U.S. DEPARTMENT OF
ENERGY
Office of Electricity

Environmentally Neutral Automated Building Electric Energy (ENABLE) Platform

TRAC Program Review

US Department of Energy, Office of Electricity

Presented at Oak Ridge National Laboratory

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Project Overview

- Project summary
  - Develop a 5 kW higher performance SPIN (ENABLE) Power Module taking advantage of wide bandgap (WBG) 3-Dimensional (3D) printed version of an AC to DC and dual active bridge DC-DC converter circuit.
- Total value of award (federal + cost share)
  - $1,250K
- Period of performance
  - 3/1/2017 to 4/30/2019
- Project lead and partners
  - Oak Ridge National Laboratory (Lead)
  - Flex Power Control

Context concerning the problem being addressed

- Need for "building to grid" power conversion systems continues to grow for
  - renewable energy resources
  - energy storage systems
  - wired and wireless charging
  - variable speed appliances
- Any energy load or resource needs its own power conversion system
  - redundancy, increased costs
  - complex coordination and communication
  - reduced energy conversion efficiency
- Significant challenges exist in firmware update

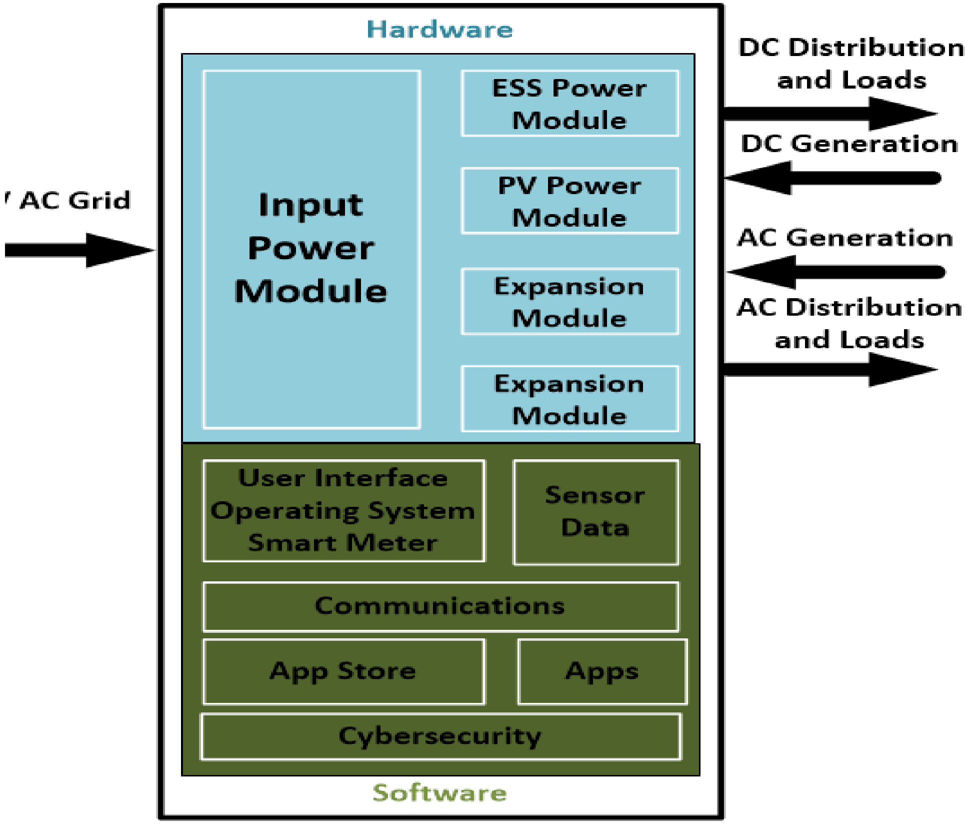
Making establishing a practical and efficient energy management system for building power demand and generation difficult

State of the art approaches for addressing the problem

- **Separate power conversion systems:**
  – PV to Grid/Home
  – Home Battery to Grid/Home
  – Grid to EV Charging
  – Various appliances
- **No way for centralized/coordinated control for all systems**
- **Lack of flexibility / smarts**

Uniqueness of the proposed solution

- **Centralized hardware/software hub that powers and controls loads and sources through a single connection to the utility grid**
  - Easier utility and consumer interaction with the energy resources and loads.
  - No need for a grid interface inverters for each energy source or load.
  - “plug and play” addition of new renewables, passive and active loads, and their power conversion modules.
- **“Smart phone” like system for Connected and Autonomous Buildings**
- **Can be scaled up for other grid applications**



The Smart Power Integrated Node (SPIN) – Flex Power Control

- One dynamic box to correct, control, secure, predict, and transact
- Automates rate arbitrage based on real time demand, forecasts, customer preferences, and grid constraints
- Charging control signals support DER management speed, accuracy, and scale
- Real Time power correction supports grid stability
- PEV Smart Charging balances intermittent solar

ENABLE TCF System Architecture

Power module - (ORNL)

– High density and high efficiency bidirectional isolated AC-DC converter using WBG devices and 3D printing technologies
– High speed low level control functions

System controller (Flex Power Control)

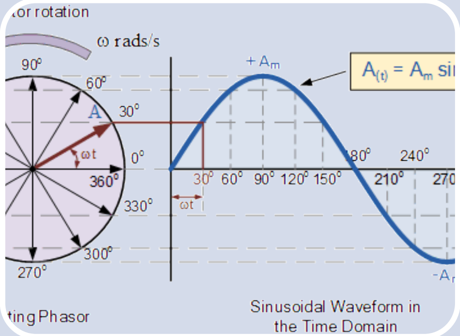
– Dictate operation modes
– System control and grid interactive functions

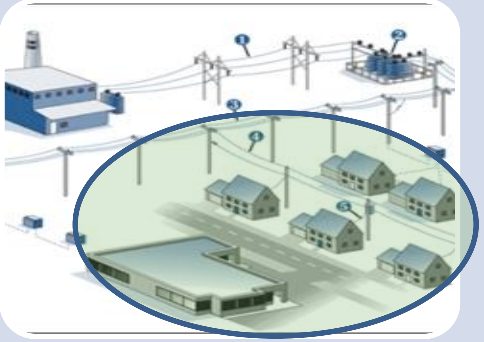
Data acquisition (Flex Power Control)

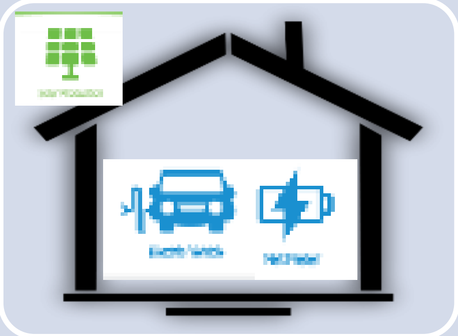
– Tests and real-time data collection
– Performance evaluation

Significance of the results, if successful

SPIN Enables Grid Functionality







What
- Digital Control

Where
- At the edge of the grid where needed
- Any building location

When
- 24 hours, 365 days a year

How
- Closing the control loop at the edge of the grid
- Integration of non centralized resources

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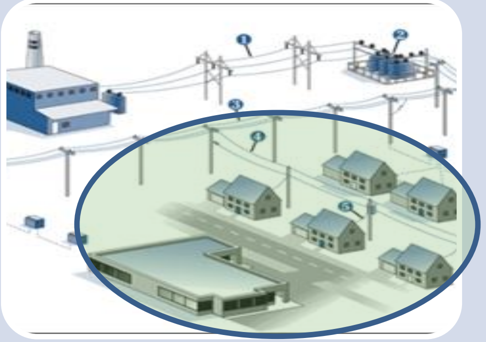
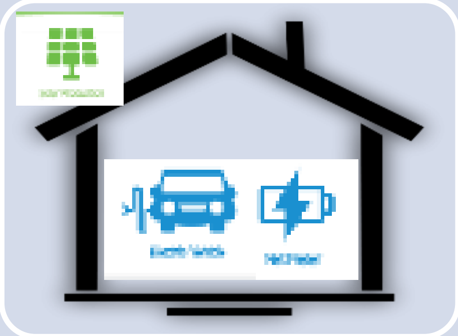
Significance of the results, if successful

