Design and Development of a Low Cost, Manufacturable High Voltage Power Module for Energy Storage Systems

DOE Phase II SBIR

EESAT Sept. 24, 2015

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APEI

Motivation

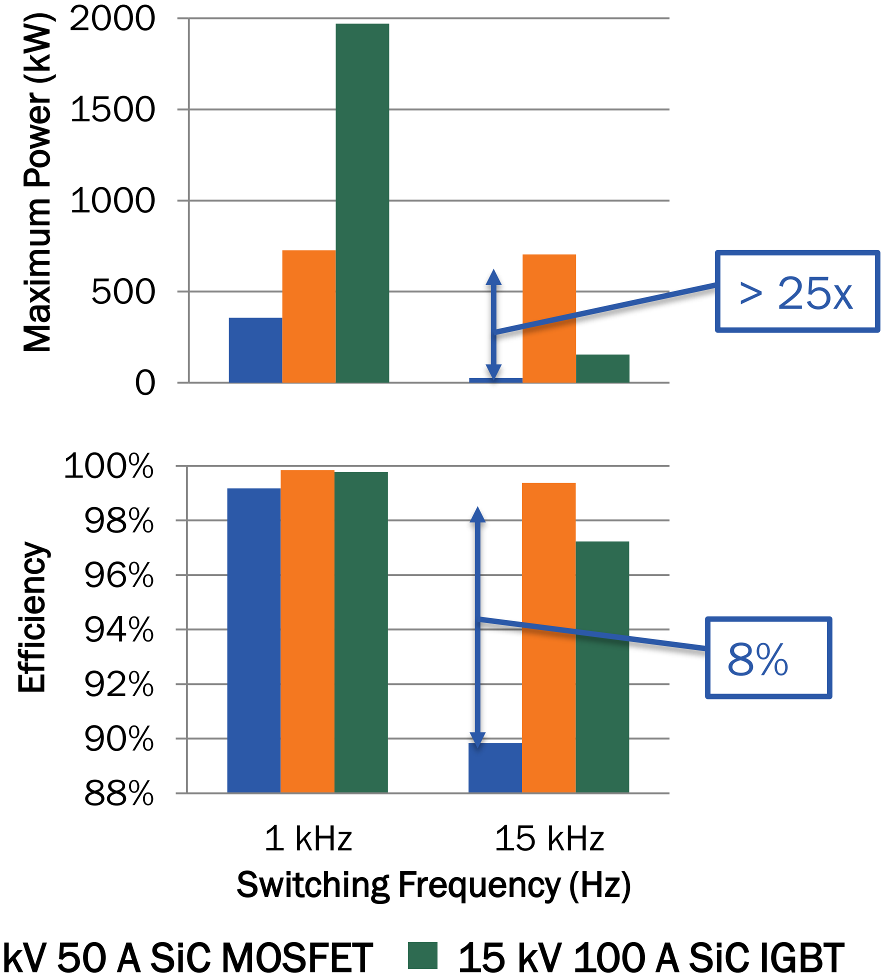
Wide bandgap enables higher efficiency and power density

Objective

Develop a high voltage (> 15kV) silicon carbide (SiC) power module to aid in the emergence of smarter, seamless powered grids.

Applications

- Energy storage systems
- Solid-state transformers
- Naval power distribution
- Electric locomotives
- Medium voltage drives
- Solid-state circuit breakers



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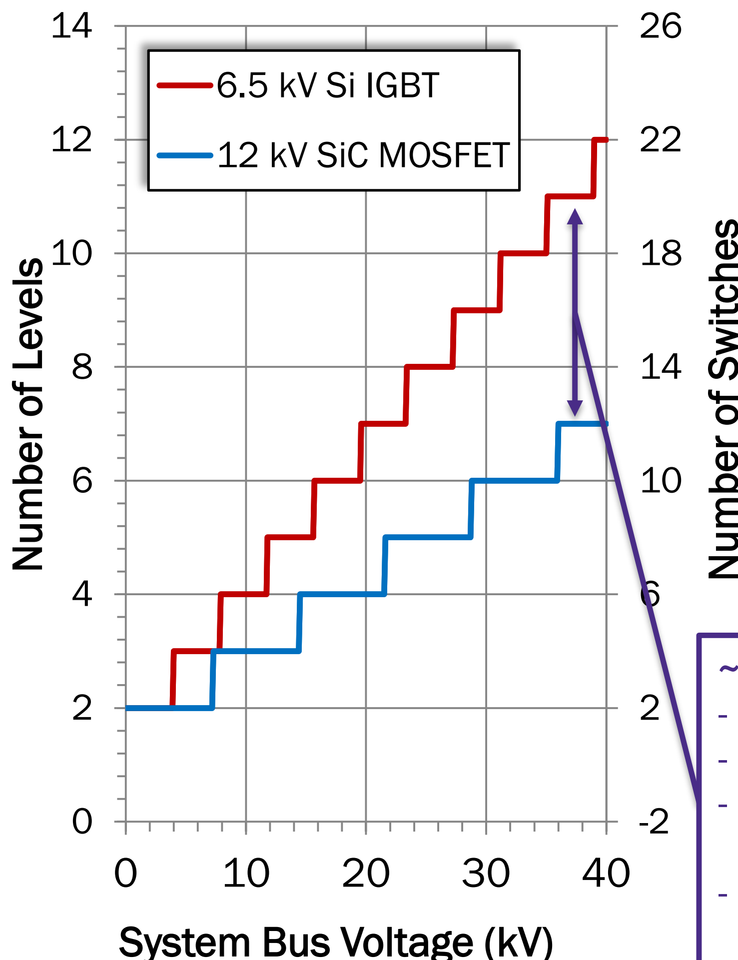
Motivation – Reduce System Complexity, Reduce Cost

