SAND2016-6322C

July 6, 2016

Miniature High Voltage, High Temperature Component Package Development

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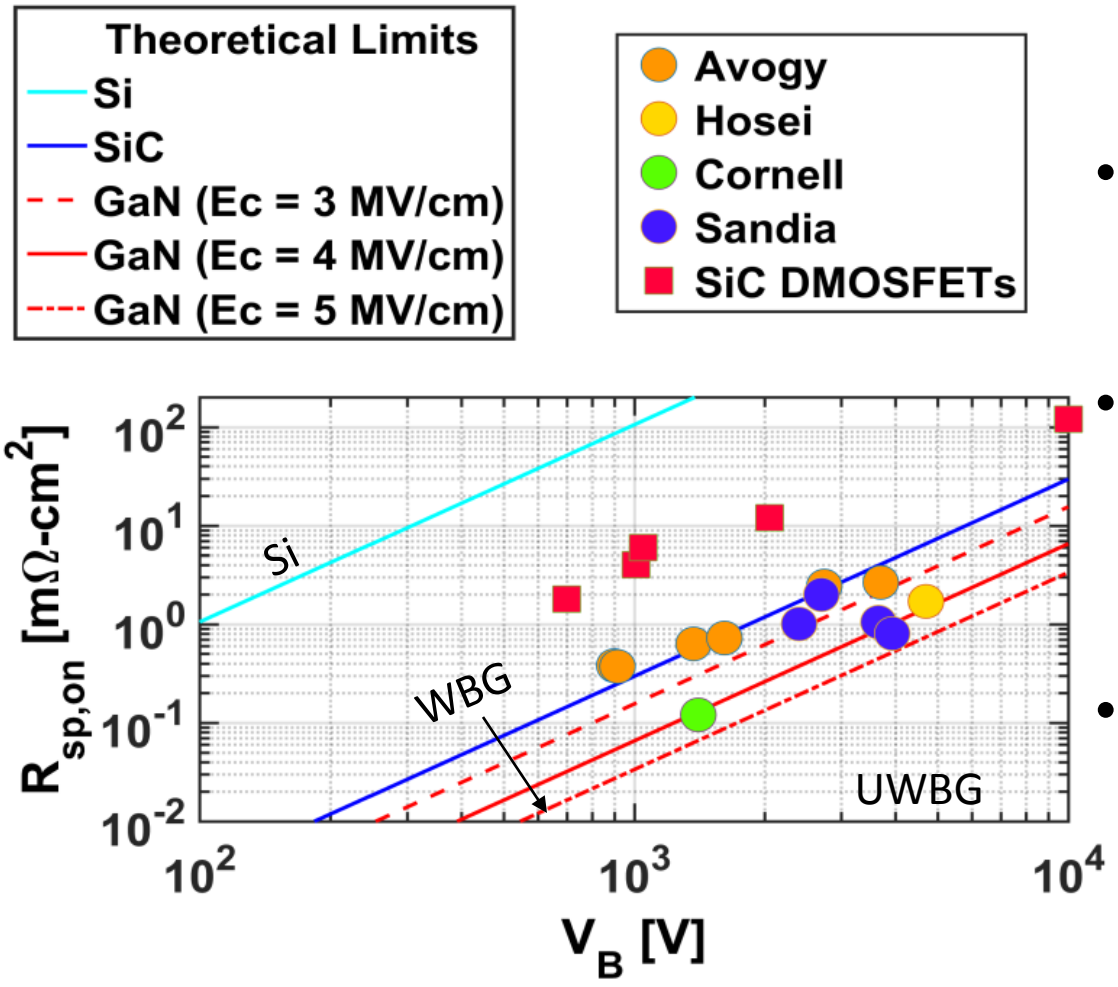
Outline

- **WBG and UWBG Semiconductors are the next generation of power electronic devices**
- **Testing Methodology is Focused on part and package performance**
- **3D Printed packages Allow for Rapid Turn Around**
  - **Design**
  - **Pin to Pin Impedance measurements**
- **Voltage Hold-off Testing is performed with custom equipment**
  - **20 kV IV tracer test bed**
  - **800 C temperature oven**
  - **Results**
- **Future Work**
- **Summary**

WBG = Wide Bandgap, UWBG = Ultra-wide Bandgap

Wide bandgap semiconductors are the next generation of power electronics



- WBG and UWBG devices have faster turn-on times.
- Higher switching frequencies allow passive element size reduction
- Higher Bandgaps enable higher temperature operation and less thermal management