SPIN Enables Features





What

- Reduction in energy cost
- Stand Alone Power
- Hi Power DC Vehicle Charging

Where

- Any building location

When

- 24 hours, 365 days a year

How

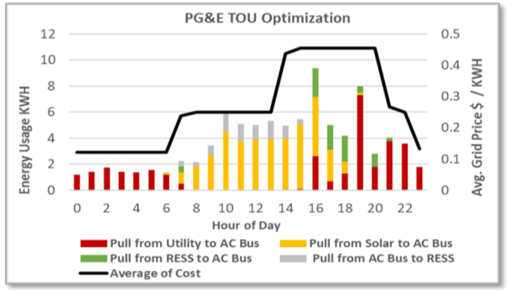
- SPIN's integration of discrete elements

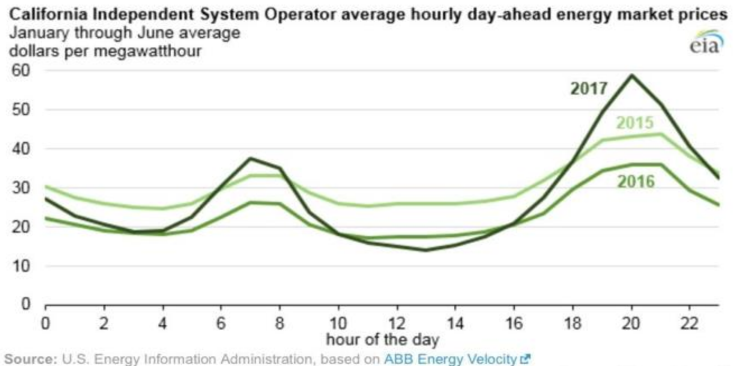
Significance of the results, if successful

Three elements of cost benefit

- Life Cycle Cost
  - Power electronics life increase 2X from current solar inverter technology
  - Single box
  - Simplified installation
  - Increased functionality
- Operating Cost
  - Lower energy cost through control of power flows (when, where, and how)
- Ancillary Grid Services
  - Allow for quick response power regulation control
  - Aggregation of power

Type	Forecasted Cost with No Solar	Forecasted Cost with Solar	Optimized Cost with Solar
Fremont	$15.25	$8.53	$6.81
Maui	$19.76	$14.02	$10.92
PG&E TOU	$24.04	$13.24	$9.62





Specific research questions being addressed

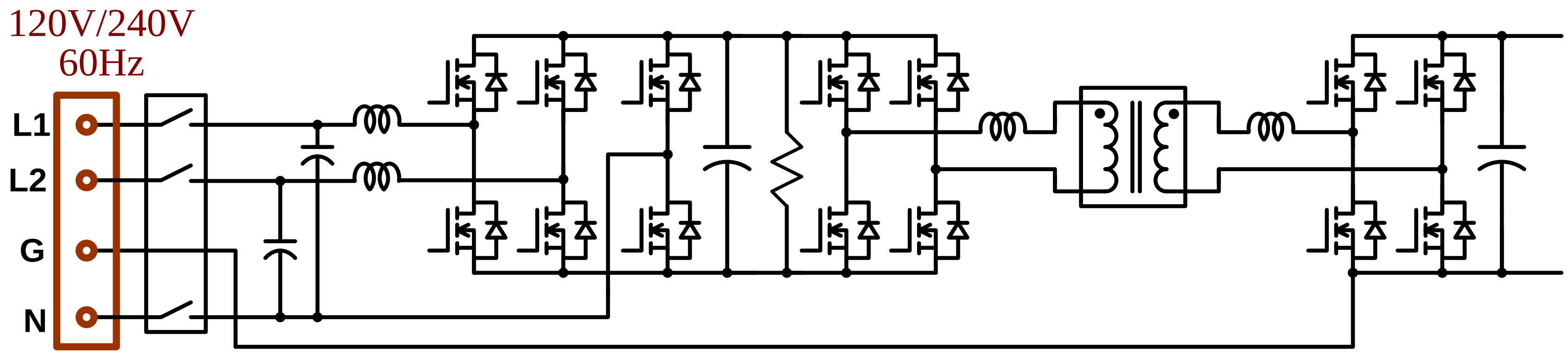
- How do 3D printed heat sinks perform compared to traditional heat exchangers?
- How does the WBG-based power module for SPIN/ENABLE perform against a Si version?

Technical explanation of the proposed approach

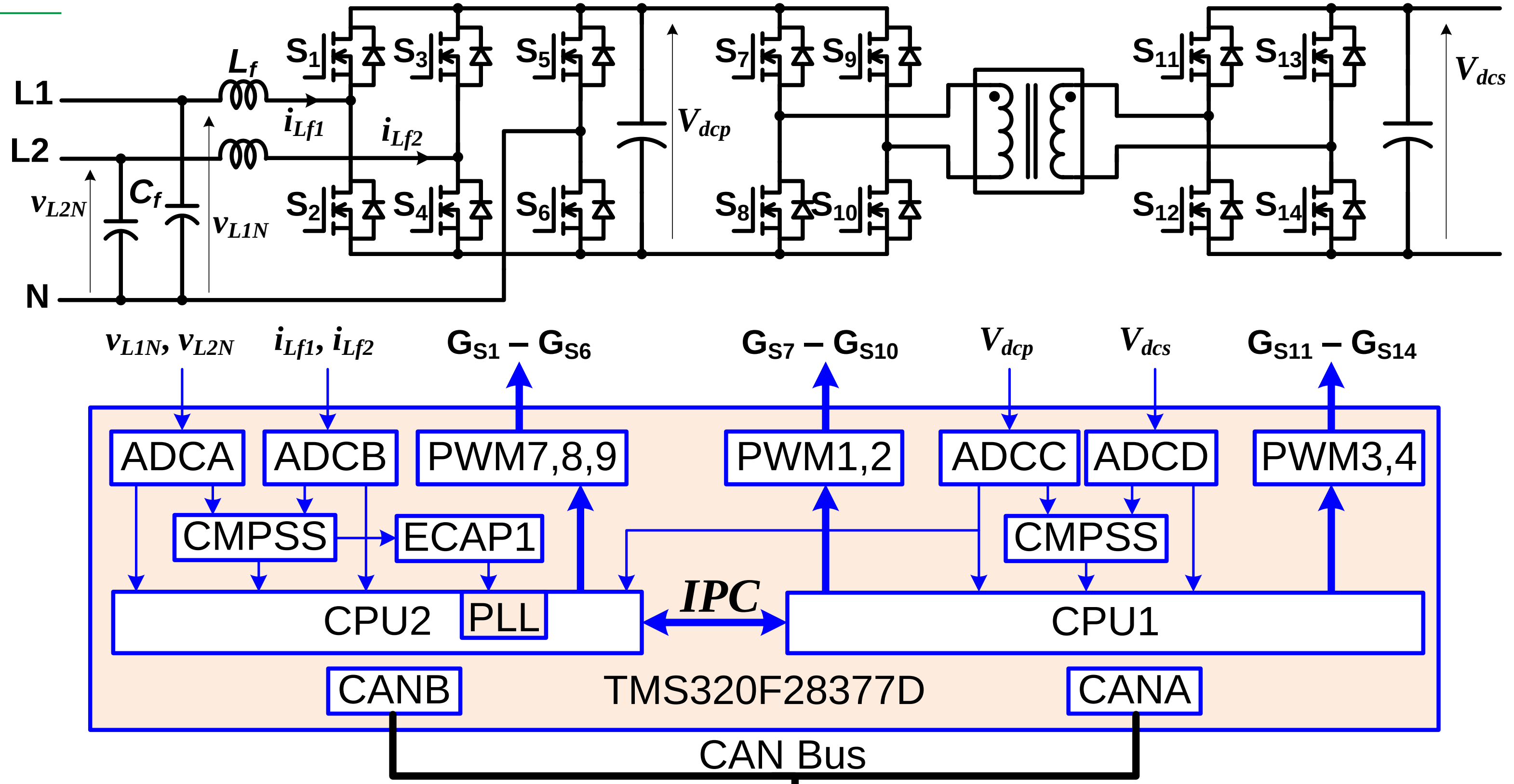
- Design, build and test a 5 kW power converter prototype using WBG devices, film capacitors, and 3D printed heat exchangers
  - Design the 5kW grid-connected ENABLE hardware platform with a source and a load module
  - Analyze and simulate the designed hardware system for component sizing and control development
  - Build the WBG-based 3D printed ENABLE hardware system
  - Evaluate the system

