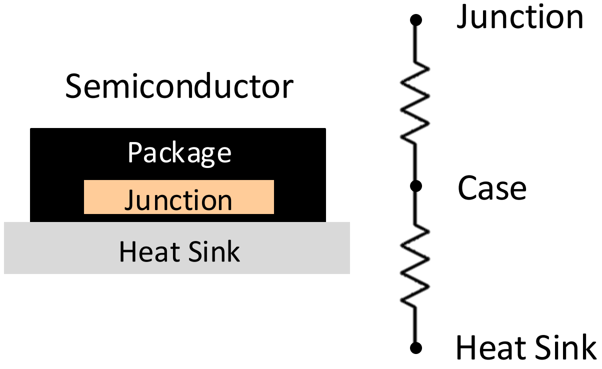


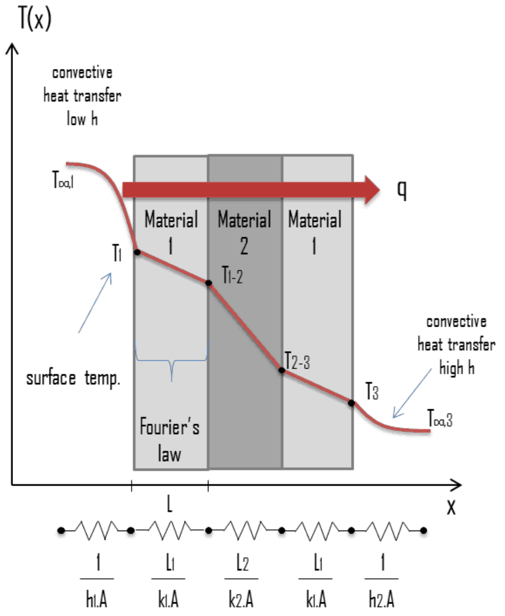

Surface Mount Devices

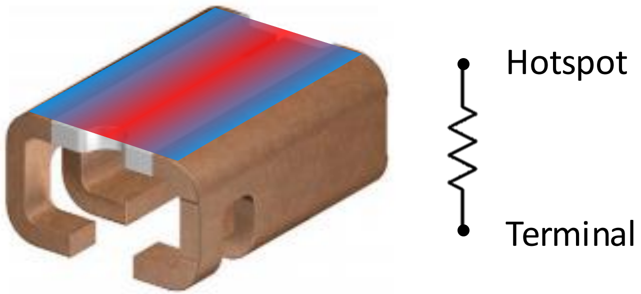
- **Ambient Power Rating** developed for axial leaded devices that generally had fine wire leads that were weak thermal paths to the PCB. (component has **high** thermal resistance)
- **Terminal temperature derating** applies to SMD devices with very short heat transfer paths that support efficient heat transfer to achieve higher powers by depending on the thermal properties of the PCB. (component has **low** comparable thermal resistance)

# Thermal Resistance

- Analogous to semiconductor devices where power ratings are based on their capacity for heat transfer from the junction to the PCB and surroundings based on thermal resistance.
- Thermal resistance of a resistor is a measure of the ability for heat energy to move through the resistor from where it is created (resistance element) to where it is dissipated (terminal).



# Thermal Resistance

- Resistor Internal Thermal Resistance ($R_{thi}$):

  (Hotspot – Terminal temp) / Applied Power

  (180.7 °C – 149.8 °C) / 12 W

  $R_{th}$ = 2.6 °C/W

- Thermal resistance of the component with the PCB determines the full power capability of the part.
- Thermal resistance is the slope of the derating power line