Advantages

- Reduce size/complexity of multi-level systems
- Eliminate cooling systems
- Increase efficiency and power density

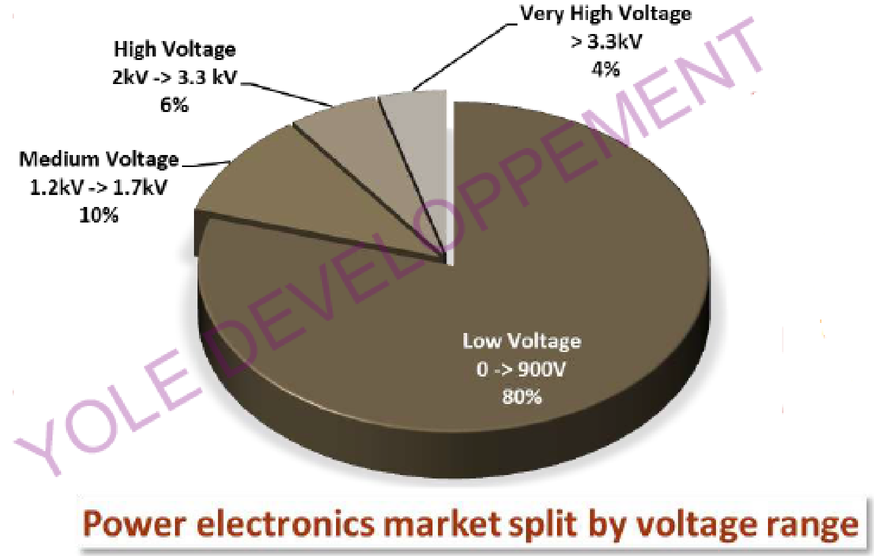


~ ½ Components
- Modules
- Gate Drivers
- Passive components
- System housing materials

Power Electronics and Energy Storage Market

SiC Power Electronics Market

- **< 600 V** - Strong Competition With Si and GaN
- **> 1.2 kV** – Ideal Area for SiC; Apps are less cost driven and performance improvement is obvious