Power Converter Architecture

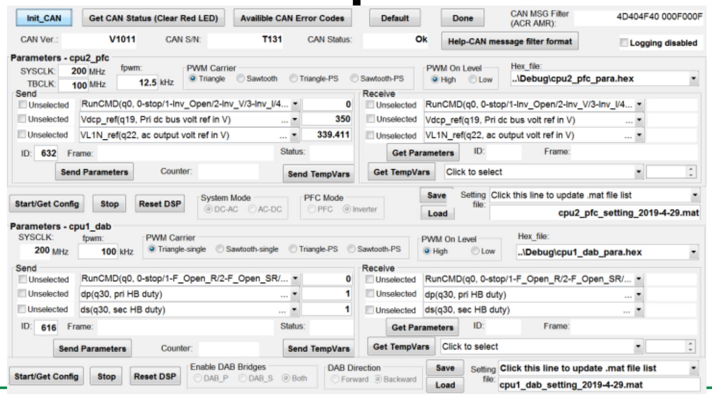
- AC input
  - 240Vrms/25Arms
  - 120Vrms/25Arm
- DC Output
  - 5kW (at 240Vac input, 250Vdc – 450Vdc output)
  - 200Vdc – 450Vdc
- WBG devices
- Air-cooled
  - Commercial and 3D printed heat sinks



Overview of Control System



- CPU system clock: 200 MHz
- PWM clock: 100 MHz



Test and Control GUI

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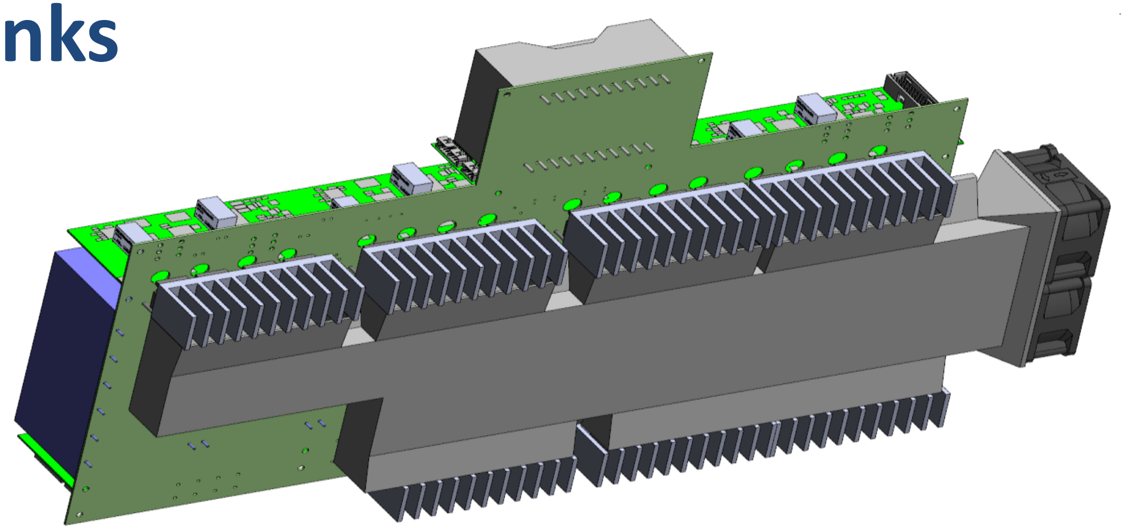
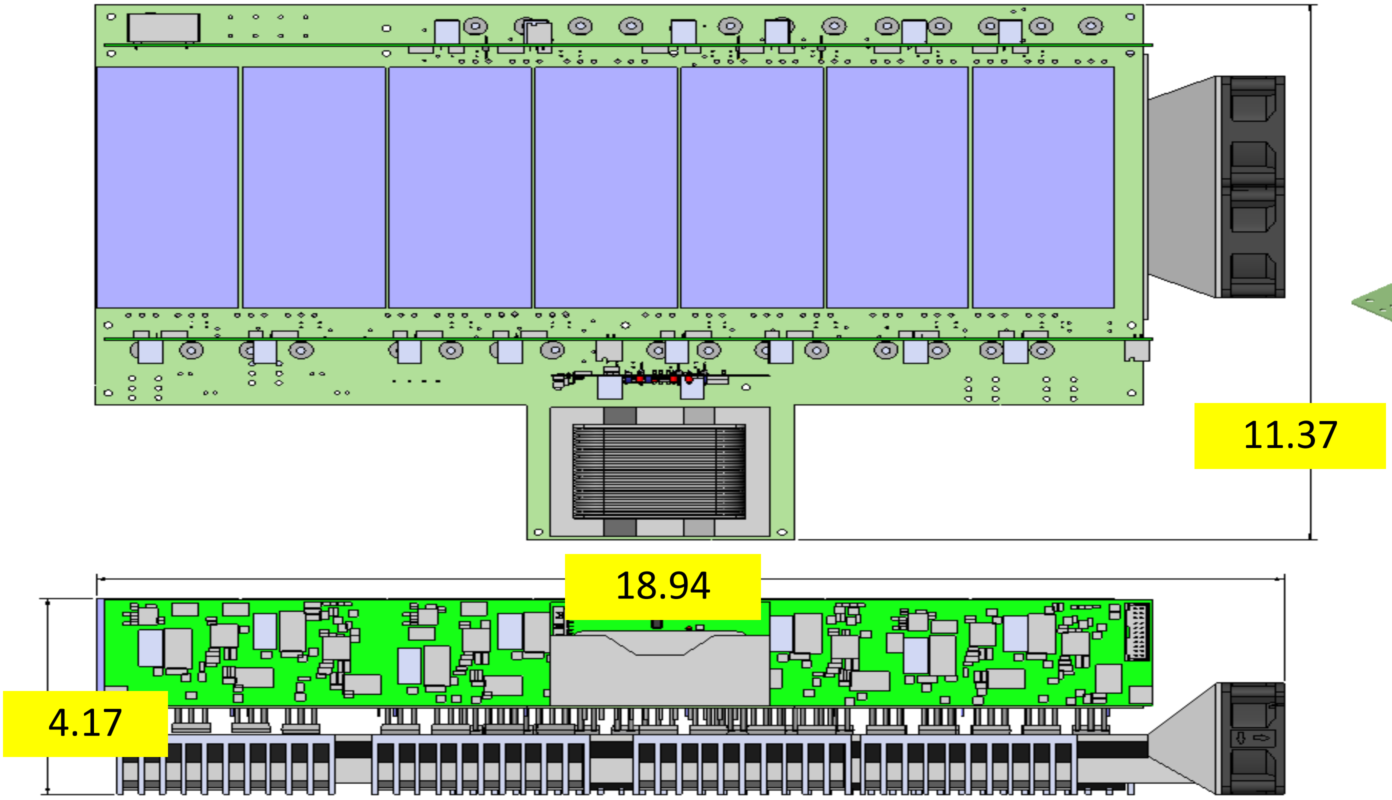
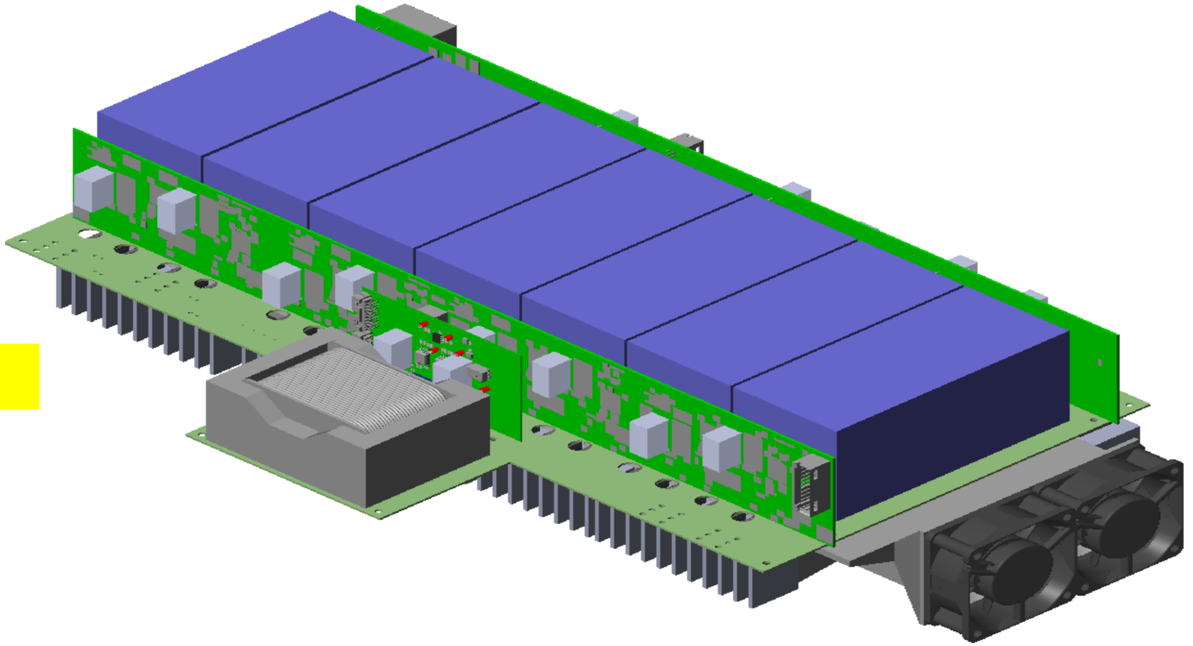
System Assembly using COTS Heat Sinks