WBG = Wide Bandgap, UWBG = Ultra-wide Bandgap

This testing methodology evaluates packaged part performance

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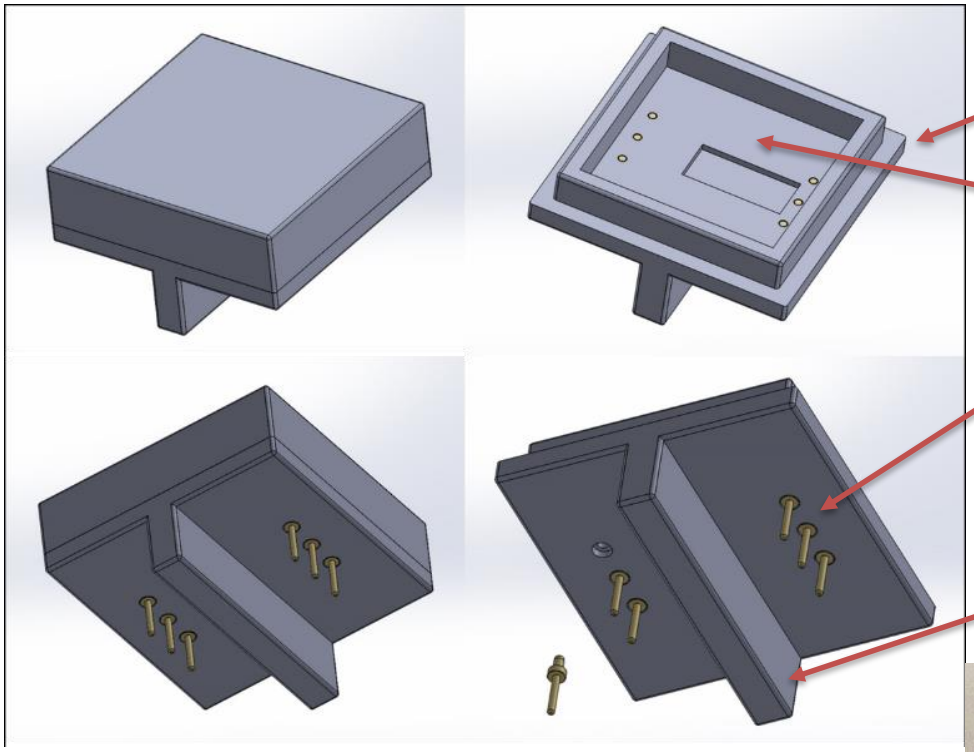
1. **Electrical properties (V_{on}, $r_{sp,on}$, etc.) of devices found with DC sweep of bare die components.**
2. **Pin to Pin electrical break down of empty packages found.**
3. **Parasitics are being evaluated through S-parameter measurements**
4. **Pin to Pin electrical break down of packaged parts confirmed.**
5. **Switching behavior of packaged components in the Buck Converter Tester.**
6. **High current/ high voltage packaged component testing in the Double Pulse Tester.**

This presentation will focus on steps 2 and 3

3D printed packages allow for rapid turn around

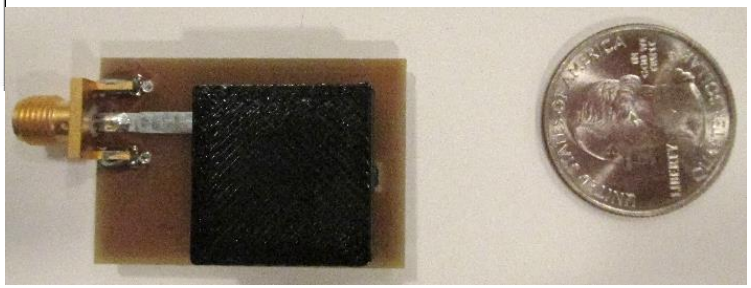


High Temperature Ultem

Potting Well

Parallel Pins connected to copper sheets for higher currents

Fin to increase path length



- **3D printed packages:**
  - **Capable of high breakdown voltages**
  - **Can be inexpensive as a process**
  - **Provides rapid turn around, new package design and manufacturing can be done in under a week**

Package impedance from pin to pin is stable up to 100 MHz

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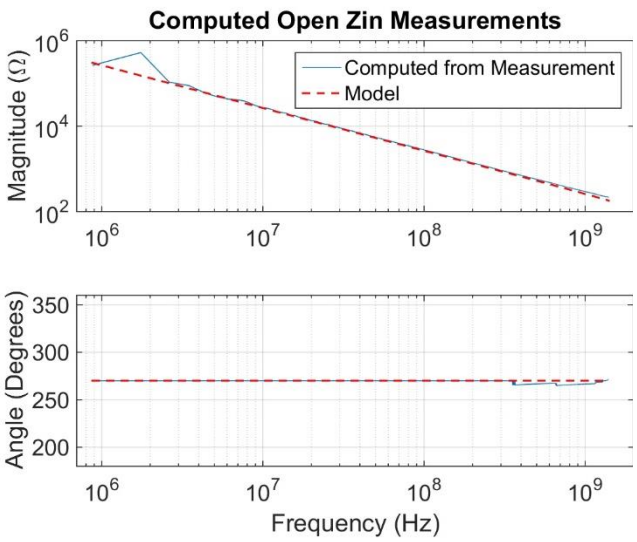
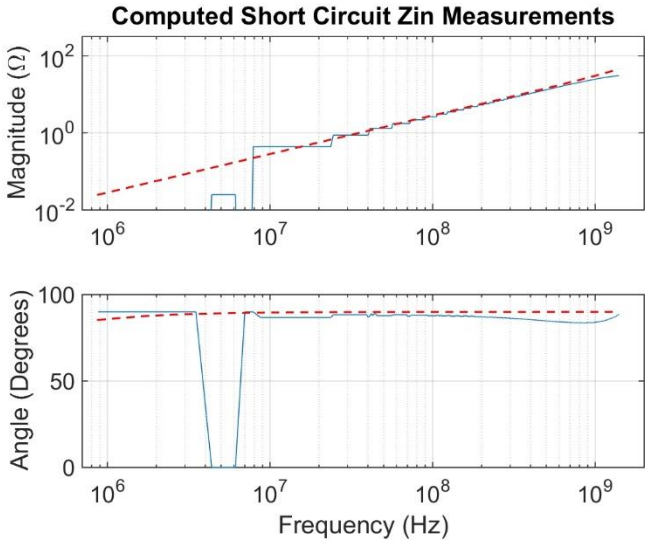
Package Impedance was Measured for three conditions, and results were used to generate a circuit model

