FREEDM SYSTEMS CENTER

Modular Solid-State Transformers Using 3.3kV SiC Devices

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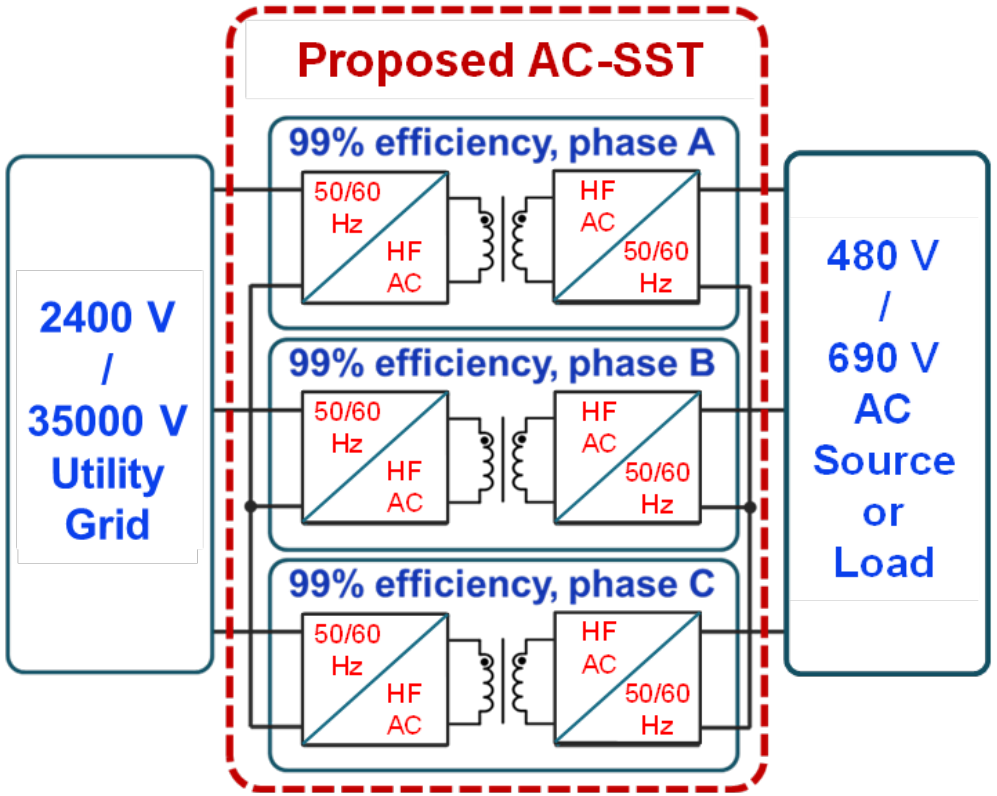
Technical Approach and Objectives

❑ Technical Approach

Modular Universal SST: Single-stage AC-AC SST or DC-DC SST

- Power semiconductors: 3.3 kV SiC MOSFET
- Advanced duo-loop digital control
- Ultra-high efficiency (99%) and high frequency (>50 kHz) isolation
- Soft-switching operation with source voltage and load current adaptability



❑ Objectives

- To achieve 99% efficiency with single-stage AC-AC SST at rated (2400Vac-480Vac) voltage and DC-DC SST at rated 4200Vdc-400Vdc
- To explore the feasibility and scalability for such technology at 66 kVac and 10 MVA levels

Key Features: "Building Block" with Scalability at Ultra High Voltage

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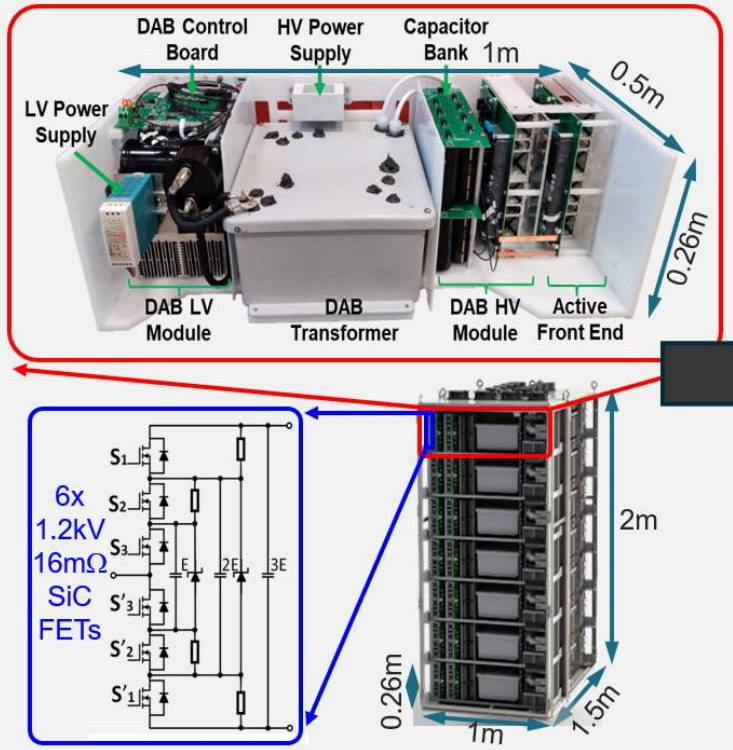
EXISTING

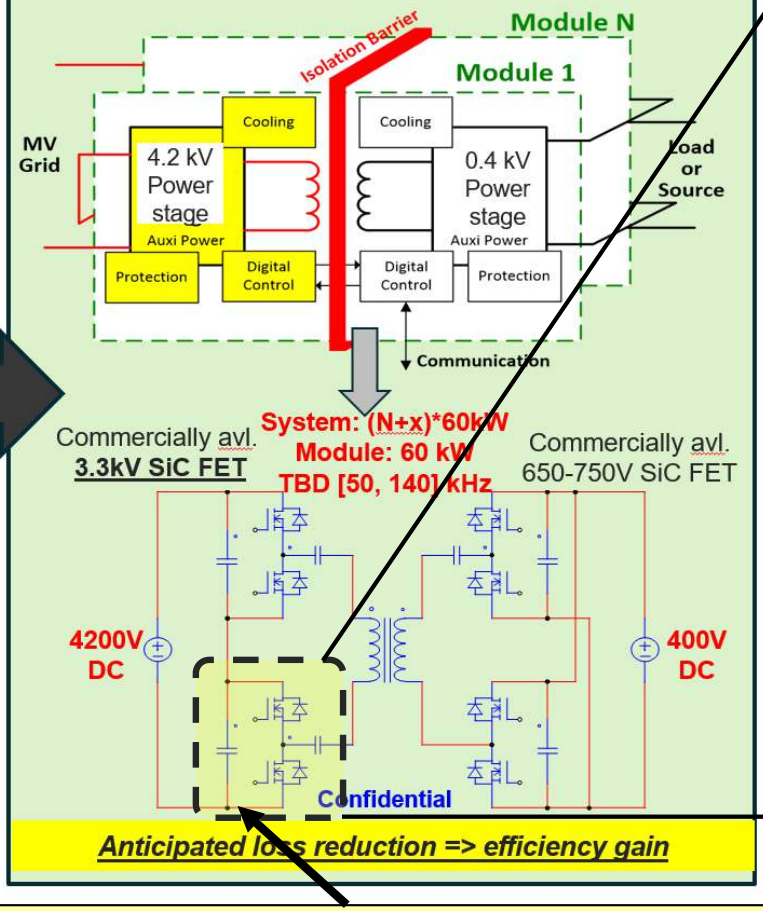
1.2kV SiC-based



FREEDM: Synchronised flying-cap ML topology
6 x 1.2kV TO-247 SiC MOSFETs verified in 1MW system

