A Screening Method Using Pulsed-Power Combined with Infrared Imaging to Detect Pattern Defects in Bulk Metal Foil or Thin Film Resistors

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To be presented by Jay Brusse at the 3rd Space Passive Component Days (SPCD) Conference, Noordwijk, The Netherlands, October 9-12, 2018.
Acronyms & Abbreviations

AI-N  Aluminum Nitride
DPA  Destructive Physical Analysis
FA  Failure Analysis
InSb  Indium Antimonide
NASA  National Aeronautics and Space Administration
NEPP  NASA Electronic Parts & Packaging (NEPP) Program
NiCr  Nichrome
ppm  Parts Per Million
PWB  Printed Wiring Board
SEM  Scanning Electron Microscope
SMT  Surface Mount Technology
STOL  Short Time Over Load
TCR  Temperature Coefficient of Resistance
Foil Resistors Have Many Favorable Attributes

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Package Configurations</td>
<td>Surface Mount Technology (SMT); Through Hole</td>
</tr>
<tr>
<td>Resistance Values</td>
<td>Custom Values; 5Ω to 125kΩ (standard SMT)</td>
</tr>
<tr>
<td>Resistance Tolerance</td>
<td>± 0.01% (± 100 ppm)</td>
</tr>
</tbody>
</table>
| Temperature Coefficient of Resistance (TCR) | < ± 1 ppm/°C  
from -55°C to +125°C                                      |
| Load Life Stability           | ± 0.03% (± 300ppm) after 2k hour life test @ 1x rated power @ 70°C    |
Basic Construction of a SMT Foil Resistor

- Resistor element is made from foil sheets of NiCr-based alloys
- Resistor gridline patterns are created by photolithography and electrochemical etching
- Resistor foil is adhesively-bonded to an alumina substrate
- Precise resistance values achieved by laser or mechanical cutting of combinations of “trim tabs” connected in parallel with resistor pattern segments of different values
- Various resistor termination options exist
- Polymeric and epoxy coatings protect the resistor element
Foil Resistor Gridline Patterns

\[ R = \frac{\rho \cdot L}{A} \]

- \( R \) = Resistance (Ω)
- \( \rho \) = Resistivity of Foil
- \( L \) = Length of Resistor Element
- \( A \) = Cross Sectional Area of Gridline (i.e., thickness * width)

Low Resistance Values
1. Wider Foil Gridlines (e.g., \(~ > 10 \, \mu m\))
2. Thicker Foil (e.g., \(~ 5 \, \mu m\))
3. Shorter Path Lengths

High Resistance Values
1. Narrower Foil Gridlines (e.g., \(~ < 10 \, \mu m\))
2. Thinner Foil (e.g., \(~ 2 \, \mu m\))
3. Longer Path Lengths

Size 1206
- 49.9 Ω

Size 1206
- 20,000 Ω
Foil Resistors Are Sometimes Produced with
Localized Constriction Defects in the Gridline Pattern

Notches

Bridges

Embedded Particles

1. Constriction defects contribute directly to the final resistance value (e.g., bridges provide parallel resistor pathway).
2. Constriction defects are at risk of breaking due to thermomechanical fatigue fracture especially during power cycling
   1. Constrictions carry higher current density and develop localized ‘hot spots’ due to Joule heating
   2. Hot spots produce locally greater expansion of the NiCr foil
3. If a constriction defect fractures, then a positive resistance shift, including open circuit, will occur.
Standard Screening Tests are **Not 100% Effective at Detecting Constriction Defects**

<table>
<thead>
<tr>
<th>Test Method</th>
<th>Test Conditions</th>
<th>Rejection Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-Encapsulation Optical Microscopy</td>
<td>30x to 60x Magnification</td>
<td>Notches &gt; 75% nominal line width Bridges &lt; 10% smallest line width</td>
</tr>
<tr>
<td>Short Time Overload (STOL)</td>
<td>6.25x Rated Power For 5 Seconds</td>
<td>$\Delta R &gt; 0.02%$</td>
</tr>
<tr>
<td>Power Conditioning</td>
<td>1x to 1.5x Rated Power @ Max Operating Temp For 100 Hours</td>
<td>$\Delta R &gt; 0.03%$</td>
</tr>
</tbody>
</table>