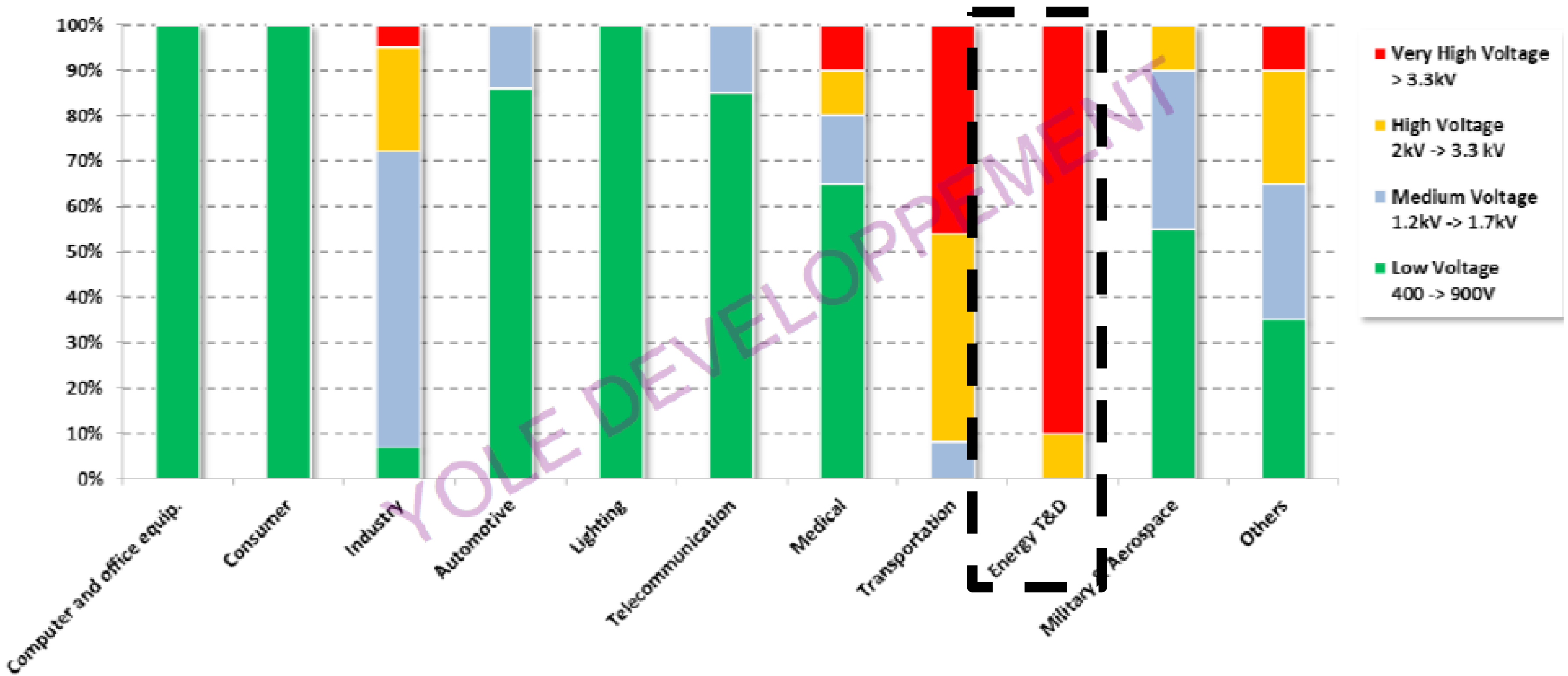
Source: Yole Développement 2012

Energy Storage Market

- The global energy storage market is expected to grow from $39.7B in 2011 to $61.9B by 2016 at an annual growth rate of 9.3% [1]

[1]. http://www.marketresearch.com/MarketsandMarkets-v3719/Advanced-Energy-Storage-Technologies-Type-6671586/

Market Segmentation in Power Electronics by Application and Voltage



[2]. Yole Developpement, 2014.

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Project Plan

Phase I | Phase II | Phase III

2012 | 2013 | 2014 | 2015 | 2016 | 2017

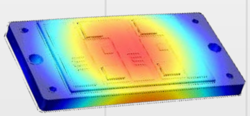
Develop HV packaging approach and demonstrate it via hardware testing

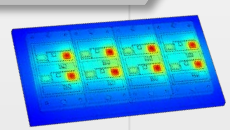
Program Start

Design HV SiC MCPM based on hardware demonstrator

Key Deliverables:
Discrete HV hardware demonstrator and MCPM design

Build and perform electrical, thermal, and reliability testing for the HV SiC half-bridge MCPM





Key Deliverables:
High Performance HV Half-bridge SiC MCPMs

Assembly process transition and manufacturing process yield optimization,

Fully qualify HV SiC MCPM

APEI, Inc. will work with its partners to transition this HV MCPM technology to a commercial product

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Design Features of XHV-3

Advantages of SiC Devices

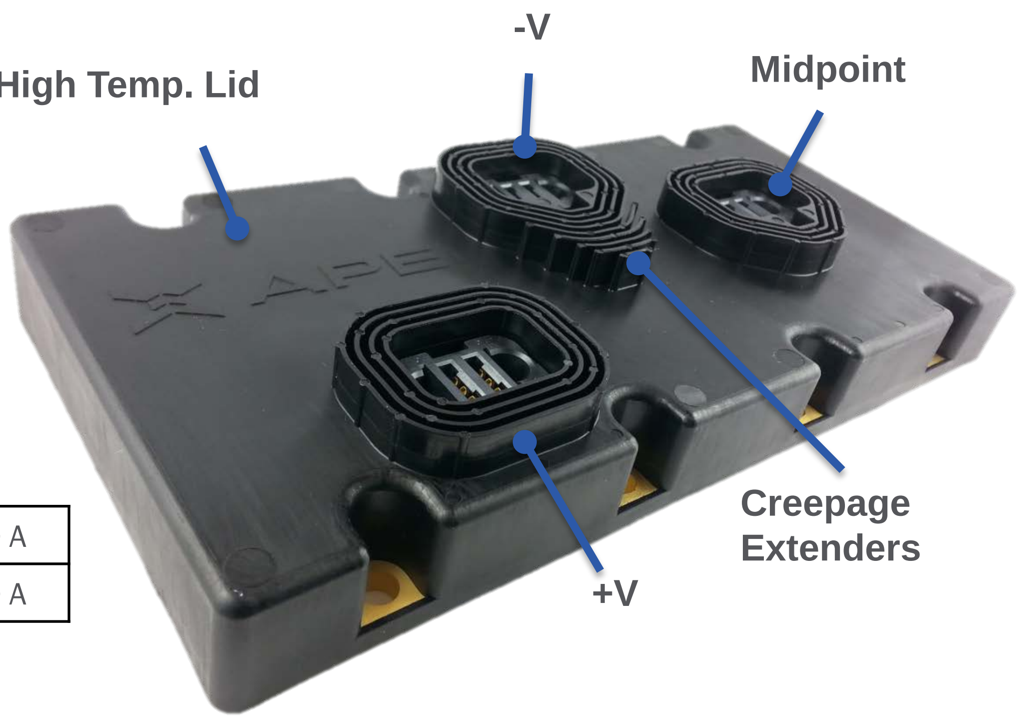
- High breakdown voltage
- High thermal conductivity
- High switching frequency
- High temperature operation