PROPOSED

3.3kV SiC-based



Anticipated loss reduction => efficiency gain

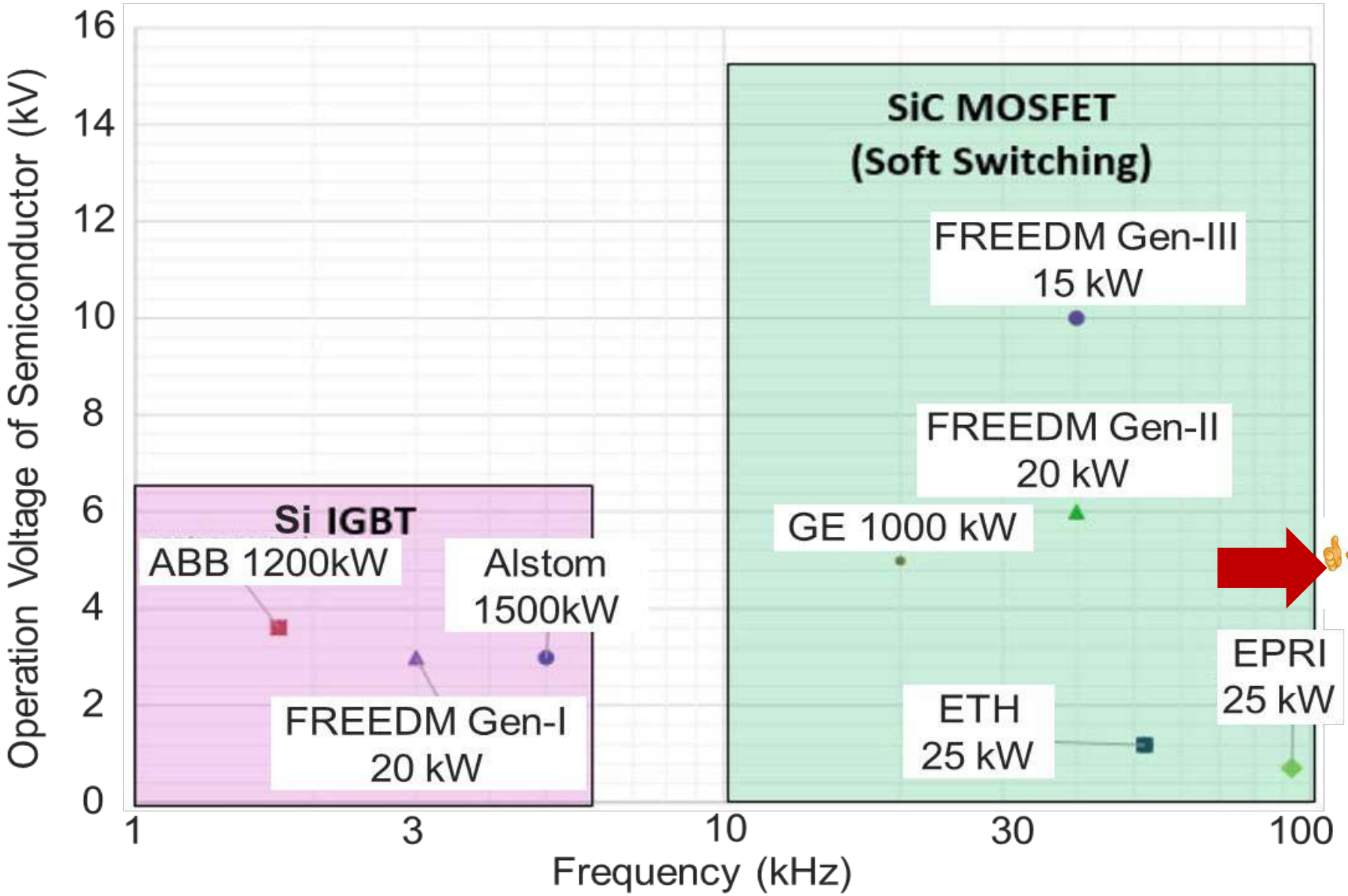
Features: Building Block with Ultra HV Scalability

- **Fiber controlled 3.3kV SiC MOSFETs**
- **Self powered** design
- **Multiple MVDC links (2.1kV) in series**
- **Ultra high voltage isolation** (control-to-power, 100kV)
- **Sealed cooling solution** to prevent contamination of electrical components

Building Blocks to be connected in series or parallel

❑ Electrical Design Progress

Why High-Voltage SiC with Soft-Switching ?