Despite Performing These Screening Tests, Resistors with Significant Constriction Defects are Still Occasionally Received

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Hot Spots! A New Screening Method to Detect Localized Constrictions

**Pulsed-Power Combined with High Resolution Infrared Imaging**

1. Apply pulsed-power to resistor
   - 6.25x rated power \(\leftarrow\) *same as STOL*
   - 50 ms, 10% duty cycle
   - 1 or more pulses
   - These conditions confine heating to the localized constrictions

2. Examine resistor with *high resolution infrared camera* (e.g. FLIR SC8300)

3. Reject resistors with “hot spots”
   - Hot spots are indicative of constriction defects (e.g., notches, bridges, embedded particles)

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Demonstration of New Screening Method
Using DPA Sample with Bridge and Notch Defects

Pulsed-Power 6.25x Rated Power
50ms On / 150ms Off

Bridge Defect
Notch Defect

SEM Image
Infrared Image
SEM Image

Video Demo

Size 1206, 2 kΩ, ±0.01%
These Protective Coatings are “See Through” for Infrared Wavelengths of 3µm to 5µm Even With No Power Applied to the Resistor

Enables Post-Procurement Screening of SMT Foil Resistors
Evaluation of New Screening Method

Obtain 280 SMT Foil Resistors *Types A, B & C

Characterize with Pulsed-Power Infrared

10k Hour Life Test
1x Rated Power @ 70°C
1.5hrs ON / 0.5hrs OFF

Repeat Pulsed-Power Infrared Characterization To Identify Changes

Failure Analysis

<table>
<thead>
<tr>
<th>Resistor Size (EIA Footprint)</th>
<th>Resistance (Ω) &amp; Tolerance</th>
<th>Power Rating (mW)</th>
<th>Qty</th>
<th>Foil Pattern Geometry</th>
<th>* Type</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Foil Thickness (µm)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Foil Gridline Width (µm)</td>
<td></td>
</tr>
<tr>
<td>0805</td>
<td>5.1k ± 0.05%</td>
<td>100</td>
<td>40</td>
<td>2.3</td>
<td>C</td>
</tr>
<tr>
<td>1206</td>
<td>20k ± 0.05%</td>
<td>150</td>
<td>40</td>
<td>2.5</td>
<td>A</td>
</tr>
<tr>
<td>1206</td>
<td>20k ± 0.05%</td>
<td>150</td>
<td>40</td>
<td>2.5</td>
<td>B</td>
</tr>
<tr>
<td>1206</td>
<td>23.5k ± 0.05%</td>
<td>150</td>
<td>40</td>
<td>2.3</td>
<td>C</td>
</tr>
<tr>
<td>1506</td>
<td>36.45k ± 0.05%</td>
<td>200</td>
<td>40</td>
<td>2.8</td>
<td>A</td>
</tr>
<tr>
<td>1506</td>
<td>36.45k ± 0.05%</td>
<td>200</td>
<td>40</td>
<td>2.8</td>
<td>B</td>
</tr>
<tr>
<td>2010</td>
<td>50k ± 0.01%</td>
<td>300</td>
<td>40</td>
<td>2.5</td>
<td>B</td>
</tr>
</tbody>
</table>

*Type

- **A**: Contains Some “Embedded Particles”
  - Pre-Encapsulation Screen: 100% Visual Inspection
  - Powered Screening: 1x Short Time Overload (STOL)

- **B**: “Particle-Free”
  - Pre-Encapsulation Screen: 100% Visual Inspection
  - Powered Screening: 1x Short Time Overload (STOL)

- **C**: “Particle-Free”
  - Pre-Encapsulation Screen: 100% Visual Inspection
  - Powered Screening: 2x Short Time Overload (STOL)