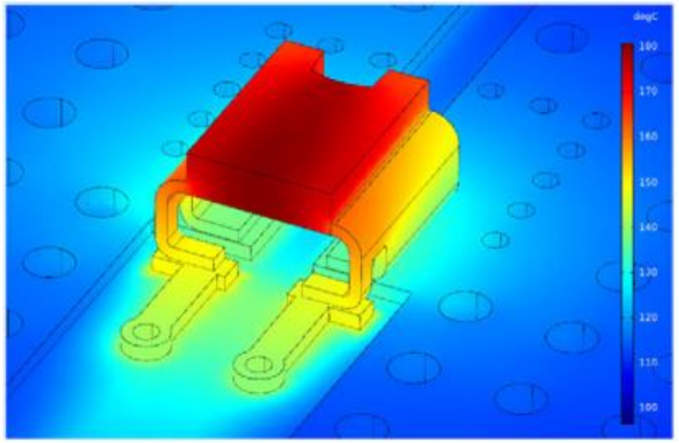
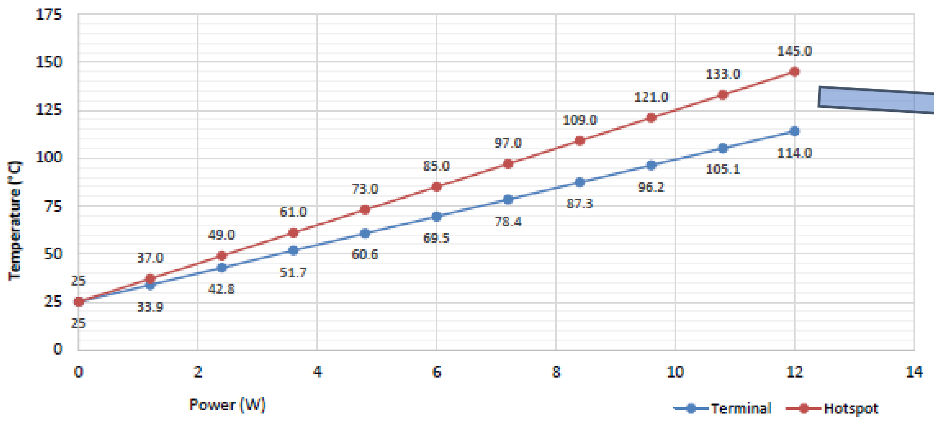
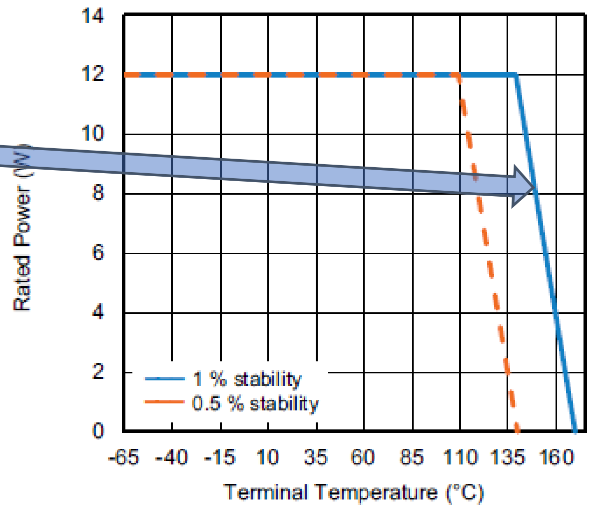


Fig. 2a - **WSLP2726L2000xyy, 200 μΩ**
Terminal = 149.8 °C, Hotspot = 180.7 °C, Power = 12 W, $R_{th}$ = 2.6 °C/W