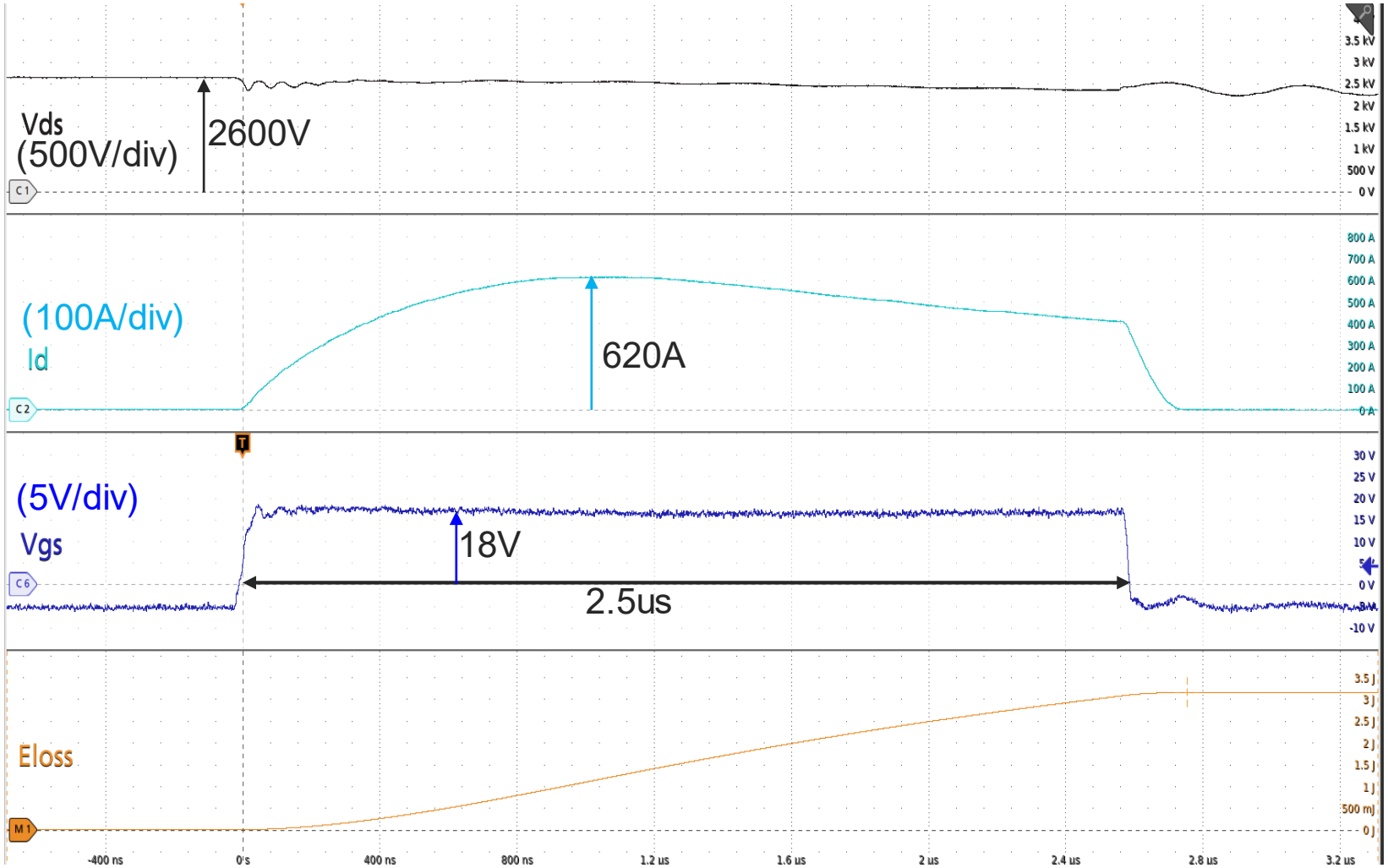


Proposed

3300V
25mΩ
SiC FET

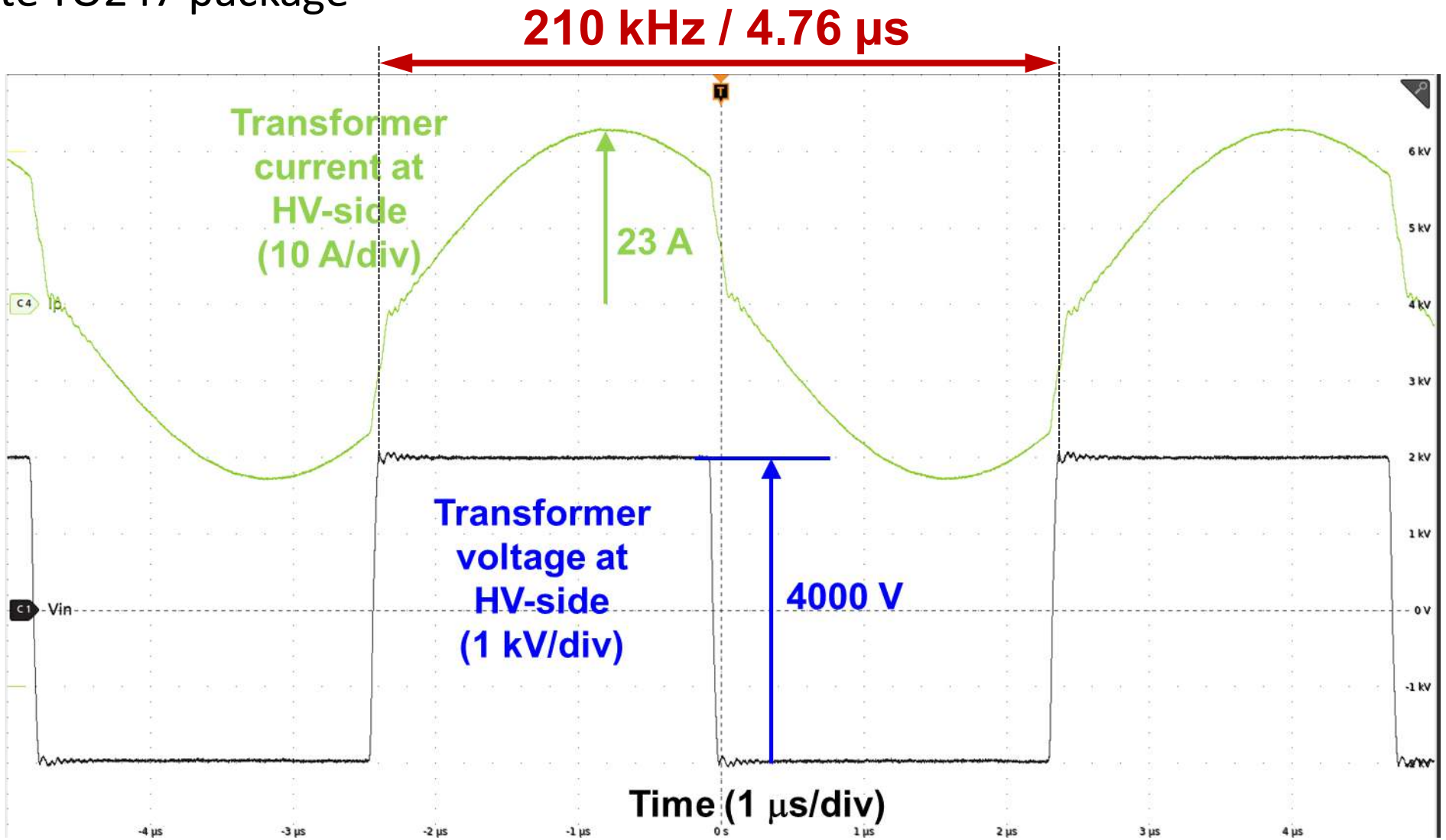
3300V SiC FET Is Very Reliable

- 3300V 80mOhm SiC FET short-circuit test results at 2600V dc-link



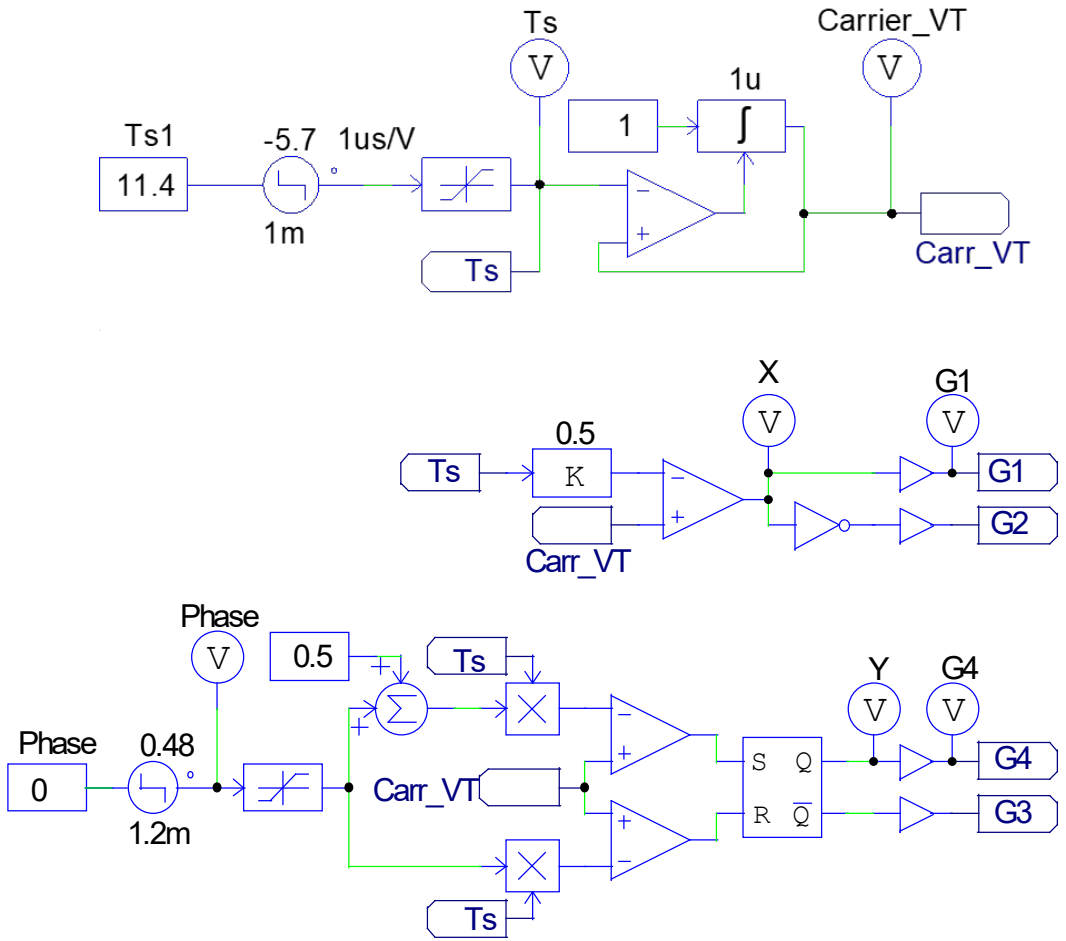
3300V SiC FET Operating at 210 kHz

- Validated high frequency (210 kHz) operating of 3.3 kV SiC MOSFETs with cost-effective discrete TO247 package