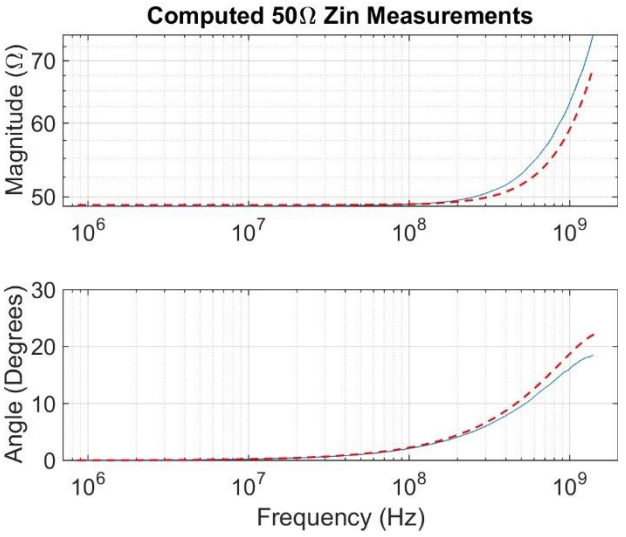
Package Open Circuit Impedance



Package Short Circuit Impedance

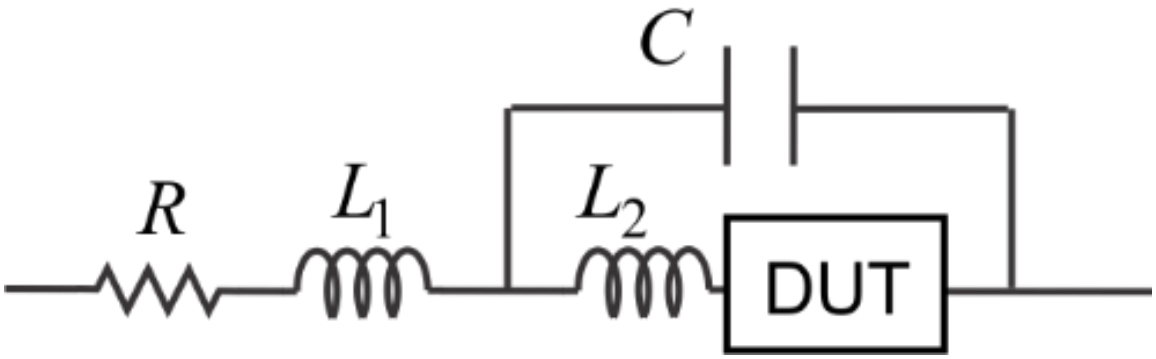


Package with 50 Ω Load Impedance



Impedance magnitude is low until above 100 MHz, which should be able to account for the necessary bandwidth for the 10 ns rise times associated with UWBG devices.

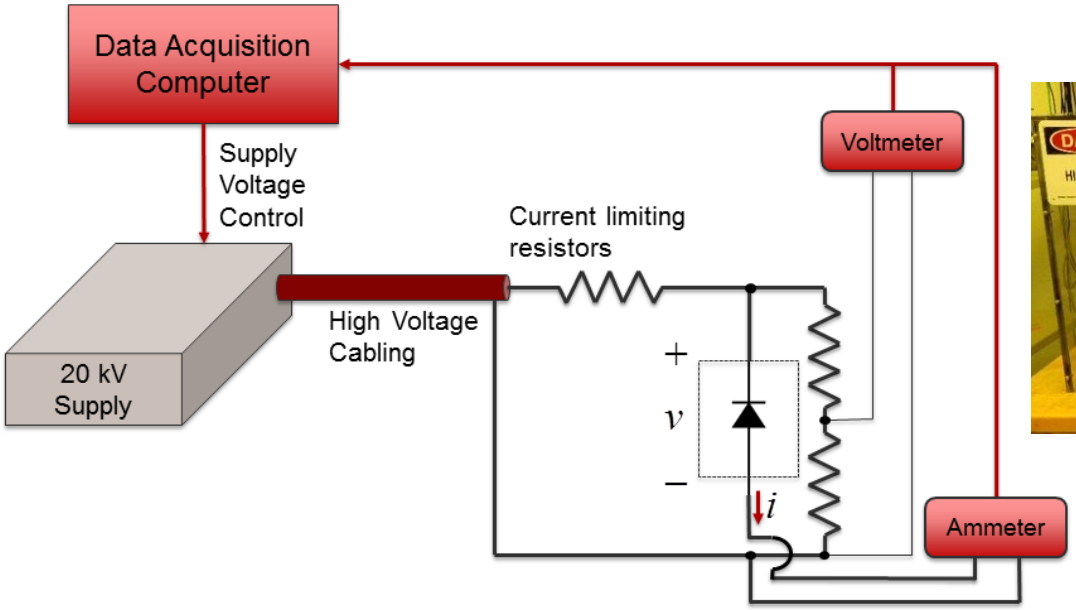
Equivalent circuit for pin to pin behavior of package obtained by fitting parameters