Power Module Features

- SiC MOSFETs or SiC IGBTs

SiC IGBT MCPM	15 kV	80 A
SiC MOSFET MCPM	10 kV	60 A

- Low profile
- Reduced volume/weight
- High temperature capable
- Reworkable



210 mm × 102 mm × 32 mm

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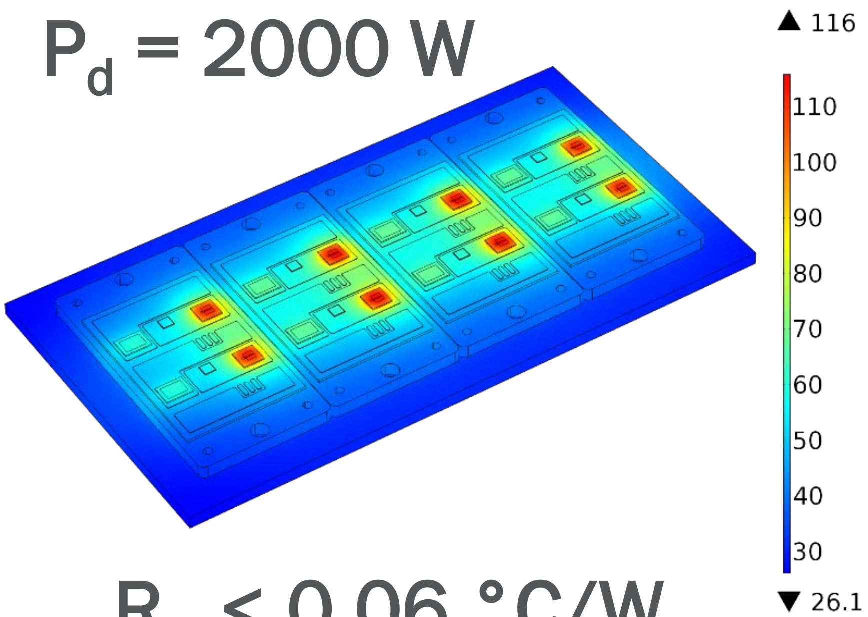
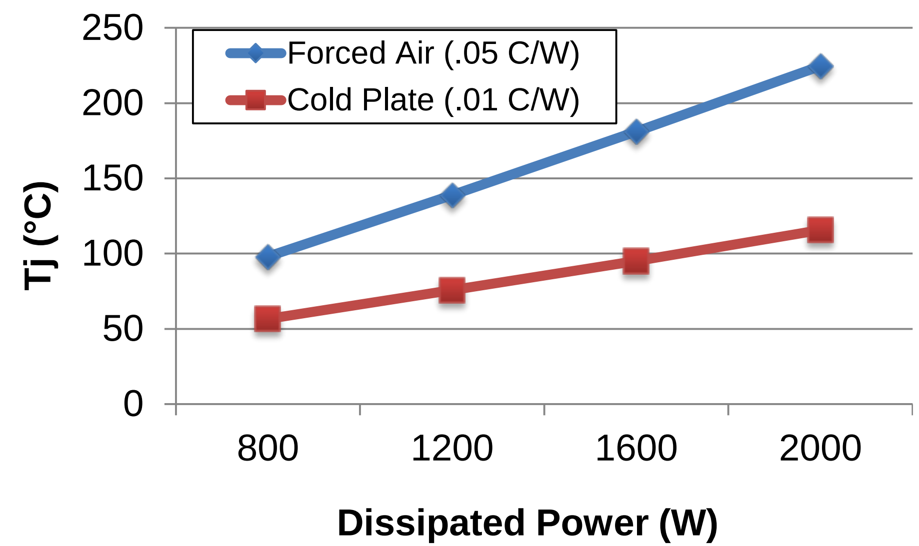
Thermal Modeling Results