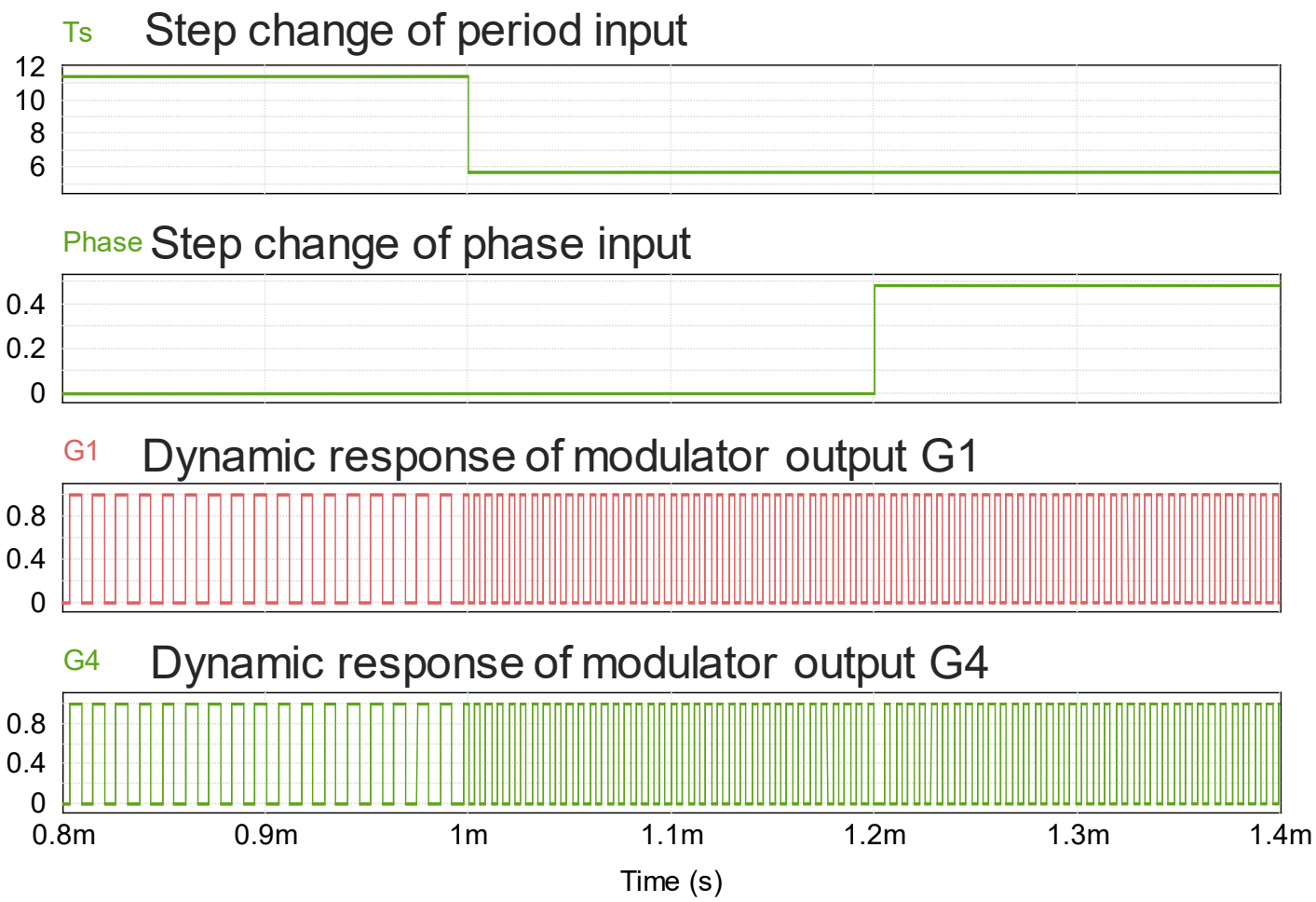


Simulation of Modulator with Two-Input Variables: Independent Period and Phase

- **Structure of independent period and phase modulation**

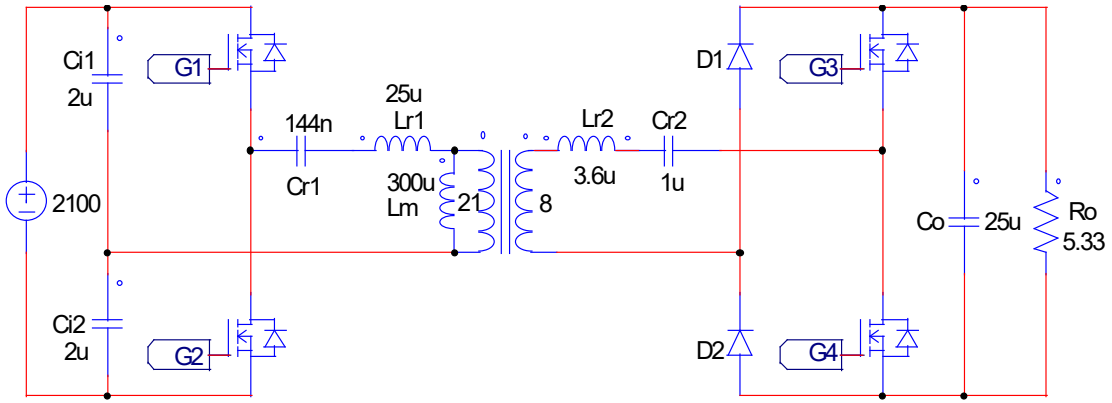


- **Modulator dynamic response to period and phase step changes**

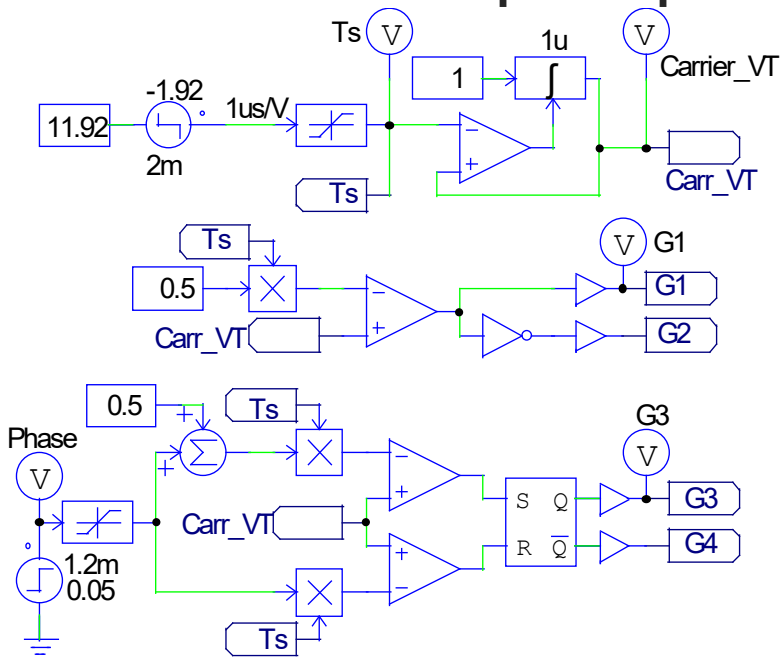


Simulation of Converter (Power Stage + Modulator)