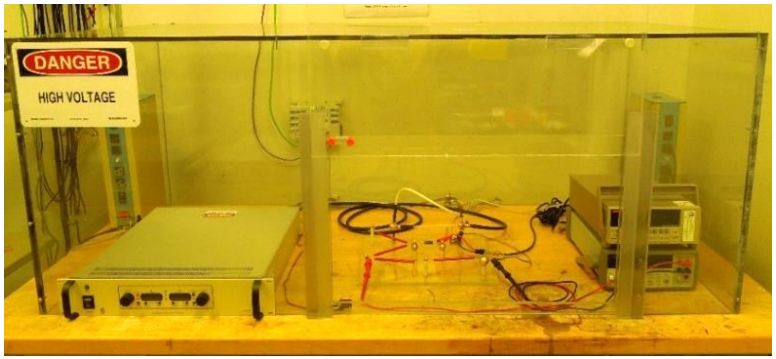


R = 0.001 Ω
L1 = 1.0 nH
L2 = 3.5 nH
C = 0.60 pF

Equivalent circuit formed by fitting impedance magnitude data to the equivalent circuit above.

Voltage hold-off of UWBG devices and packaging is being tested up to 20 kV





- Commercial IV curve tracers rarely exceed 10 kV
- 20 kV IV tracer constructed to test the breakdown behavior of high voltage devices and packages