To be presented by Jay Brusse at the 3rd Space Passive Component Days (SPCD) Conference, Noordwijk, The Netherlands, October 9-12, 2018.
Results: Pre-Life Test Pulsed-Power Infrared Screening
~10% to 25% of Resistors Per Lot Tested Had Constriction Defects

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Results: 3 Life Test Failures (280 Resistors Tested)

Abrupt Positive Resistance Shift Failure Modes

*S/N 12 exhibits 2 distinct positive shifts during life test*
Failure Analysis: 0805, 5.1kΩ, S/N 12, Type “C”

Conclusion:
Two bridge defects fractured during life test causing total ΔR ~11000 ppm

Pulsed-Power Infrared Screen detected both bridge defects as ‘hot spots’ BEFORE Life Test

Pulsed-Power Infrared Screen

BEFORE Life
4 Hot Spots

AFTER 250 & 2k hrs Life
2 Hot Spots Disrupted

Fractured Bridge #1

Fractured Bridge #2

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Failure Analysis:  
1206, 20kΩ, S/N 28, Type “A”

Conclusion:  
*One bridge defect fractured* during life test causing $\Delta R \sim 19400$ ppm

**Pulsed-Power Infrared Screen** detected this bridge defect as a ‘hot spot’ BEFORE Life Test

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To be presented by Jay Brusse at the 3rd Space Passive Component Days (SPCD) Conference, Noordwijk, The Netherlands, October 9-12, 2018.
Conclusion:
*One bridge defect fractured during life test causing $\Delta R \sim 4200$ ppm*

**Pulsed-Power Infrared Screen** detected this bridge defect as a ‘hot spot’ **BEFORE Life Test**

**AFTER 4k hrs Life**
**Hot Spot Disrupted**
Conclusions

1. Resistor failures (i.e., positive $\Delta R$ and open circuit) sometimes occur due to thermomechanically-induced fatigue fracture of localized constriction defects in the resistor pattern (e.g., notches, bridges, embedded particles).

2. Standard screening techniques (e.g., pre-encapsulation visual, STOL, DPA) Do NOT detect all resistors with significant constriction defects in the resistor pattern.

3. New Pulsed-Power Infrared Screening technique has been developed
   - Detects localized constriction defects as “hot spots” using high resolution infrared thermography
   - Proven effective via 10k hour life test with failure analyses correlating pre-existing constriction defects to ‘hot spots’ and subsequent fractured constrictions after life test
   - Suitable for use as an ‘In-Process Manufacturer Screening Inspection’ prior to encapsulation And as a non-destructive ‘Post-Procurement’ screen for SMT foil resistors

New Screening Technique Can Take a Super Stable Resistor Technology and Make it Super Reliable Too

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## Acknowledgements

**Work Performed in Support of the NASA Electronic Parts & Packaging (NEPP) Program**

<table>
<thead>
<tr>
<th>Mike Sampson</th>
<th>Dr. Henning Leidecker</th>
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<tbody>
<tr>
<td>Manager, NASA Electronic Parts &amp; Packaging Program</td>
<td>Chief Parts Engineer, NASA Goddard Space Flight Center</td>
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<tr>
<th>Jack Shue</th>
<th>Alexandros Bontzos, Chris Greenwell, Tim Mondy, Nilesh Shah, Ron Weachock</th>
</tr>
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<tr>
<td>NASA Goddard Space Flight Center Office of Safety and Mission Assurance</td>
<td>NASA Goddard Space Flight Center Parts Analysis Laboratory</td>
</tr>
</tbody>
</table>

**Foil Resistor Samples and Life Testing Services Provided by**

Vishay Precision Group (VPG)
Backup Slides
High Resolution Infrared Camera with 4x lens option

**FLIR SC8200, SC8300 Series**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detector</td>
<td>InSb</td>
</tr>
<tr>
<td>Spectral Range</td>
<td>3 µm to 5 µm</td>
</tr>
<tr>
<td>Measurement Temperature Range</td>
<td>-20°C to +350°C</td>
</tr>
<tr>
<td>Field of View</td>
<td>~4.6mm x 5.6mm (&gt; 1 million pixels)</td>
</tr>
<tr>
<td>Resolution</td>
<td>~ 5 µm per pixel</td>
</tr>
<tr>
<td>Focal Working Distance</td>
<td>~25mm</td>
</tr>
<tr>
<td>Frame Capture Rate</td>
<td>&gt;100 frames per second (fps)</td>
</tr>
</tbody>
</table>
Comparison of Two Different Infrared Cameras

*Inspecting the same resistor with 2 constriction defects while applying power pulses*

**FLIR SC660**

~25 µm per pixel

1 hot spot detected?