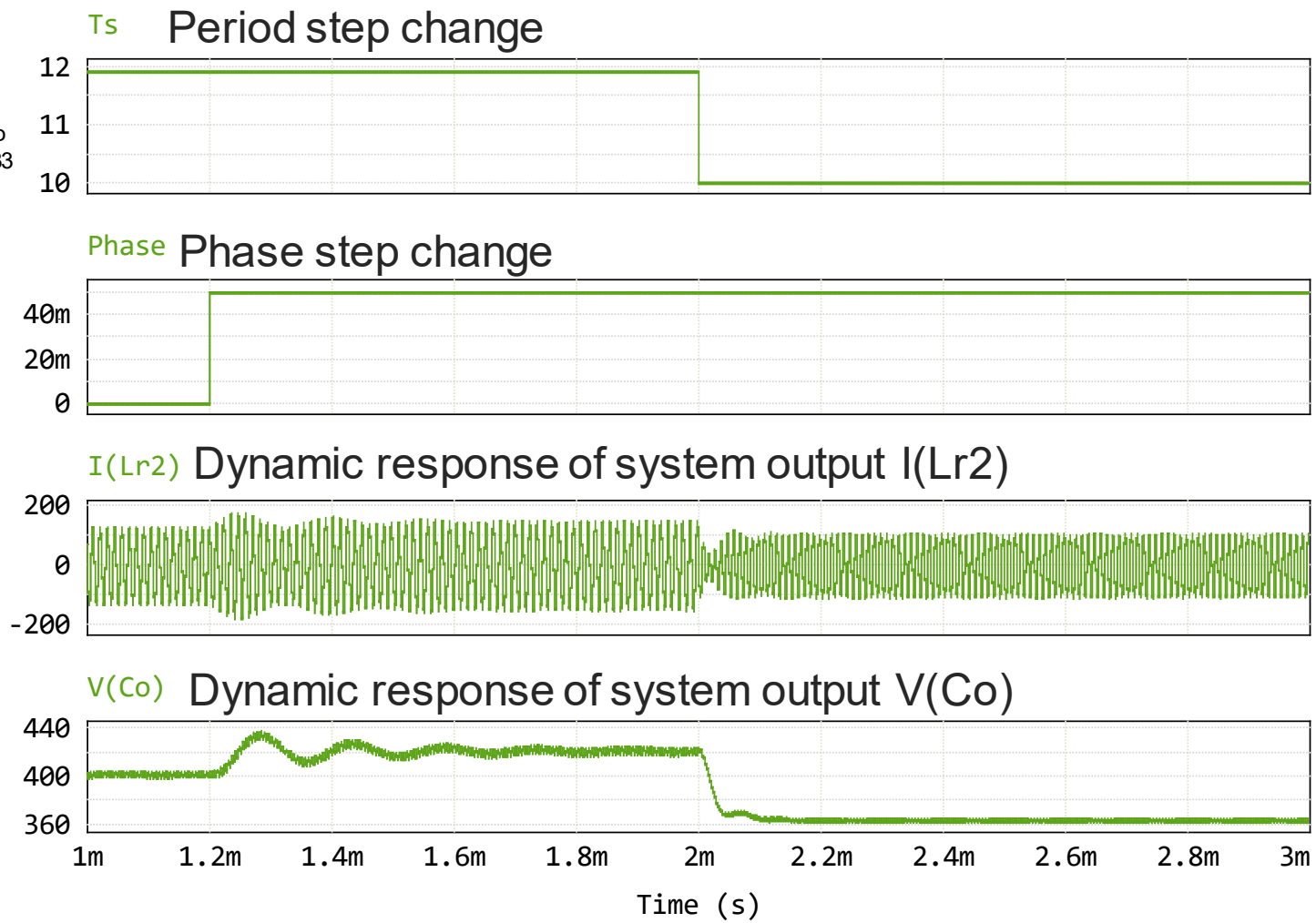
- **Power stage**



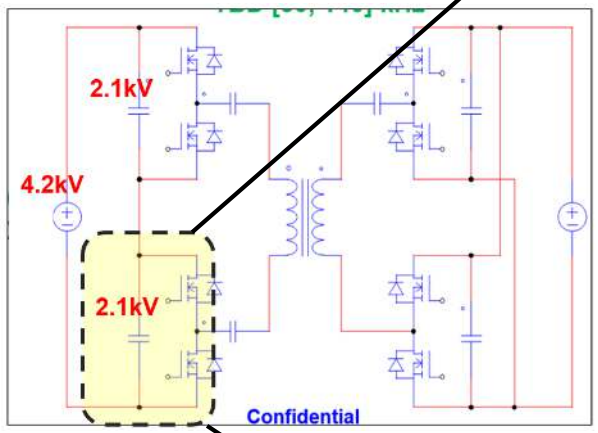
- **Modulator with 2-indepent-input**



- **Converter dynamic response to 2-input step changes**



Looking Inside: Single Building Block with Ultra HV Scalability



Local Power Supply
(no need of external PSU – "self powered")