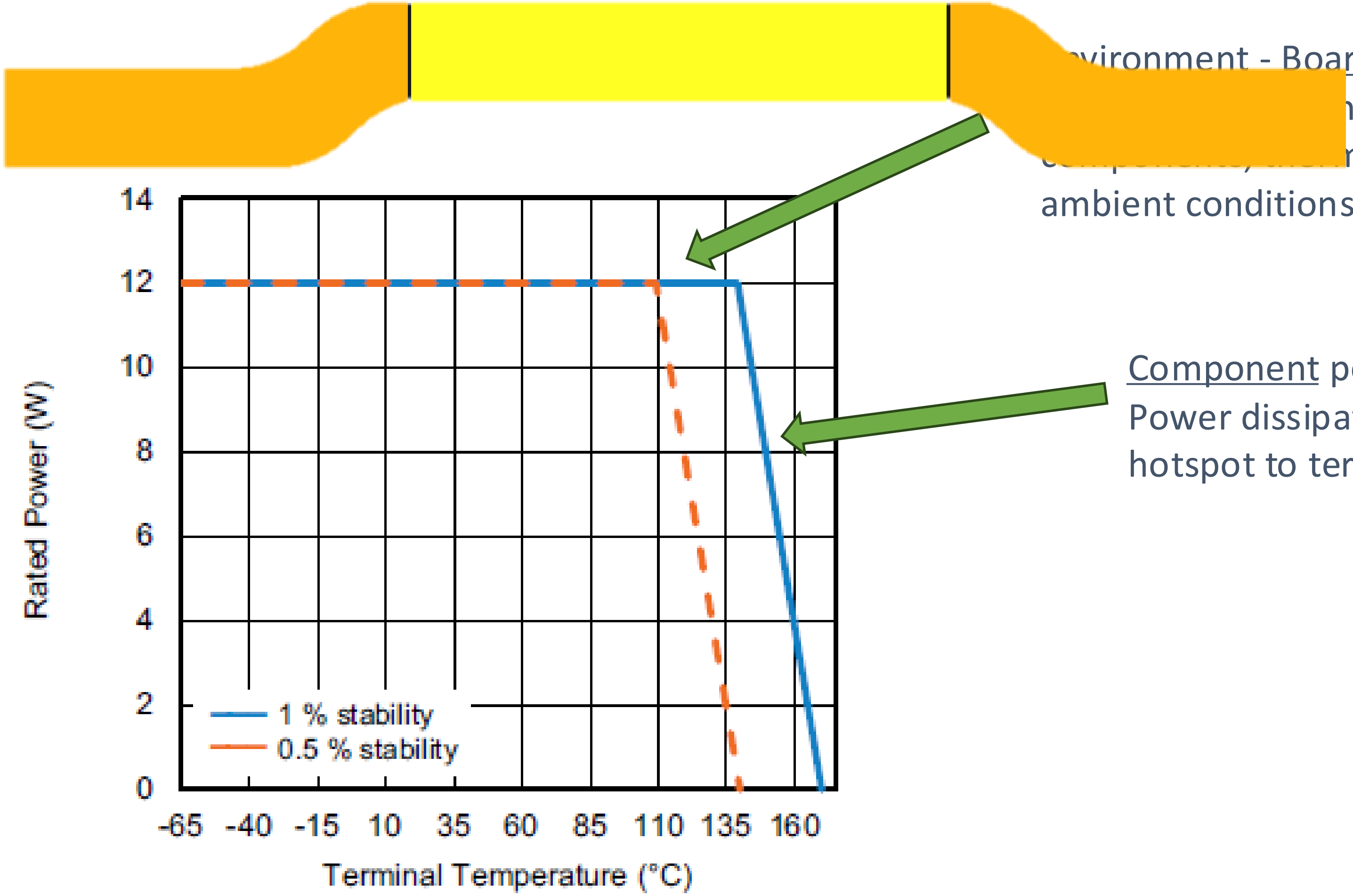



Power vs Temperature



# Thermal Resistance

- Another Perspective




...vironment - Board performance
...nboring
...nal capacity,
ambient conditions

Component performance
Power dissipation from
hotspot to terminal

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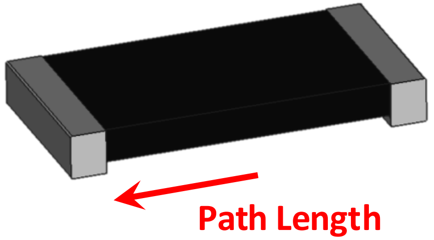
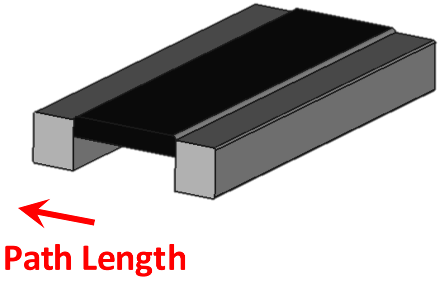
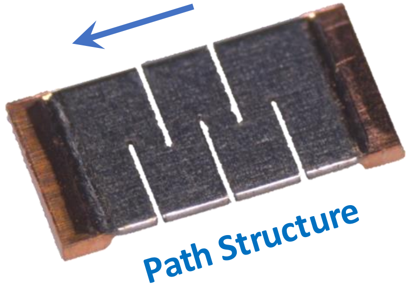
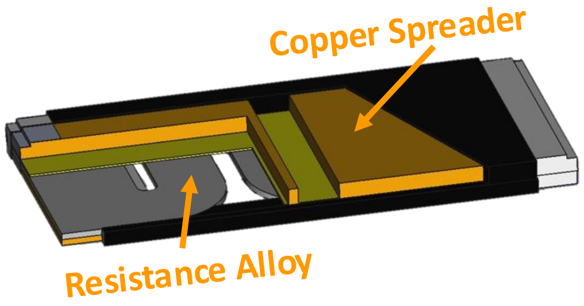
# Thermal Resistance vs Construction