$P_d = 2000$ W





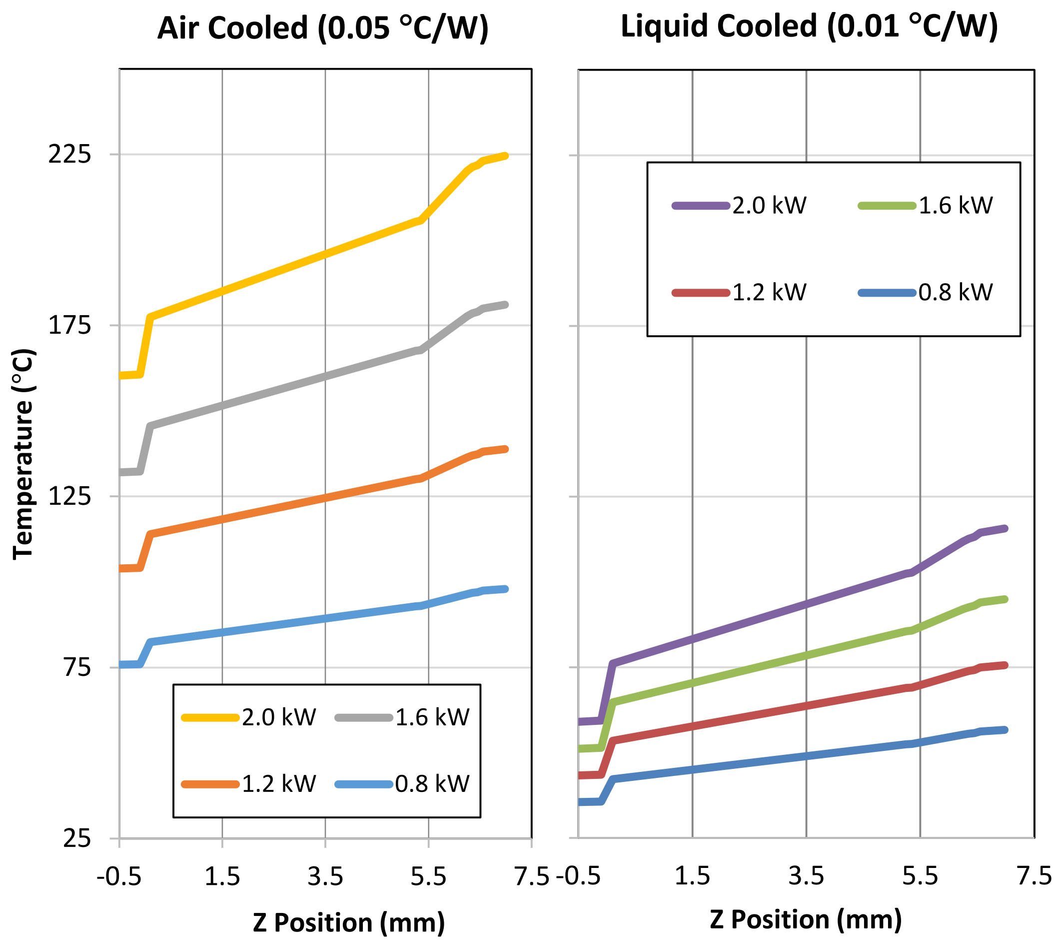
$R_{jc} < 0.06$ °C/W

(per switch position)

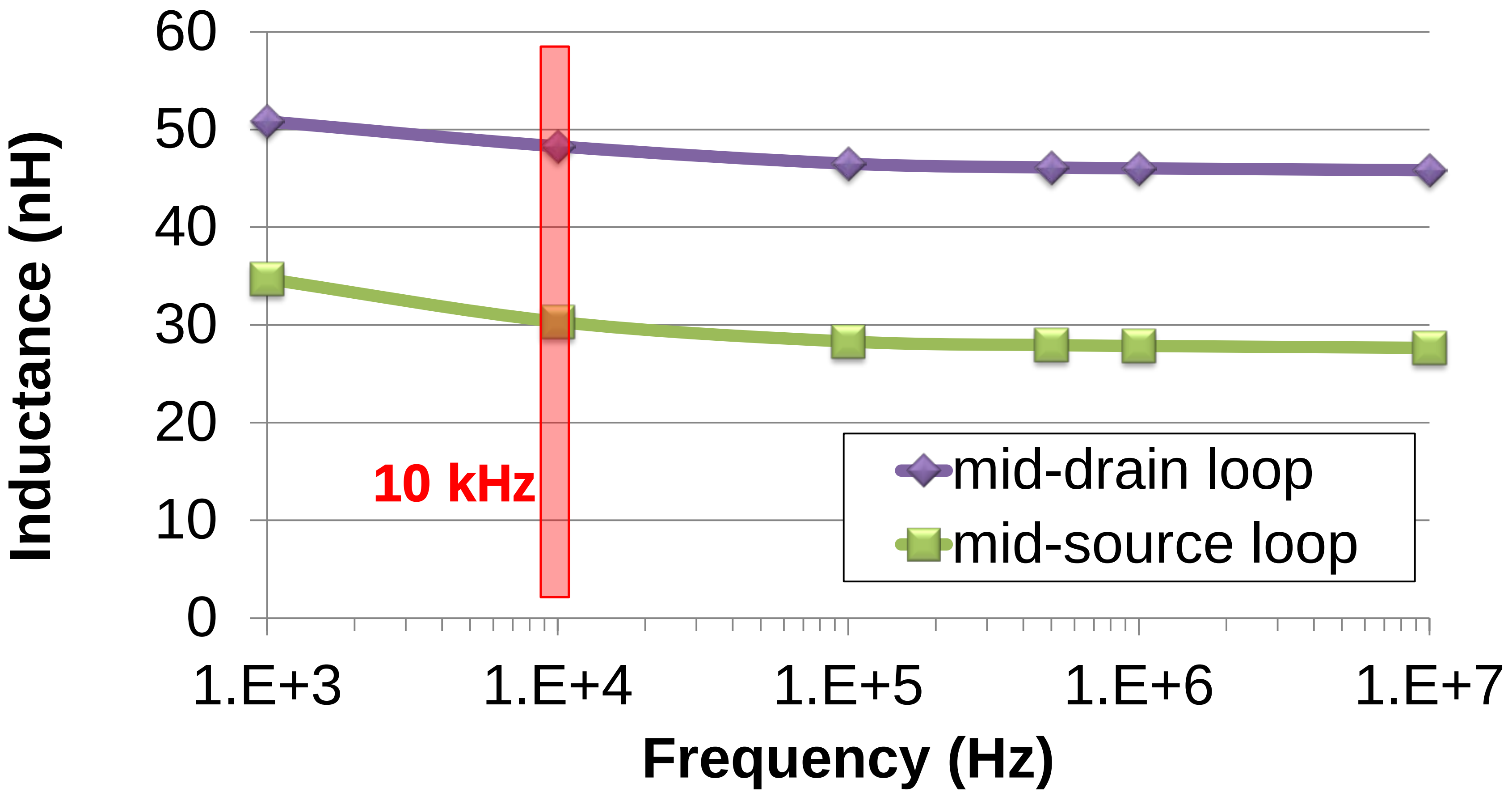
Thermal Simulations

The change in temperature through the thickness of the power module stack-up for a (top) fan-cooled heat sink and (bottom) liquid cold plate.