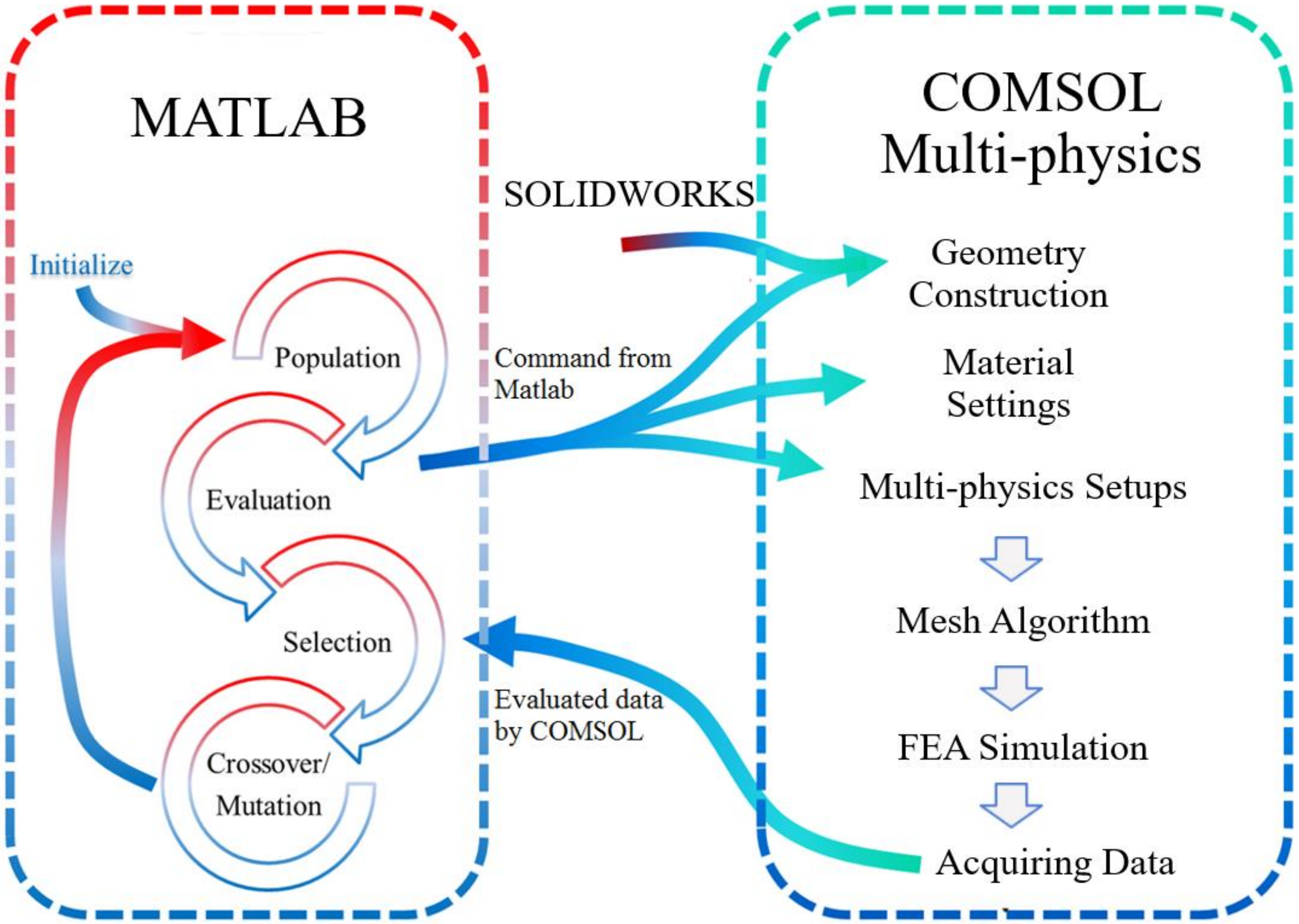
- Ducted Cooling 1 Heat Sink per Phase
- Extremely low profile
- 2 Fans (increased reliability)
- Minimal dead space (also usable)
- Duct design ensures equal flow across heat sinks
- Duct outlet has asymmetrical orientation