DC-link midpoint as reference – halves the isolation requirement

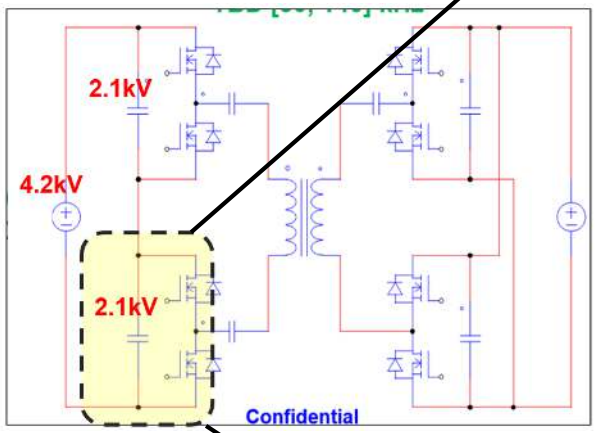
3.3kV SiC half-bridge

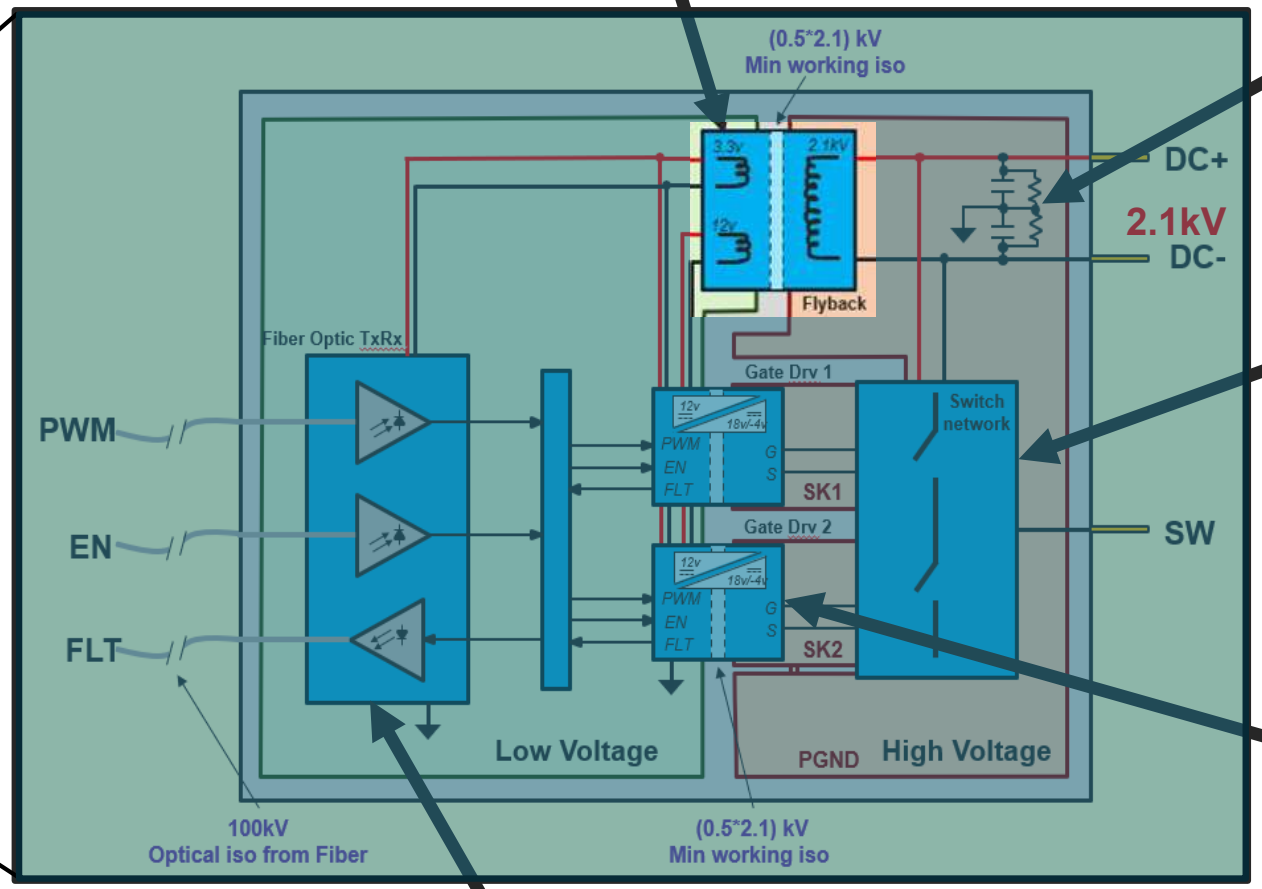
Local isolated gate driver
local isolated power supply
and local heatsinks

Fiber Optic for bidirectional communication
(provides control-to-power 100 kV isolation)

Looking Inside: Local Power Supply with 200-2100V Input

Local Power Supply
(no need of external PSU – "self powered")





DC-link midpoint as reference – halves the isolation requirement

3.3kV SiC half-bridge

Local isolated gate driver
local isolated power supply
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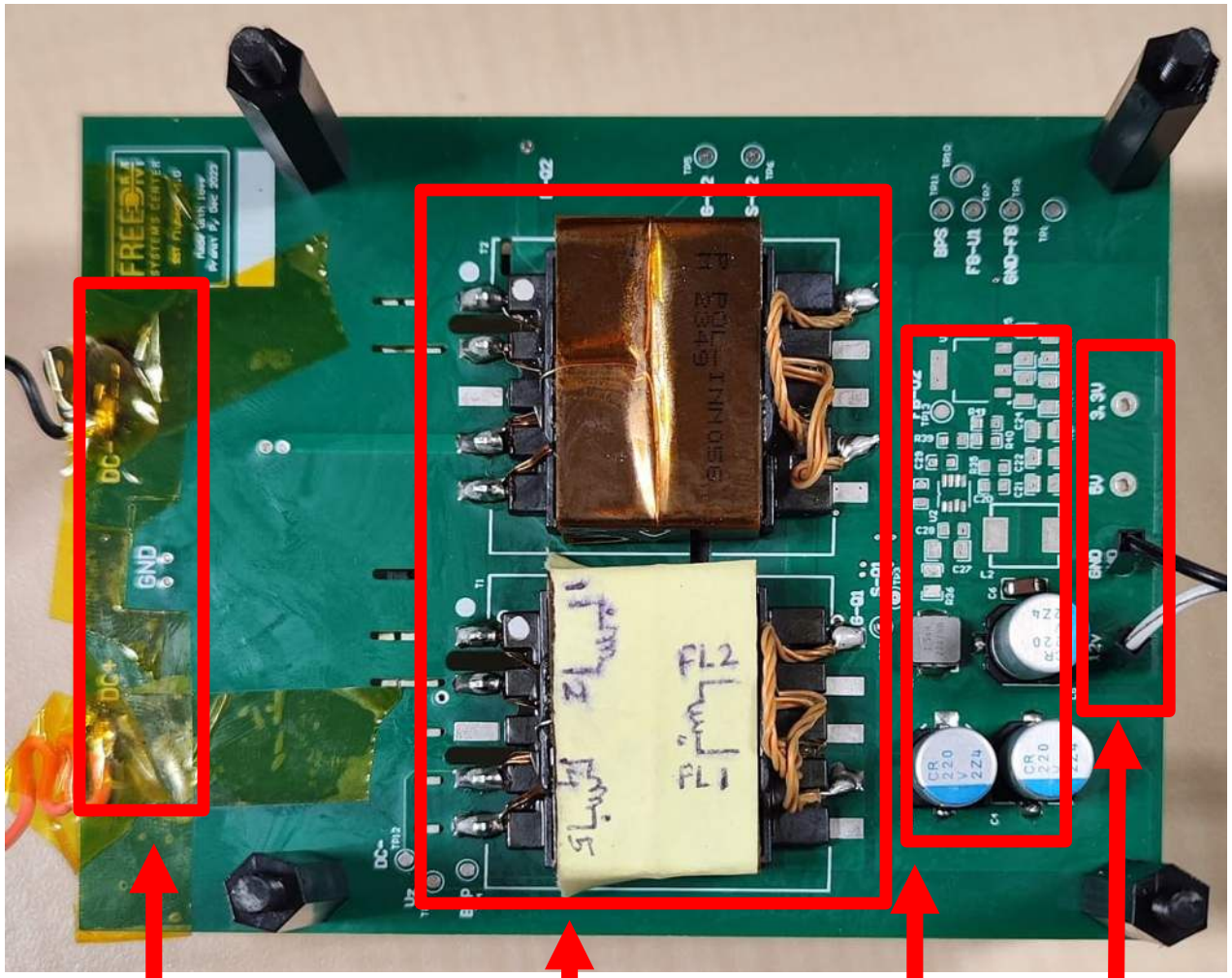
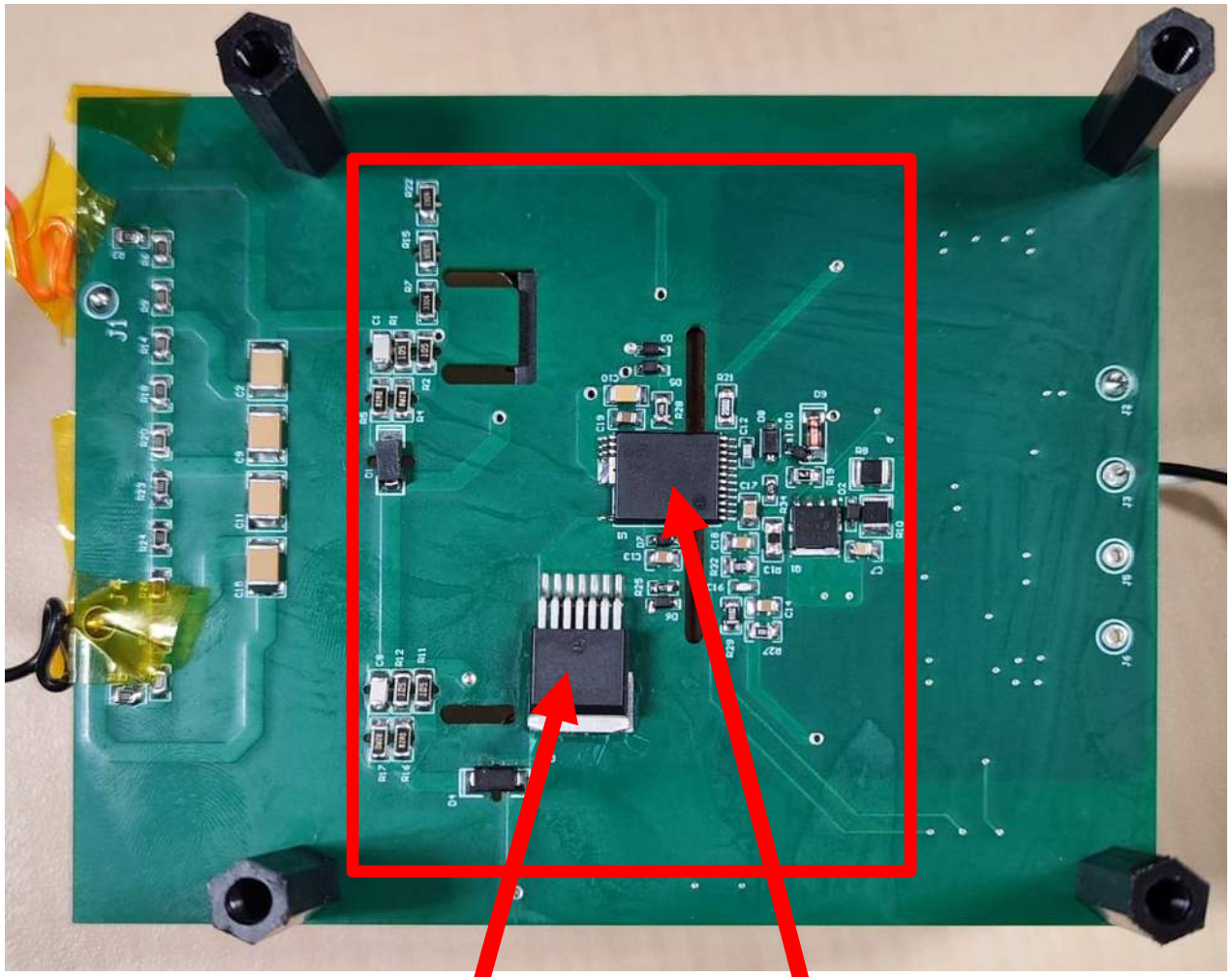
Fiber Optic for bidirectional communication (provides control-to-power 100 kV isolation)