Performance is being evaluated up to 200 °C

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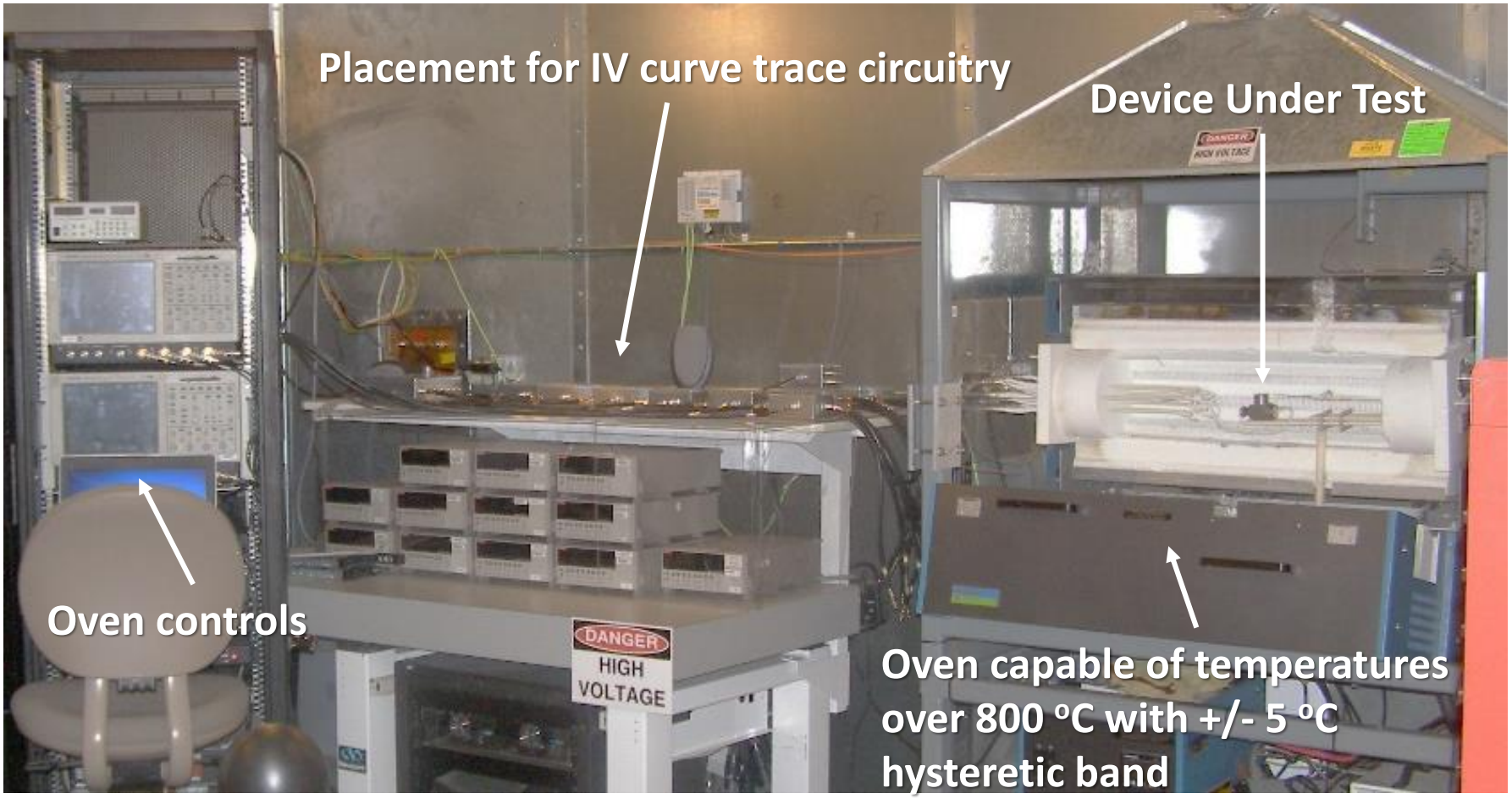
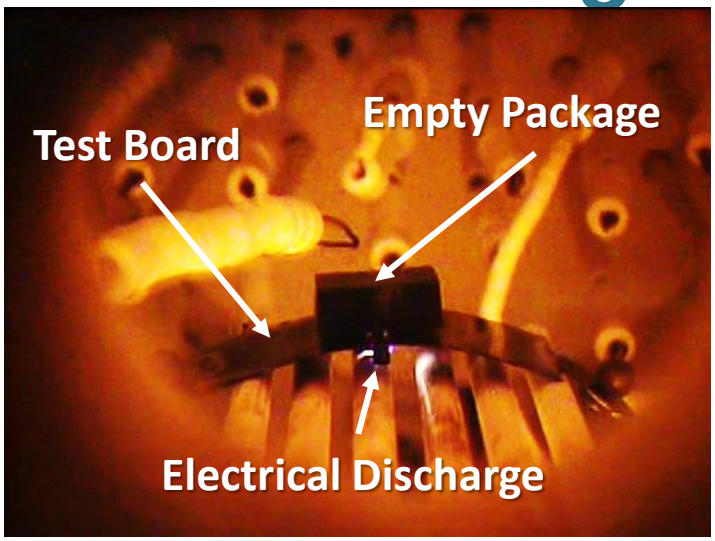
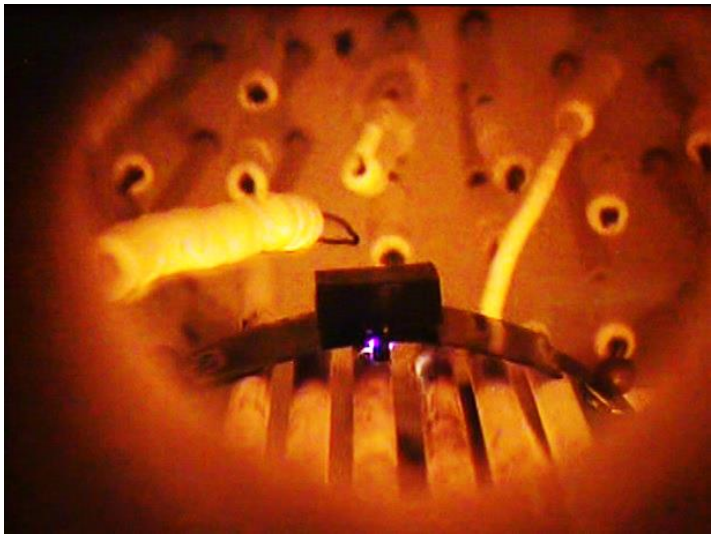