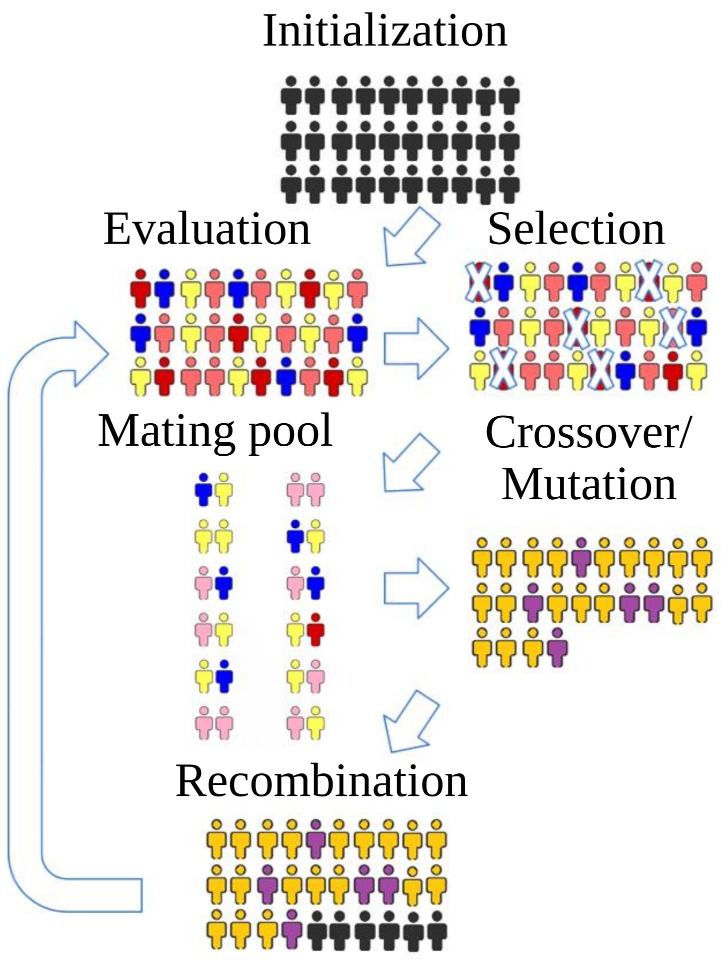




3D-Printed Heat Sink - Genetic Algorithm Implementation



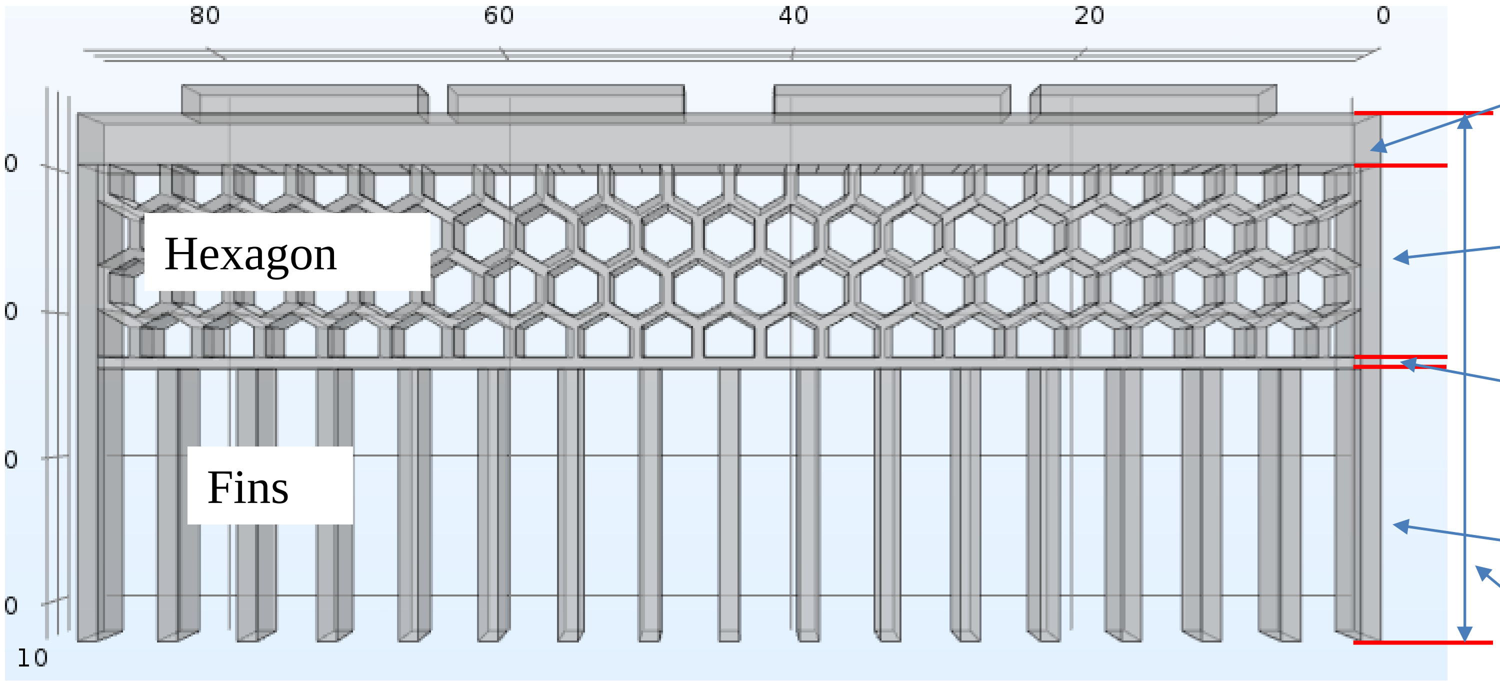
Machine learning based Automatic Co-simulation
Iterating Loop



General concept of Genetic Algorithm
"Survival of the fittest"

3D-Printed Heat Sink - Genetic Algorithm Based Optimization

- **Optimization target: Junction temperature & Height**



Optimization parameters:

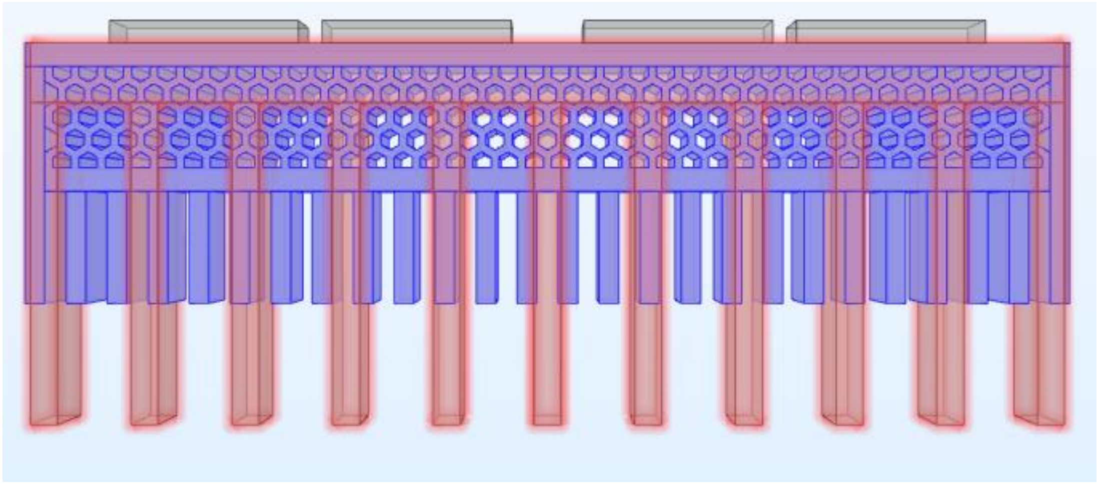
Baseplate thickness

Layer of hexagons
# of hexagons per layer
Thickness of hexagon boundary

Secondary baseplate thickness
# of fins
Thickness of fins (Distributed)
Distribution of fins