Hardware of Local Power Supply (200-2100V Input)





Input (200-2100V)

Flyback Components (TOP)

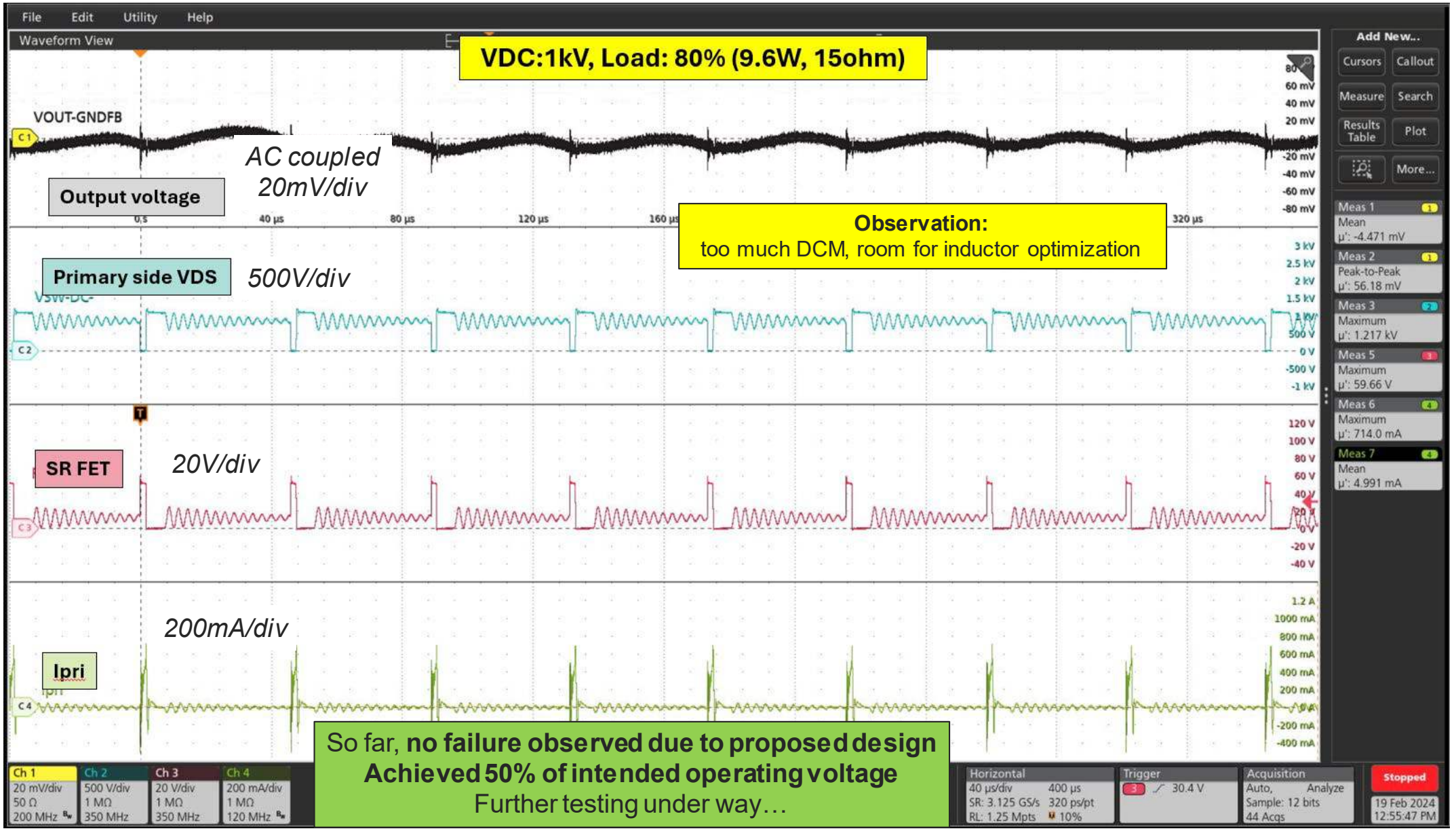
Filter and LDO

Output (12V, 5V, 3.3V)

3.3 kV SiC FET (BOTTOM)

Single IC (BOTTOM)