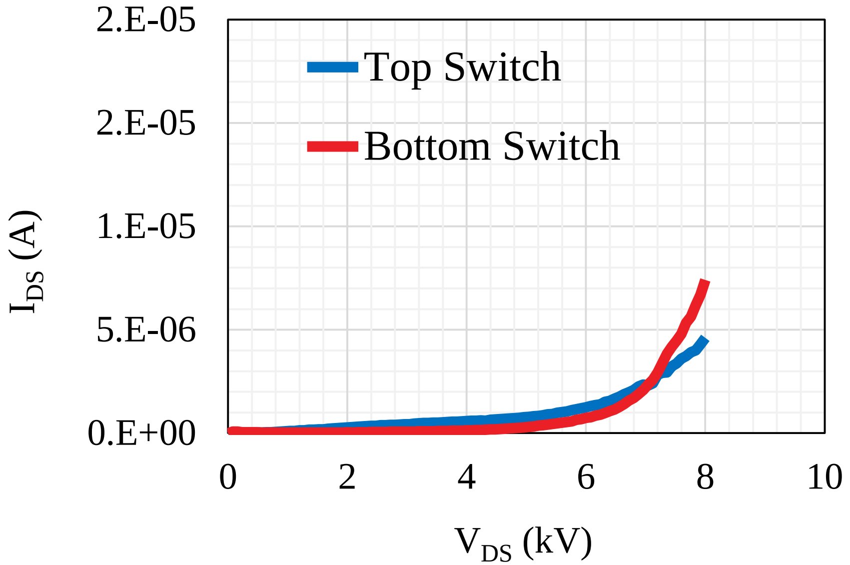
Thick dielectric necessary for voltage isolation hinders thermal performance

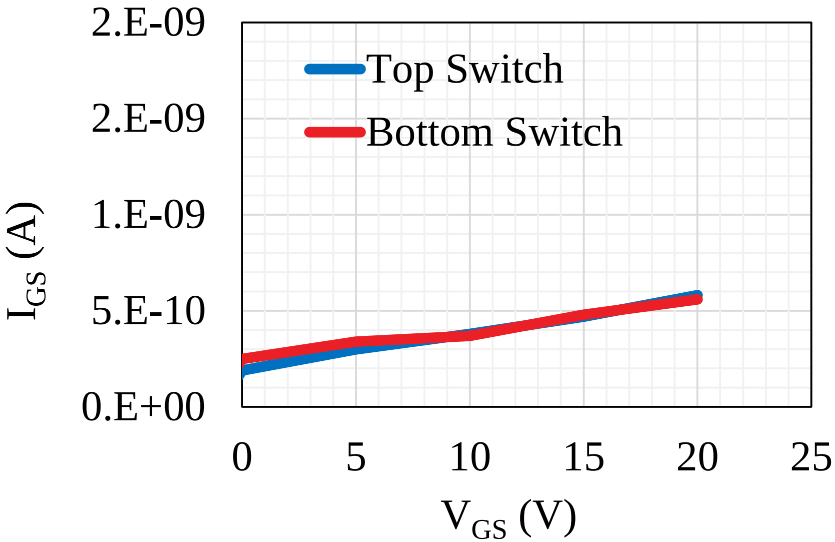


Parasitic Simulations

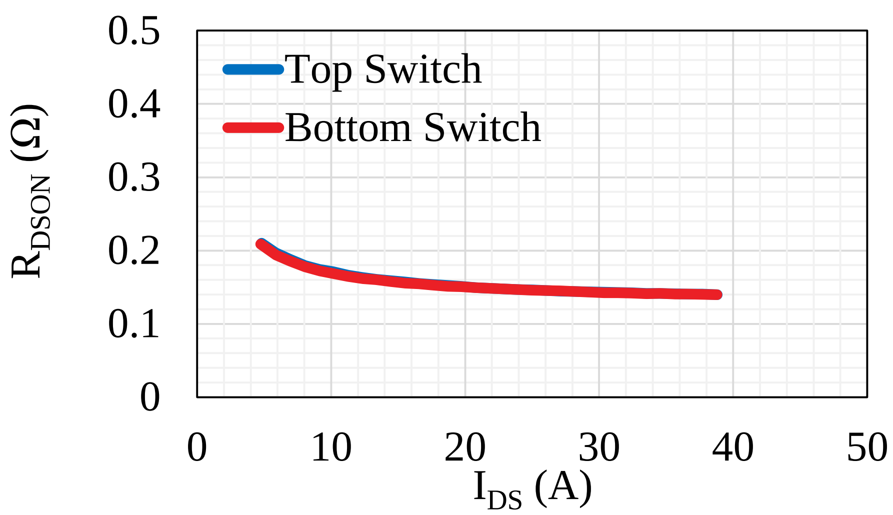


Static Testing





Four 10 kV / 10 A SiC MOSFETs and Four 10 kV / 10 A Schottky Diodes Per Switch Position