**FLIR SC8300HD + 4x Lens**

~5 µm per pixel
Basic Construction of a SMT Foil Resistor

Cross Section

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- Epoxy Coating (~10 - 20µm)
- Polymer Coating (~10µm)
- Resistor Foil (~2 - 5µm)
- Adhesive (~5µm)
- Alumina Substrate
SMT Thin Film Resistors Inspected Using New Pulsed-Power Infrared Screening Method
Applying 6.25x Rated Power for 100 ms pulses; 10% duty cycle

Infrared Inspection Performed Without Removing Resistor Protective Coatings
A Case for an Improved Screening Method:
Embedded Al-N Particle in Foil Resistor Size 1206, 30 kΩ

Fractured NiCr Gridline With Embedded Al-N Particle

Aluminum Nitride Particle
Traditional Resistor Screening Methods

Optical Microscopy

<table>
<thead>
<tr>
<th></th>
<th>Thin Film (MIL-PRF-55342)</th>
<th>Foil Resistors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test Conditions</td>
<td>30x to 60x optical microscopy prior to encapsulation</td>
<td></td>
</tr>
<tr>
<td>Sample Size</td>
<td>100% in-process screen</td>
<td>100% high reliability products only</td>
</tr>
<tr>
<td>Rejection Criteria</td>
<td>Voids &gt; 50% nominal line width</td>
<td>Voids &gt; 75% nominal line width</td>
</tr>
<tr>
<td></td>
<td>Bridges &lt; 50% smallest line width</td>
<td>Bridges &lt; 10% smallest line width</td>
</tr>
</tbody>
</table>

- **Void > 75% in Foil Resistor**
- **Bridge < 10% in Foil Resistor**

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Traditional Resistor Screening Methods

Short Time Overload (STOL)

<table>
<thead>
<tr>
<th>Test Conditions</th>
<th>Thin Film (MIL-PRF-55342)</th>
<th>Foil Resistors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample Size</td>
<td>20 pcs (space level only)</td>
<td>10 pcs (high reliability products)</td>
</tr>
<tr>
<td>Rejection Criteria</td>
<td>$\Delta R &gt; 0.1%$</td>
<td>$\Delta R &gt; 0.02%$</td>
</tr>
</tbody>
</table>

STOL may sometimes force failure of devices with the most severe pattern constrictions
Traditional Resistor Screening Methods

**Power Conditioning**

<table>
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<tr>
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<th>Thin Film (MIL-PRF-55342)</th>
<th>Foil Resistors</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Test Conditions</strong></td>
<td>1.5x rated power for 100 hours at 70°C</td>
<td></td>
</tr>
<tr>
<td><strong>Sample Size</strong></td>
<td>100% (space level only)</td>
<td>100% (high reliability products only)</td>
</tr>
<tr>
<td><strong>Rejection Criteria</strong></td>
<td>$\Delta R &gt; 0.2%$</td>
<td>$\Delta R &gt; 0.03%$</td>
</tr>
</tbody>
</table>

*Power Conditioning may sometimes force failure of devices with the most severe pattern constrictions*
Failure Analysis

0805, 5.1kΩ, S/N 12, Type “C”

Two Positive Resistance Shifts During Life Test

ΔR1 = +10440 ppm @ 250 hrs; ΔR2 = +815 ppm @ 2000 hrs

Conclusion:
This Resistor Exhibited Two Abrupt Positive ΔR Shifts During Life Test.
Both Shifts Were Caused by Thermomechanically-Induced Fatigue Fracture of Two Separate Foil Bridge Defects