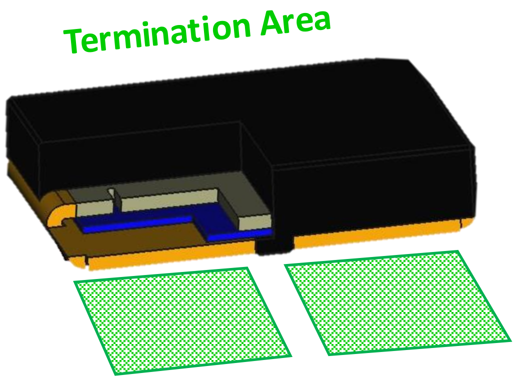
- Construction matters:
  - Path length
  - Path Structure
    - laser trim pattern
    - Plate thickness
  - Termination area
  - Materials
    - Copper Spreader
    - High temperature resistance alloys
    - Substrates



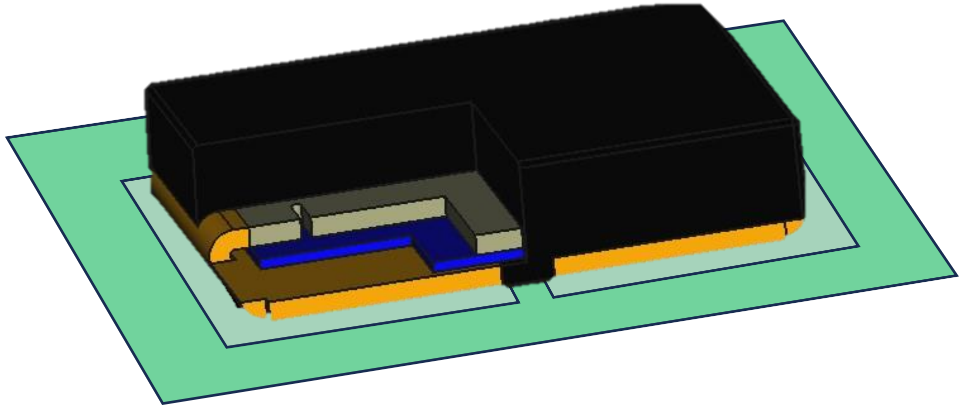



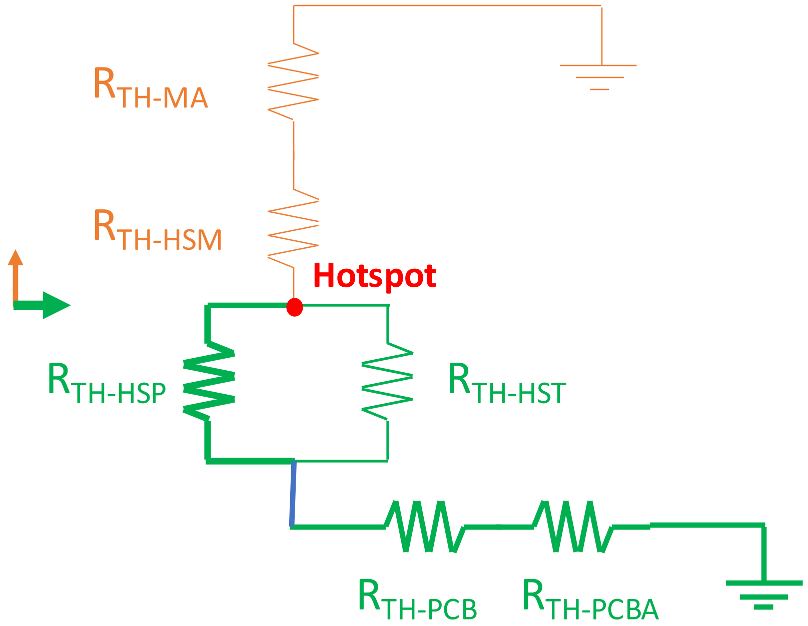



# Thermal Resistance

- **Bold** line indicates most efficient path.
- Thermal conductivity of PCB is important to support power capability within temperature limits.
  - Copper weight
  - Layer count
  - Thermal vias
- Power dissipating neighbors contributing to PCB temperature that affects resistor terminal temperature.

**$R_{TH-MA}$** – Rth Molding to Air
**$R_{TH-HSM}$** – Rth Hotspot to Molding surface
**Hotspot** – Highest temp of resistance element
**$R_{TH-HSP}$** – Rth Hotspot thru Polymer
$R_{TH-HST}$ – Rth Hotspot thru Terminal
$R_{TH-PCB}$ – Rth thru PCB
$R_{TH-PCBA}$ – Rth thru PCB to Air





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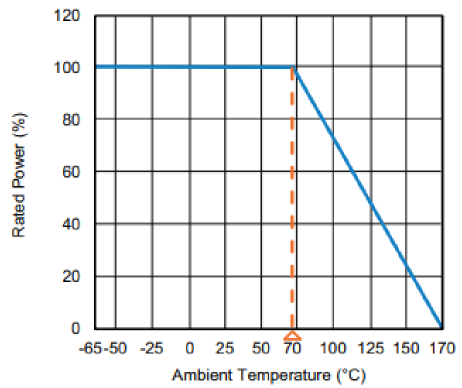