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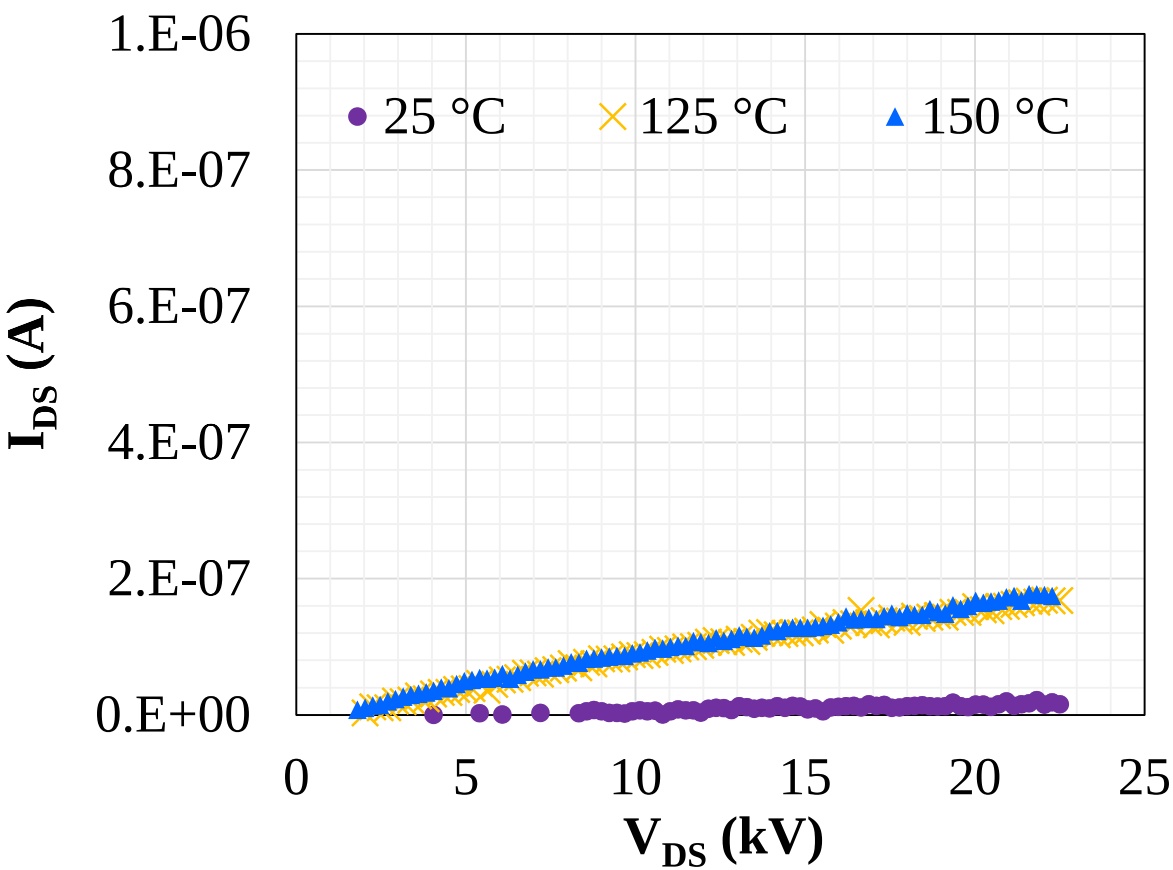
High Voltage, High Temperature Static Isolation Tests

- Tested BV and leakage of a fully assembled/potted module as a function of temperature
- Isolation test = All connections were shorted and the baseplate was connected to low
- The leakage was less than 0.2 μA at 150 °C.
- This is orders of magnitude lower than the device leakage at temperature



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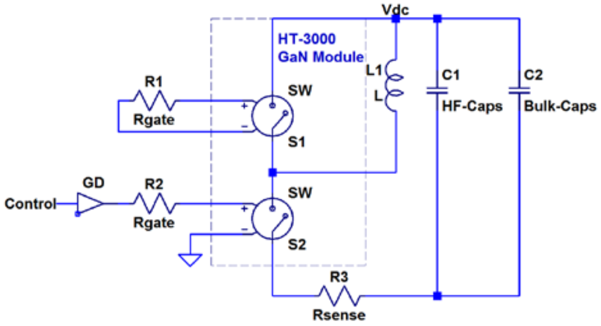
Dynamic Testing

Double Pulse Test Setup Utilizing a Clamped Inductive Load (CIL)