Pin to Pin Voltage Breakdown is Found through DC sweep

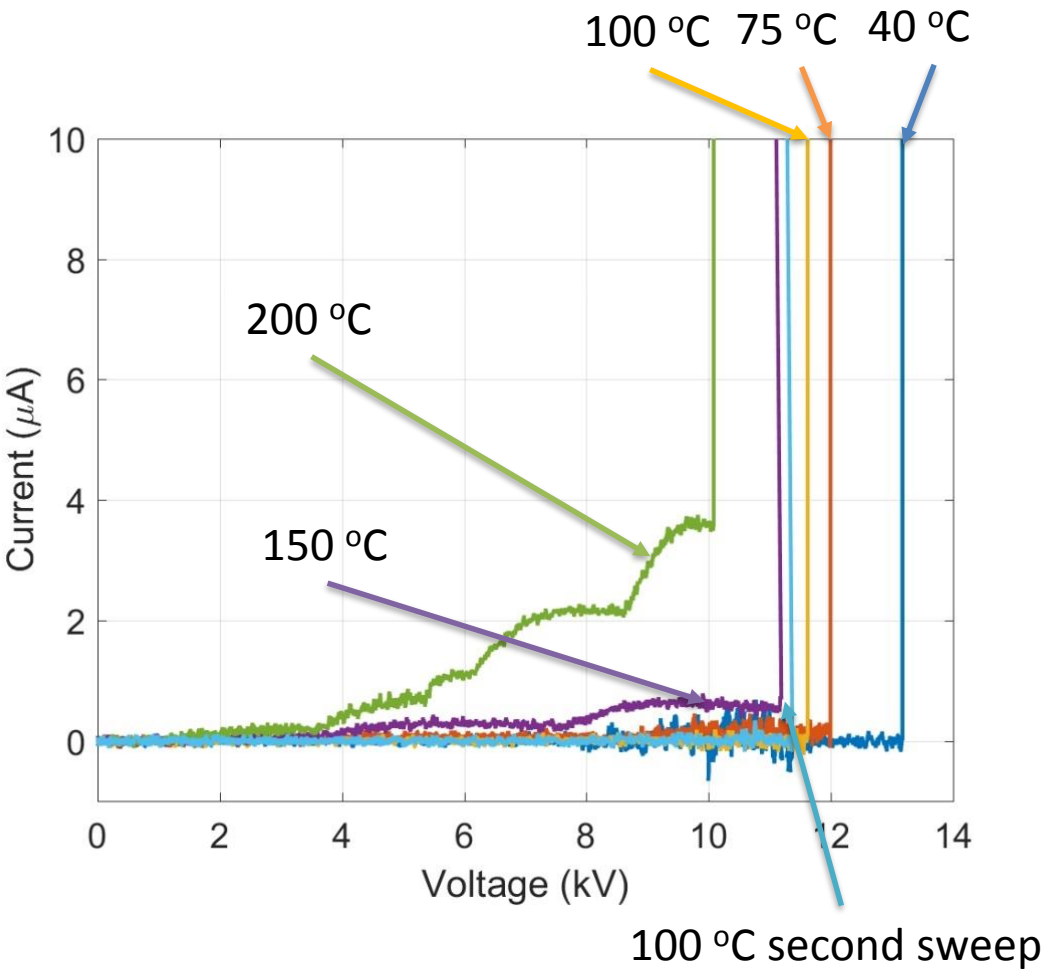




- Example of breakdown shown to left for part temperature of 200 ^{o}C.
- Breakdown occurred at approximately 10 kV.
- Breakdown occurs through air via surface tracking around the barrier.
- Since breakdown occurs through air it does not reflect the actual package breakdown, but does show the limitations of the geometry without under filling or additional potting.

DC Sweeps Show Decrease in Voltage Hold-off from Pin to Pin as Temperature Increases

- Fast average of 5 data points to filter oven noise.
- Breakdown voltage drops as a function of temperature.
- Max leakage current of 4 µA at 10 kV with an external temperature of 200 C.
  - 40 mW power dissipated
  - Leakage probably through the part since breakdown does not occur.



Current vs. Voltage as temperature increases

Future Work

- While packages have been examine in simulation, the actual behavior of the parts at frequency has not been tested.
- Package testing was mostly over short time periods, the effects of prolonged exposure to voltage and temperature has yet to be tested.
- Developing this package for future power electronics applications requires modification to allow for high current and high power operation.
- Additional packaging concerns include the effects of ultraviolet light and radiation
- Even higher temperature parts might be possible by 3D printing molds instead of actual parts

Summary

- **Packaging for next generation of WBG and UWBG power electronic devices is critical for leveraging full semiconductor performance**
- **Test methodologies to insure that parts and packaging perform to the required specifications are vital**
- **3D printing allows for rapid prototyping and testing of packaging and circuitry**
- **Device and packaging performance is being evaluated up to:**
  - **15 kV**
  - **200 C**
  - **1.4 GHz**
- **Pin to pin parasitics have limited impact up to 100 MHz**
- **Voltage hold-off is effected by temperature, but package design is capable of holding 8 kV even at high temperatures**

WBG = Wide Bandgap, UWBG = Ultra-Wide Bandgap

The contributions of the Sandia Ultra-Wide-Bandgap Grand Challenge team and the support of Sandia's LDRD program are gratefully acknowledged