# Mil Spec for Metal Strip Current Sense

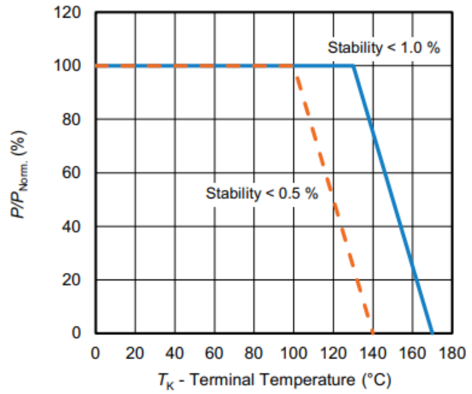
- Commercial, Military, Space level
- MIL-PRF-32773 : *Ambient* Derating




## Main Features

- Higher thermal resistances supports lower temperature terminal minimizes solder joint aging.
- Laser trimmed for flexible resistance values

- MIL-PRF-32783 : *Terminal Temperature* Derating




## Main Features

- Lower thermal resistances supports supports high power at high altitude or vacuum. (limited or no convection)
- High Current capability at ultra low resistance values, down to 100 µΩ

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1. Introduction
2. Specification Hierarchy
3. Construction & Thermal Resistance
4. **Qualification data**

# AECQ200 Qualification Data

Production Part Approval

AEC-CDF- Passive Component Qualification

**Vishay Test Report #E2009001, 139720, 143974, 143975, 146051, E20310005, E20090016 & Criteria Report 36035, 36037, 36041, 144703**