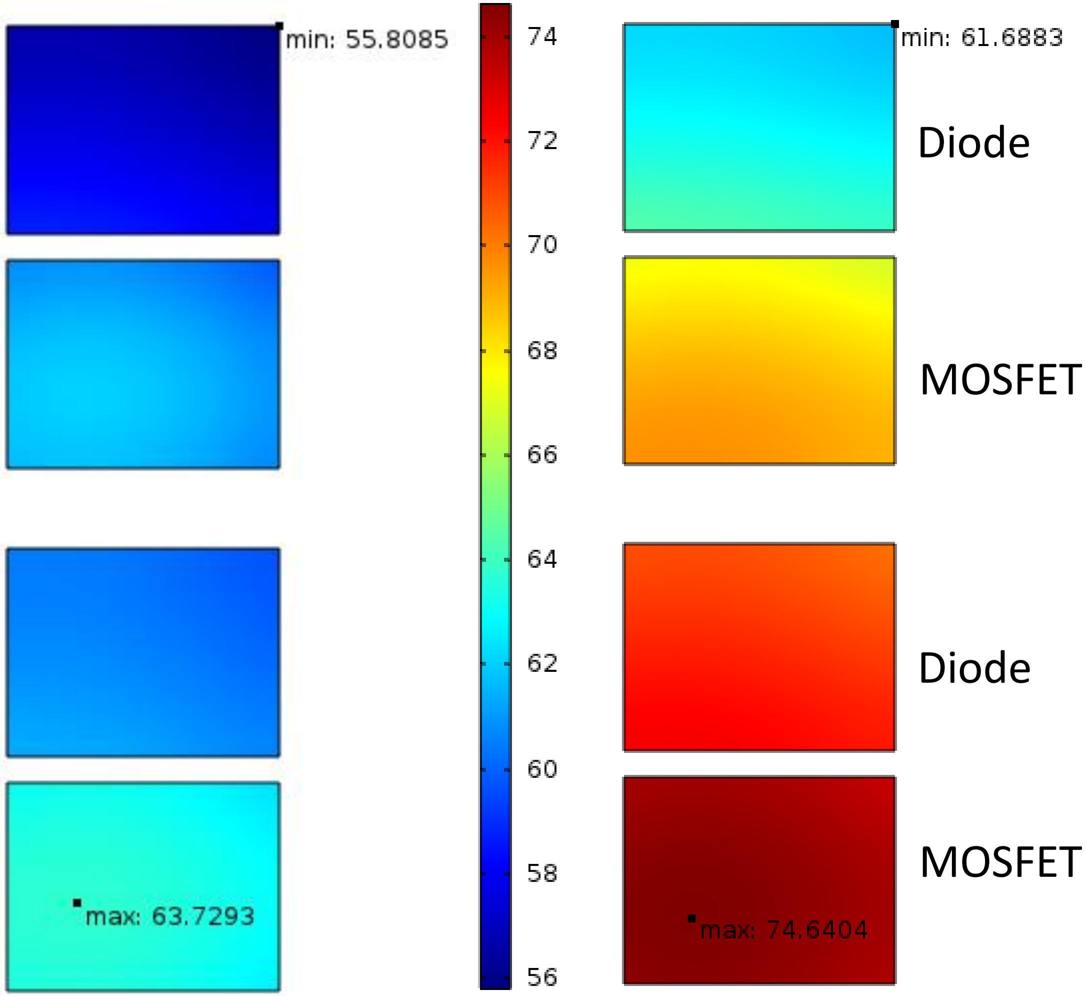
Overall height

3D-Printed Heat Sink - Summary



Height comparison between Aavid HS (Red) and GA HS (Blue)

- Applying GA based optimization on single unit reduced
  - height by 38%
  - maximum device junction temperature by more than 20%.
- Further improvement possible with
  - larger optimization iterations
  - more design features
  - higher design freedoms to fully utilized the benefits of 3D printing



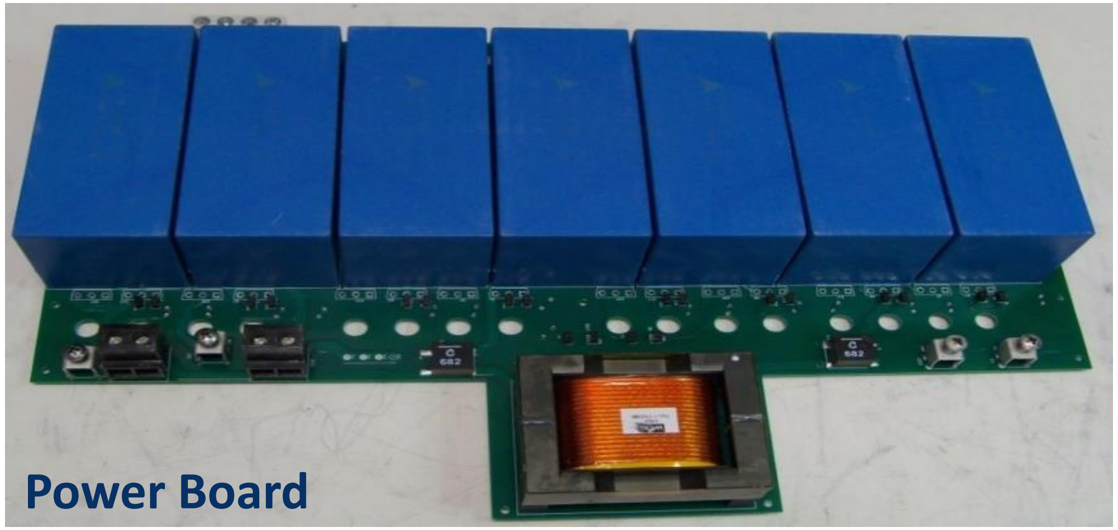
Temperature comparison between Aavid HS(Right) and GA HS(Left)

Hardware Design Summary

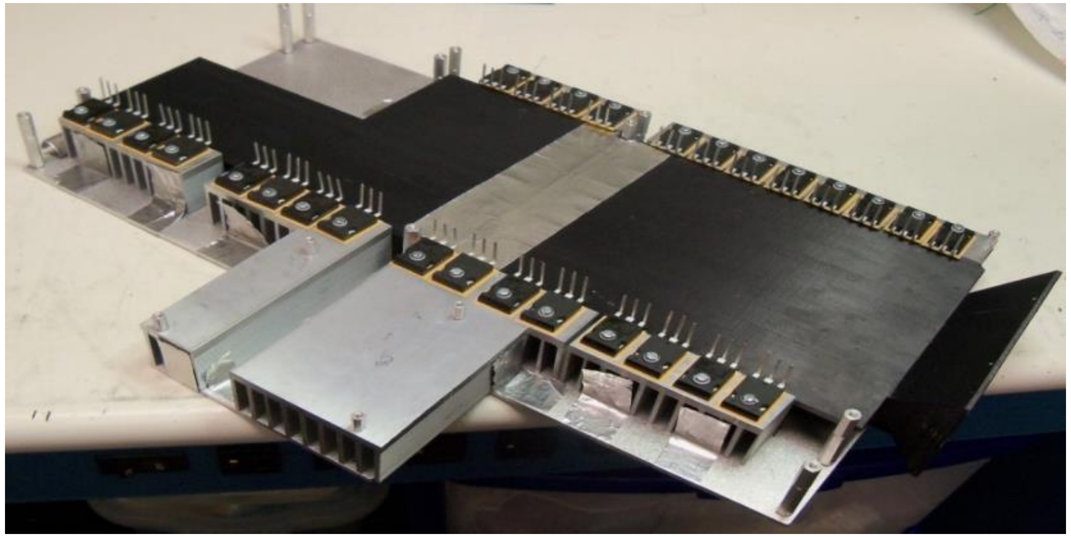
	Ver. 2	Ver. 1	Note
SiC MOSFET	Rohm SCT3022ALGC11 14	Rohm SCT3022ALGC11 14	Replaced Cree/Wolfspeed C2M0025120D
SiC diode	Microsemi APT30SCD120B 14	Microsemi APT30SCD120B 14	
DC Cap	EPCOS B32778J5367K000 6x360=2160µF	EPCOS B32778J4487K000* 4x480=1920µF	*not in stock
Inductor	Coilcraft SER2918H 2 (10µH each)	Wurth 74435580330 2 (3.3µH each)	
Transformer	Custom made (4:3)	Custom made (1:1)	
Output Cap	EPCOS B32778J5367K000 1	EPCOS B32778J4487K000* 2	

- Completed designs for a 5kW WBG-based ENABLE hardware system
  - Ver. 1 designed for operating at a fixed dc output voltage (400V)
  - Ver. 2 designed for operating at over a wide output dc voltage range (200V-450V)