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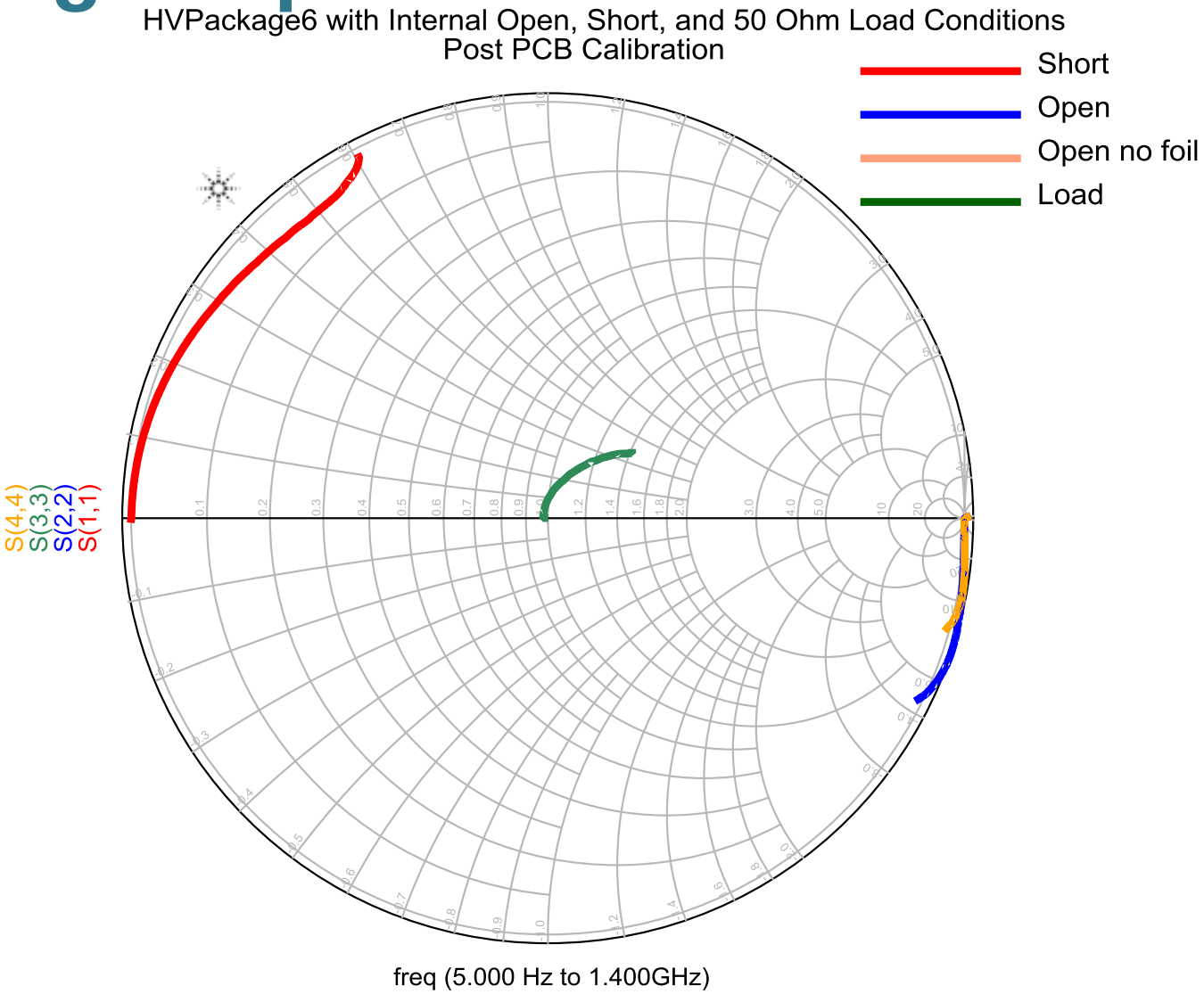
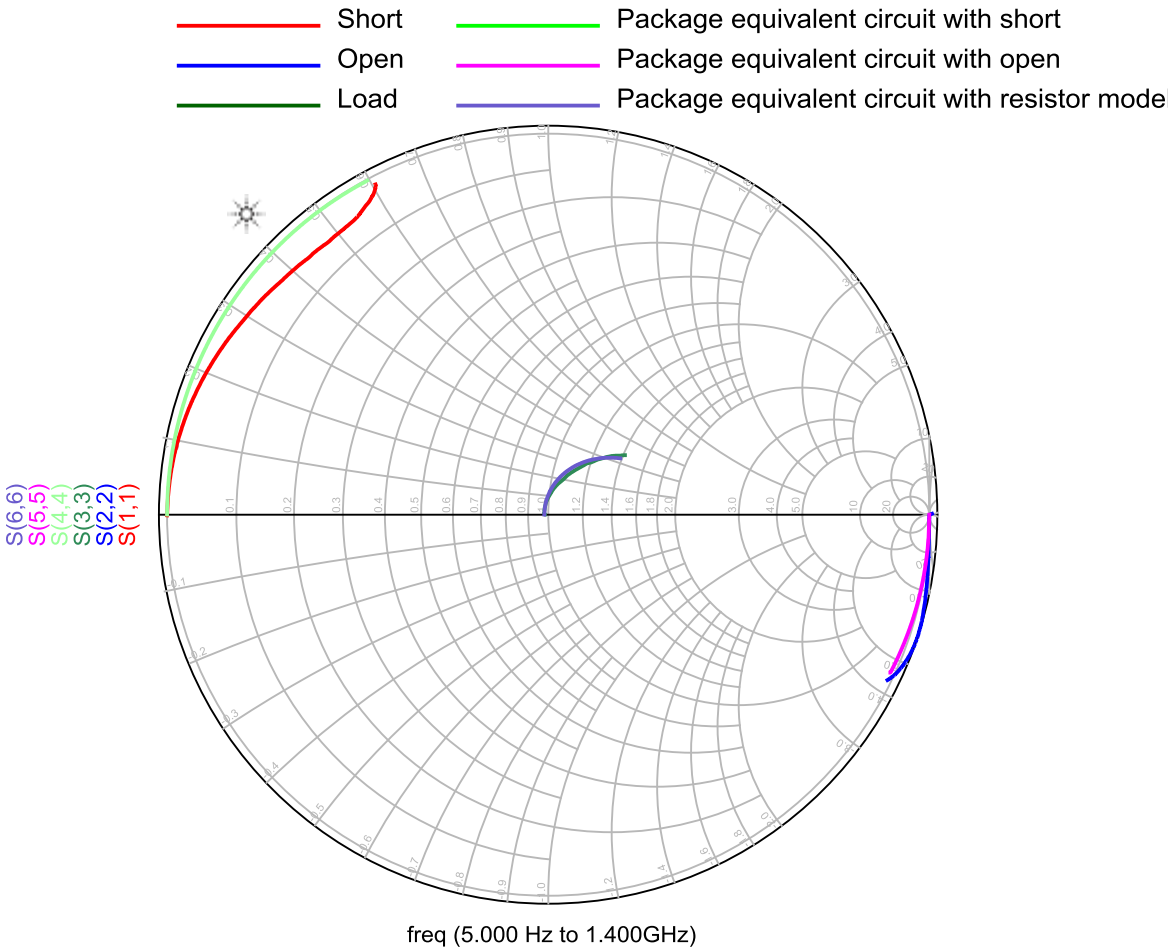
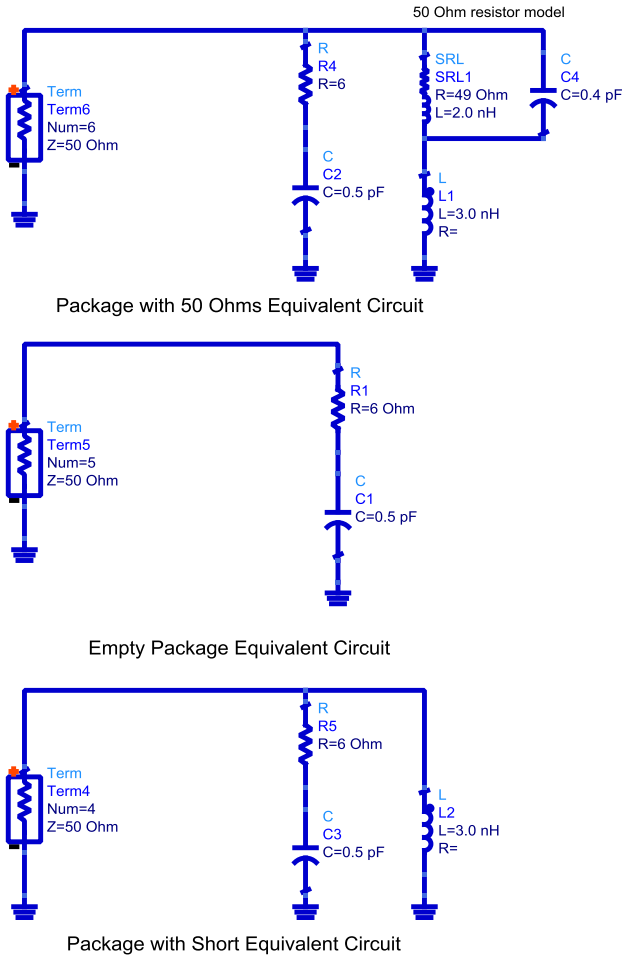
Backup Slides