| **SUPPLIER - Vishay-Juarez** | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **NAME OF LABORATORY - Vishay Dale Electronics Test Lab** | **PART NAME -WSLP2726/4026 .0002 Ohm Surface Mount Wirewound Resistor** | | | | | | | | | | | | |
| **DESCRIPTION** | **AEC TEST #** | **TEST CONDITIONS** | **LIMIT** | **QTY. TESTED** | **HOURS/ CYCLES** | **RANGE** | | | **MEAN** | **STD. DEV.** | **CPK** | **PASS** | |
| High Temperature Exposure | 3 | MIL-STD-202, Method 108, 2000 Hrs @ T=170°C @ 0% power, Measurements at 24± 2 hrs | ± (1.0%) | 77 | 2000 | -0.2243 | TO | -0.0733 | -0.1461 | 0.0355 | 8.027 | PASS | |
| Temperature Cycling | 4 | MIL-STD-202 Method 107 Condition F, -55°C to 150°C, Dwell time = 15min, 2000 Cycles. | ± (0.5%) | 77 | 2000 | -0.2189 | TO | -0.0812 | -0.1512 | 0.0334 | 3.477 | PASS | |
| Moisture Resistance | 6 | MIL-STD-202, Method 106, t=24 hours/cycle. Note: Steps 7a & 7b not required, 0% power, No Polo, 65°C, Measurement at 24± 2 Hrs after test. | ± (0.5%) | 77 | | 0.0050 | TO | 0.0200 | 0.0125 | 0.0039 | 41.667 | PASS | |
| Biased Humidity | 7 | MIL-STD-202, Method 103, 2000 hrs 85°C/85%RH. Note: Specified conditions: 10% of rated power. Measurement at 24± 2 hrs | ± (0.5%) | 77 | 1000 | -0.0090 | TO | 0.0570 | 0.0140 | 0.0109 | 14.862 | PASS | |
| Operational Life 70°C | 8A | MIL-STD-202 Method 108 (Ambient 70°C) | ± (1.0%) | 24 | 1000 | -0.2930 | TO | 0.1860 | 0.0330 | 0.1130 | 2.853 | PASS | |
| Operational Life 125°C | 8 | MIL-STD-202 Method 108 (Ambient 125°C) | ± (1.0%) | 77 | 2000 | -0.9140 | TO | -0.0890 | -0.3921 | 0.1819 | 1.114 | PASS | |

# Qualification Summary

## Limits, Range, Standard Deviation

| DESCRIPTION | AEC TEST # | TEST CONDITIONS | LIMIT | QTY. TESTED | HOURS/ CYCLES | RANGE | | | MEAN | STD. DEV. | CPK |
|---|---|---|---|---|---|---|---|---|---|---|---|
| High Temperature Exposure | 3 | MIL-STD-202, Method 108, 2000 Hrs @ T=170°C @ 0% power, Measurements at 24± 2 hrs | ± (1.0%) | 77 | 2000 | -0.2243 | TO | -0.0733 | -0.1461 | 0.0355 | 8.027 |
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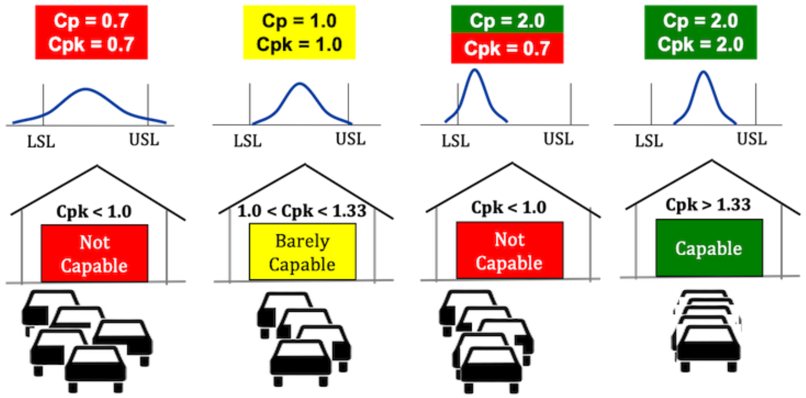



The driver is unsteady. The car often scrapes the walls. You will produce defect parts unless process width is reduced and process is centered.

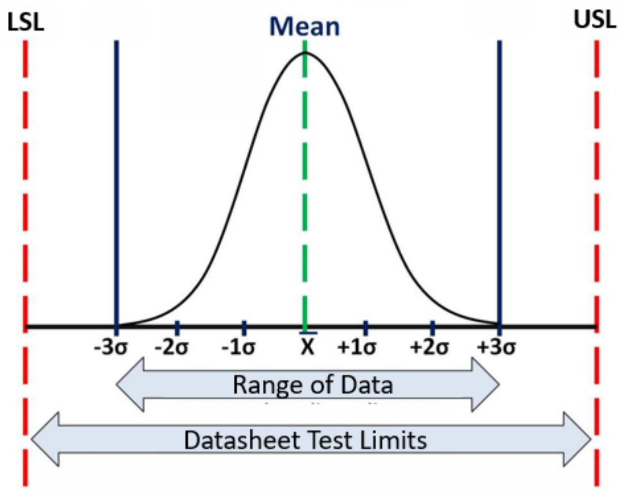
The driver is still unsteady but better than before. He often comes too close to the walls. You are likely to have a defect unless the process width is reduced.