- Two controlled pulses turn DUT on and off
- Inductive load facilitates control of current through the DUT
- Allows for measurement of turn-on and turn-off switching losses at desired drain-to-source voltages and currents
- Gate Drive Circuit
  - 10 kV Isolation, 10 kV DC rail capable
  - Controllable gate output rails (Set at +20V / -5V)
  - Gate resistor was varied to control speed of switch: **2.5 Ω, 10 Ω, and 20 Ω**
- Safety
  - Test Setup has multiple mechanical fail safes
  - Test Setup is completely controlled via wireless communication



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Switch Curves of Submodule

- Rg=2.5 Ohms, I_test = 28 A
- Voltage fall time (turn-on) has increased but not in the same amount
- Voltage Rise time (turn-off) has reduced to 100ns during turn off

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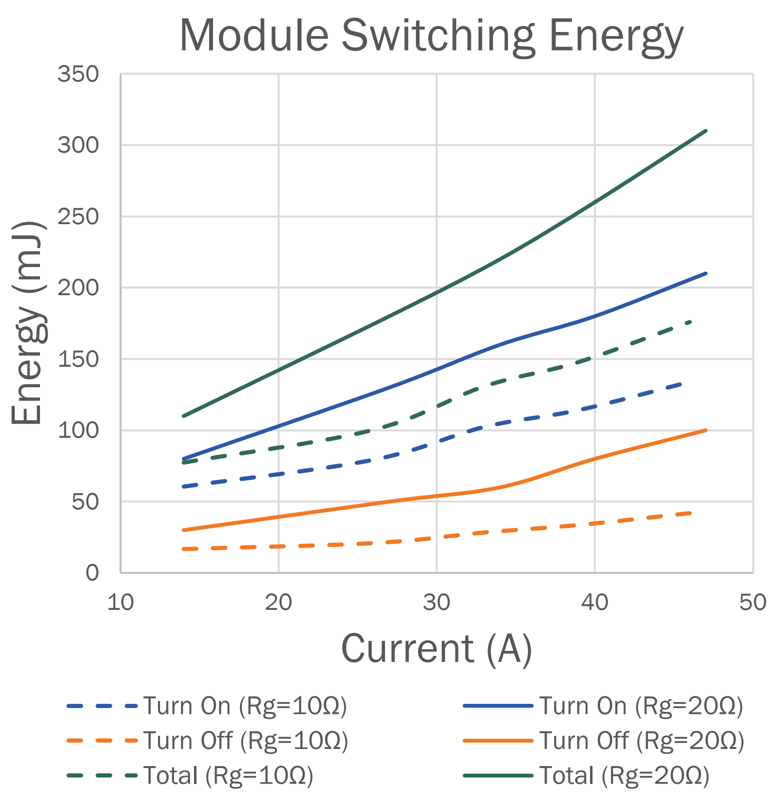
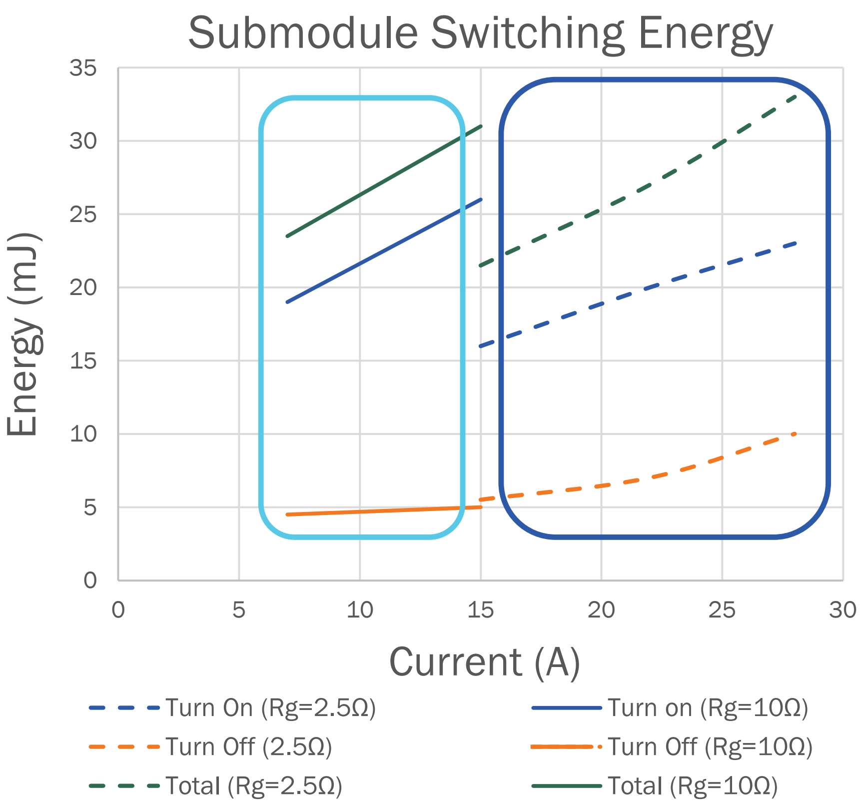
Switching Losses vs. Current at 8 kV





- Total switching losses for a commercial Si 6.5 kV / 250 A module are ~ 2.6 J [3]
- This higher power density SiC Module has over an order of magnitude lower losses

[3]. FZ250R65KE3 datasheet.

Acknowledgements

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