Smith Chart of Pin to Pin Package Impedances



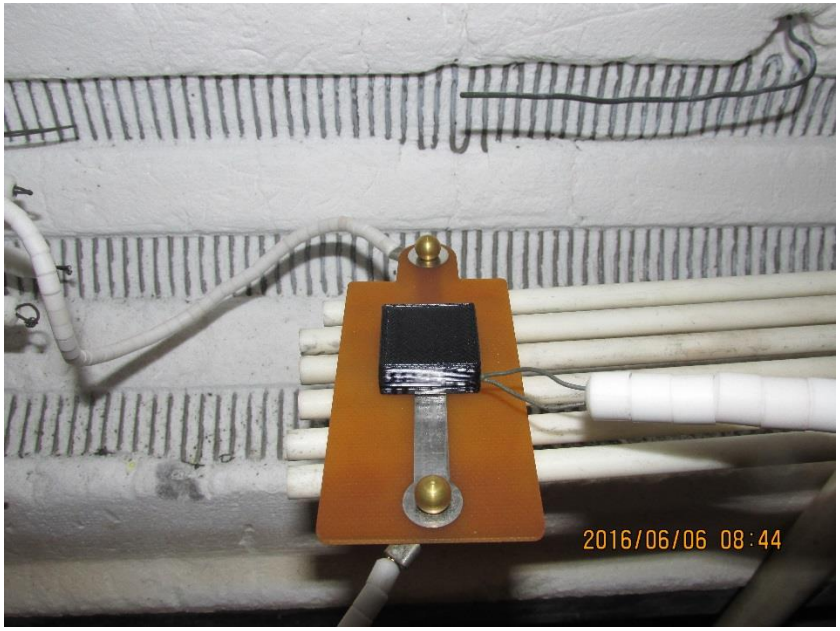
Pin to Pin Package Impedance is found by fitting circuits to Smith Chart





Comparison of Measured Short, Open, Load to Package Equivalent Circuit

Importance of Temperature Tolerance



- Melting occurred at 130 C, well below the rated temperatures of either the Ultem plastic or DP270 Scotch Weld potting material
- Mounted using high temperature SAC305 lead free solder
- Mounted on FR4 board that was not rated for temperature
- Board breakdown an exothermic process, resulting in thermal runaway and destroying part.