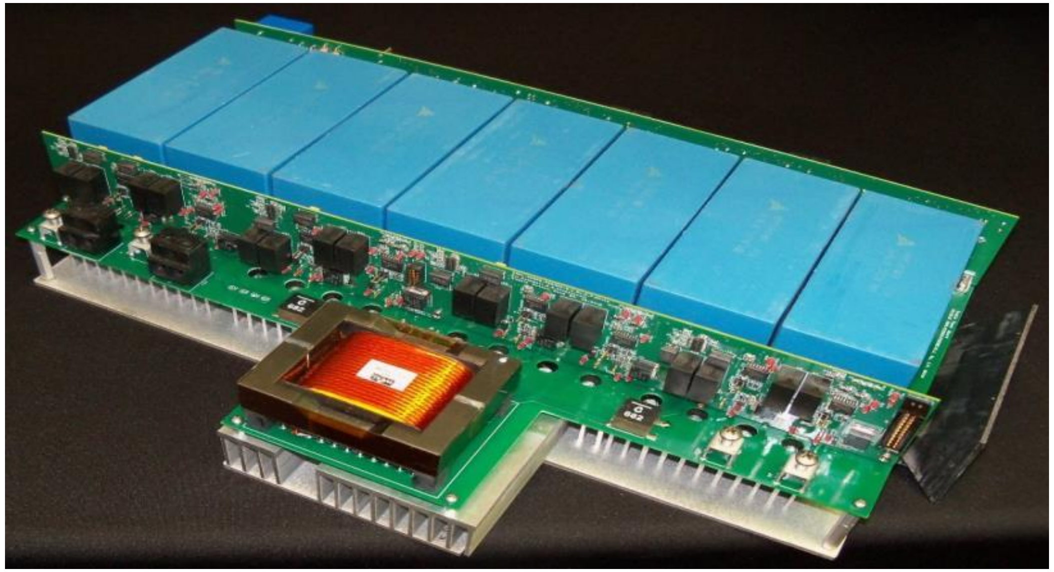
Hardware Assembly



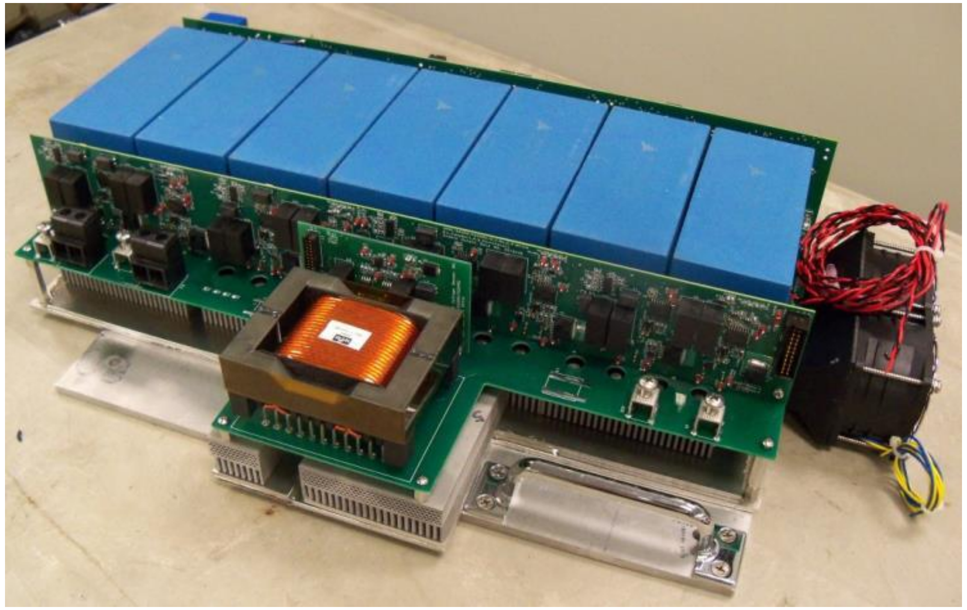
Power Board



COTS heat sinks

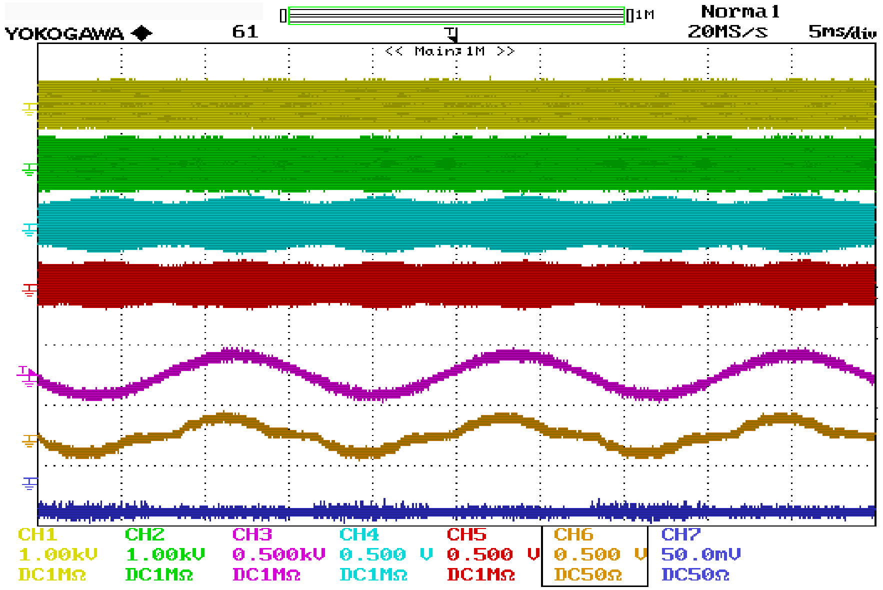


System using COTS heat sinks



System using 3D-printed heat sinks

Test Results



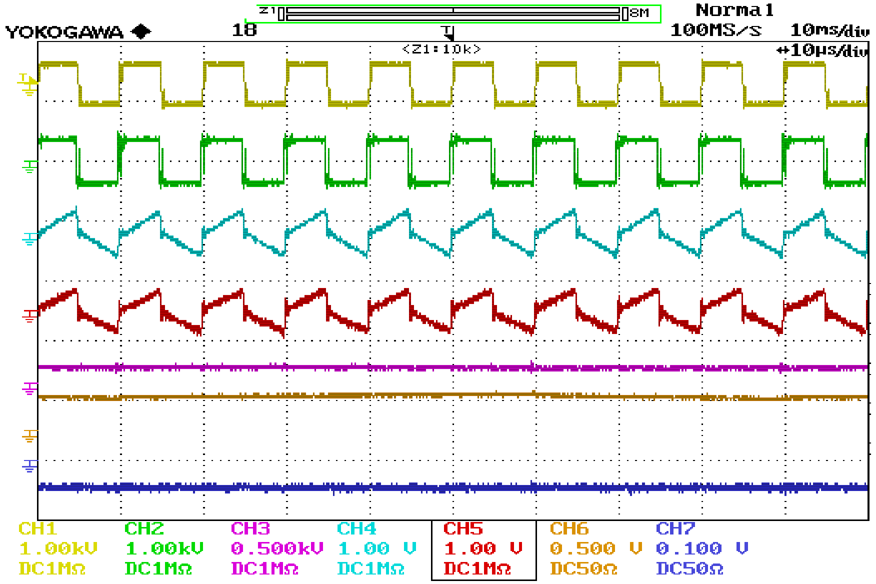
DAB voltages

DAB currents

Source voltage

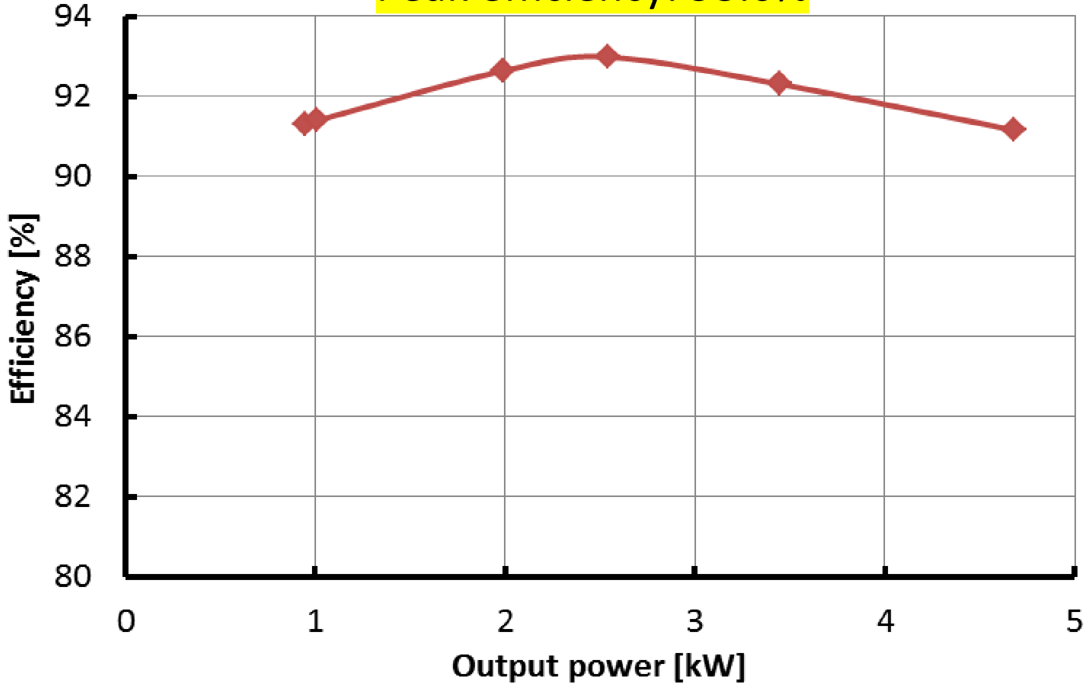
Source current

Output current



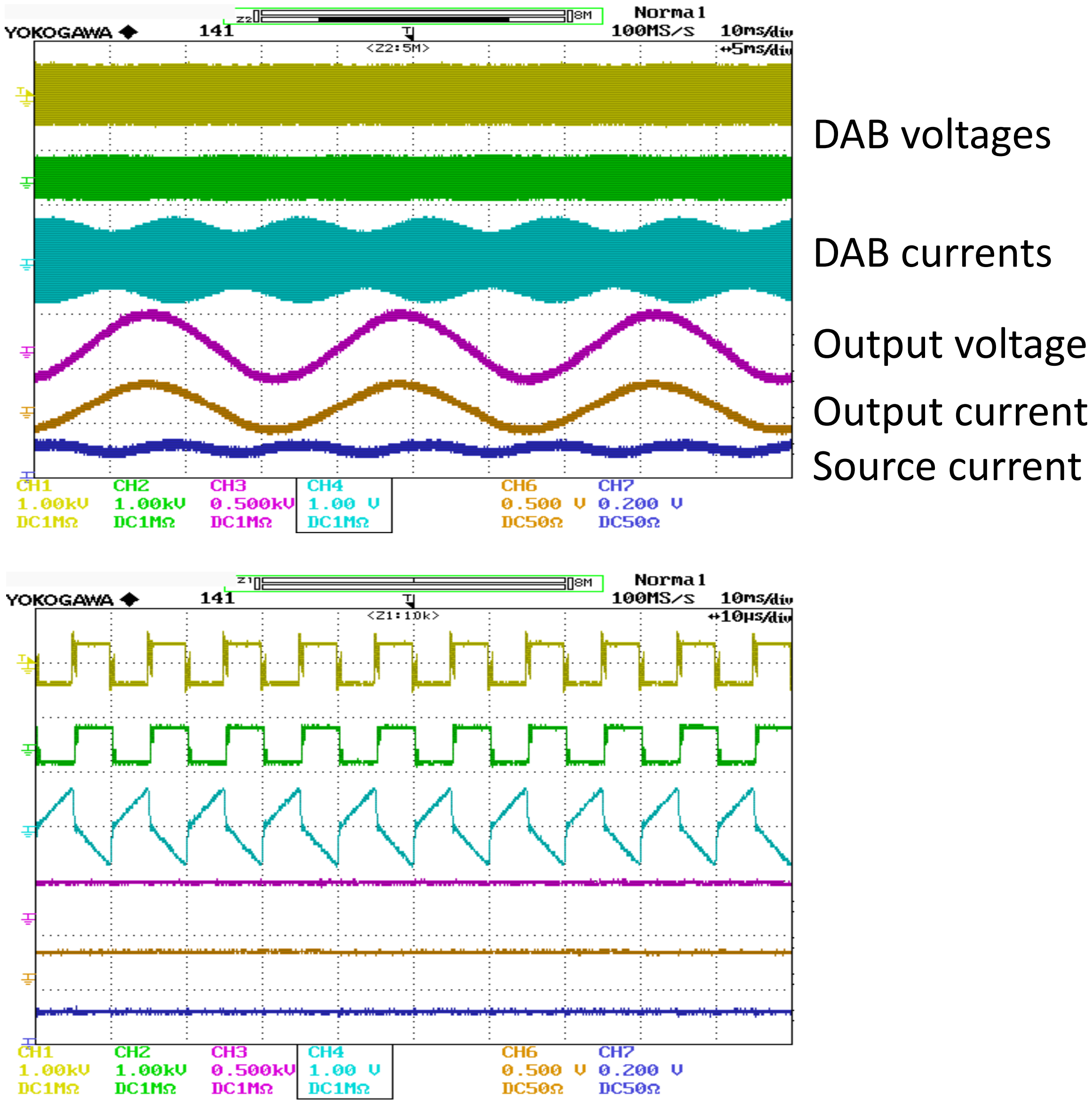
AC to DC conversion

Peak efficiency: 93.0%

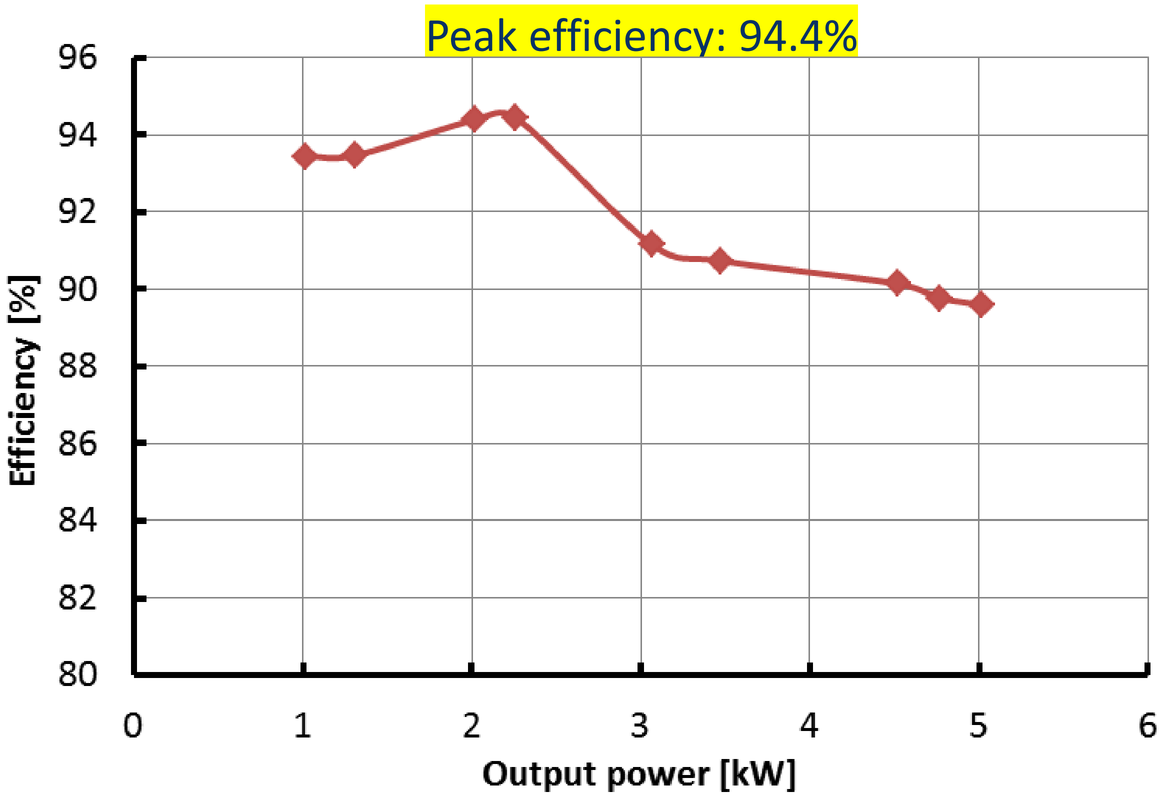


AC-DC conversion efficiency vs. output power

Test Results



DC to AC conversion



DC-AC conversion efficiency vs. output power

Project schedule, deliverables, and current status

- $1250K spent

Date	Milestones and Deliverables	Status
Jun 2017	Complete circuit analysis to size components and to develop a control strategy	**Complete**
Sep 2017	Complete circuit simulation to verify the analysis results, generate efficiency data for various operating and power flow conditions, and to validate the controls	**Complete**
Dec 2017	Complete design for WBG-based 5kW ENABLE hardware system	**Complete**
Sep 2018	Complete the build of the hardware	**Complete**
Apr 2019	Complete test and evaluation of the hardware system	**Complete**

Anticipated challenges and risk mitigation strategies

- Project complete

Next steps

- Project is complete
- For commercialization, the power module needs to be extensively evaluated for each mode described earlier.

Broader Impact

- A manuscript will be prepared for publishing the results of the project.
- More discussions will be held with Flex Power Control for commercialization of this technology.

Contact Information

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