The driver is unable to center the car. But he's consistent – always too close to one side. You are likely to have a defect, unless the process is re-centered.

The driver always parks successfully without scraping the sides. The process is centered, and with a narrow distribution. You are unlikely to have defects even if the process shifts slightly to either side.

$$C_p = \frac{USL - LSL}{6 \times std.Dev}$$

$$C_{pk} = \min\left(\frac{USL - mean}{3 \times std.Dev}, \frac{mean - LSL}{3 \times std.Dev}\right)$$

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# Failures in Time (FIT rate)

## based on units Shipped vs Field returns

### FIT rate as calculated by Observed Failure Rate

The observed failure rate is estimated from field failures reported by our customers.
FITobserved figures can be derived from this database by applying the following assumptions:
- all resistors failed in an application are reported
- the confidence level of the estimation can be stated at 90 % (resulting in a Poisson parameter λ = 2.71)
- As a conservative estimate, the average number of operating hours for assessed components is 1000 h

FITobserved = (1+λ) / [(1/failure rate [ppb]) * average Component hours] * ((10^-9)/h)

| Observed Fit Rate | |
|---|---|
| Product | M32773 Ambient |
| Date | 2/4/2025 |
| Confidence level of 90% = λ | 2.71 |
| Field returns (minimum of 1) | 17 |
| Parts shipped | 8,814,476,814 |
| failure rate [ppb] = (Field Returns) / (Parts Shipped) | 1.929 |
| Average Component Hours | 1000 |
| FITobserved [ppb hr^-1] = | 0.0072 |

| | |
|---|---|
| MTBF [hrs] | 139,757,044,776 |

| | |
|---|---|
| Years | 10 |
| hours | 87600 |
| P(t) [probabilty of failure in 10 operation years] | 0.01% |

### FIT rate as calculated by Observed Failure Rate

The observed failure rate is estimated from field failures reported by our customers.
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FITobserved = (1+λ) / [(1/failure rate [ppb]) * average Component hours] * ((10^-9)/h)

| Observed Fit Rate | |
|---|---|
| Product | M32783 Terminal |
| Date | 2/4/2025 |
| Confidence level of 90% = λ | 2.71 |
| Field returns (minimum of 1) | 1 |
| Parts shipped | 358,658,324 |
| failure rate [ppb] = (Field Returns) / (Parts Shipped) | 2.788 |
| Average Component Hours | 1000 |
| FITobserved [ppb hr^-1] = | 0.0103 |

| | |
|---|---|
| MTBF [hrs] | 96,673,402,695 |

| | |
|---|---|
| Years | 10 |
| hours | 87600 |
| P(t) [probabilty of failure in 10 operation years] | 0.01% |

# Power Metal Strip® - Technical Reference Links

For more information related to the content of this presentation.

- Current Sense Product Overview Video
  https://www.youtube.com/playlist?list=PLLgCVRjr9_hRlre6FUAnKoOlI1un6LrM4
- Current Measurement
  https://www.vishay.com/docs/30304/currentmeasurement.pdf
- Terminal Derating
  https://www.vishay.com/docs/30380/terminalderating.pdf
- Temperature Coefficient of Resistance
  https://www.vishay.com/docs/30405/whitepapertcr.pdf
- Surface Mount Product Overview
  https://www.vishay.com/docs/49581/_power_metal_strip_product_overview_vmn_pl0407_1703.pdf
- Power Metal Strip® Current Sensing
  https://www.vishay.com/docs/49677/_pl0042-2003-powermetalstrip.pdf

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# MIL spec / Metal Strip Questions

- MIL-PRF 32773 Ambient temperature power derating
- MIL-PRF-32783 Terminal temperature derating
- Thermal Resistance
- Metal Strip Resistors
- AECQ200 Qualification data
- Additional Resources and technical Contact : ww2bresitors@Vishay.com

Questions…?

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