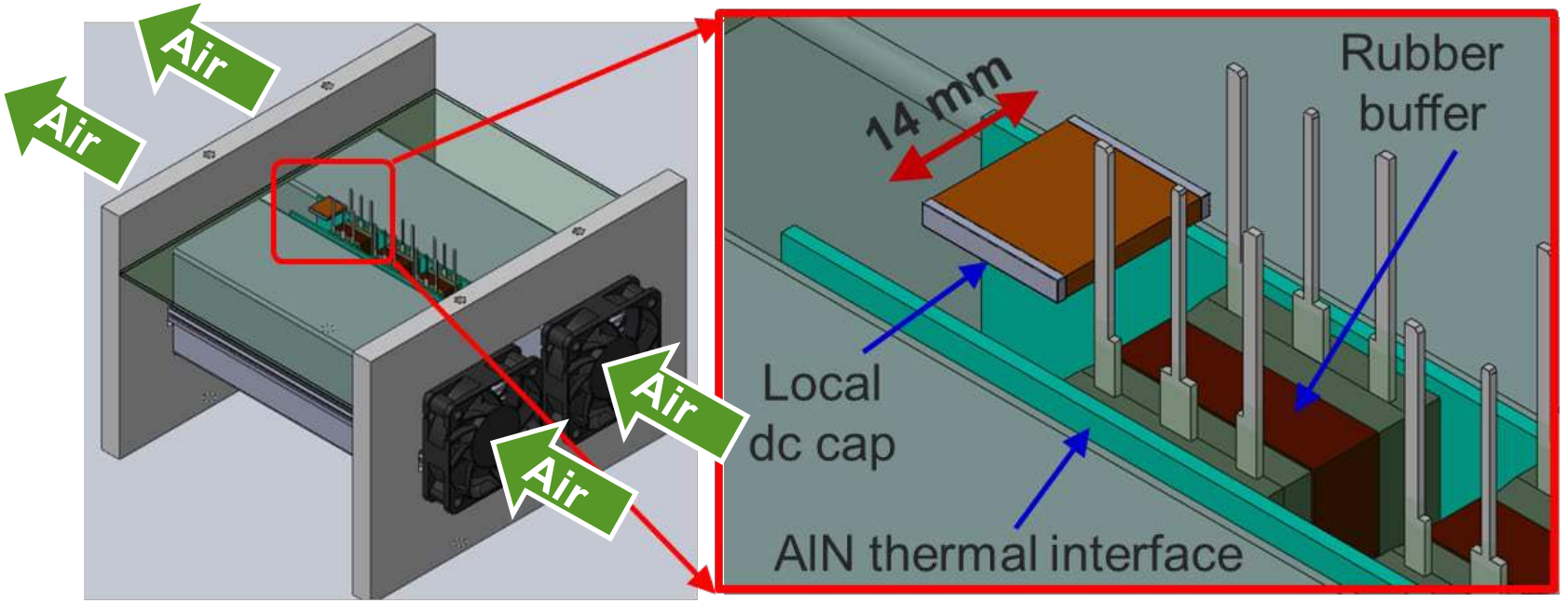
Testing of Local Power Supply (200-2100V Input)



❑ Mechanical Design Progress: From Single Block To System Level

Cost-Effective 3D Packaging of Single Block with Discrete 3300V SiC Devices

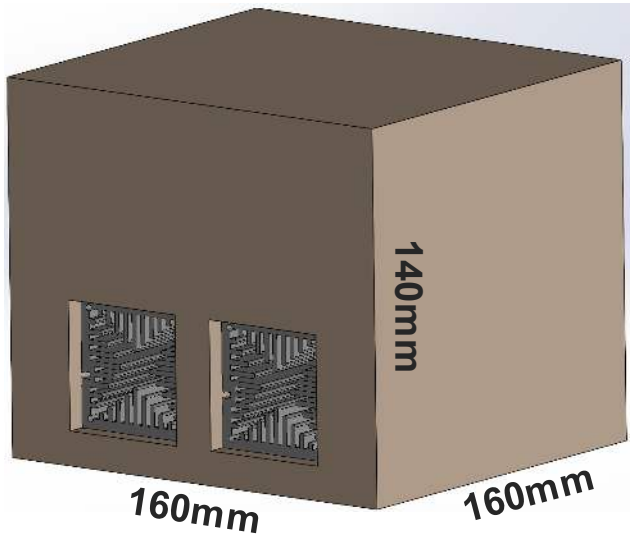
- ❑ **Low cost discrete 3300V SiC MOSFETs with sealed air cooling**
- ❑ **High performance Aluminum Nitride (AlN) thermal interface**
  - Very high voltage isolation
  - Very low thermal resistance
- ❑ **Optimized rubber buffer assembly**
- ❑ **Minimum commutation loop inductance**

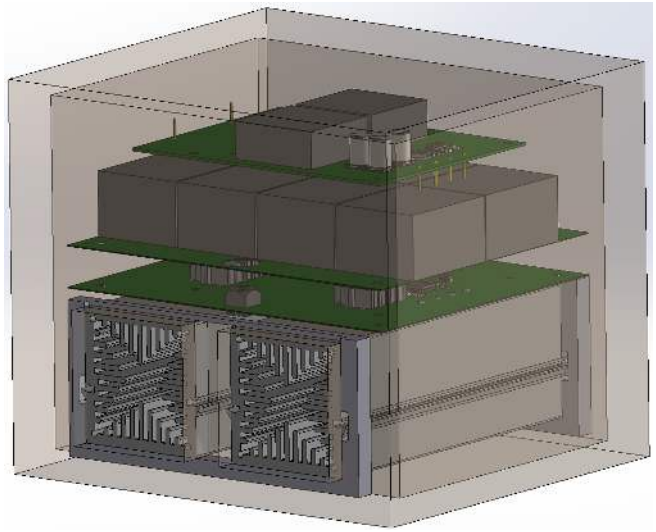


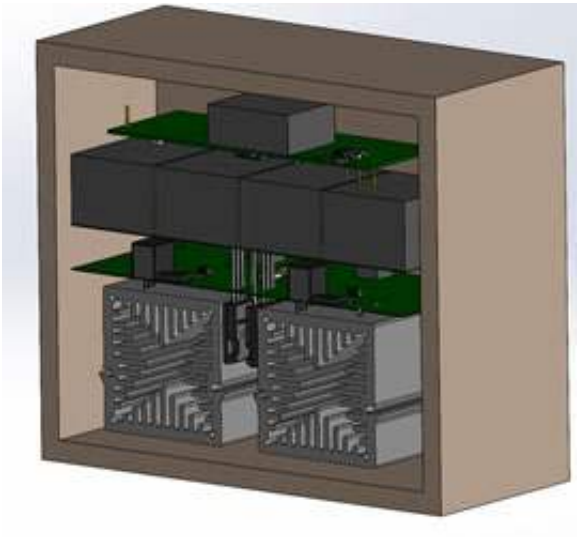
3300V 25mΩ discrete SiC FET

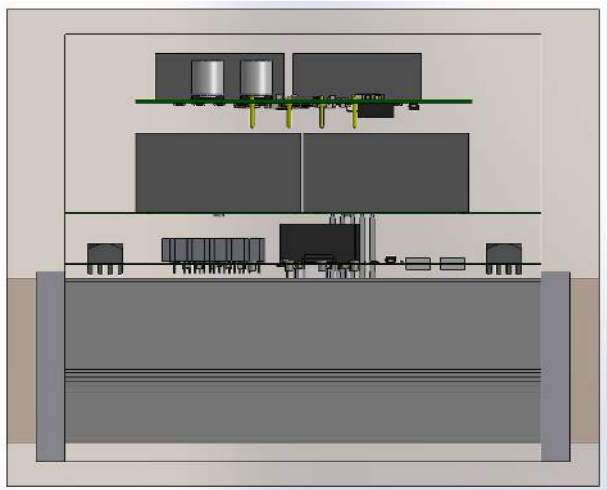
Reference: Wensong Yu, Dakai Wang, and Srdjan Lukic, "High Voltage Isolation Using Discrete Non-Isolated Devices And Electrically Isolating, Thermally Conductive Substrate" U.S. Patent Application #: US20220385081A1.

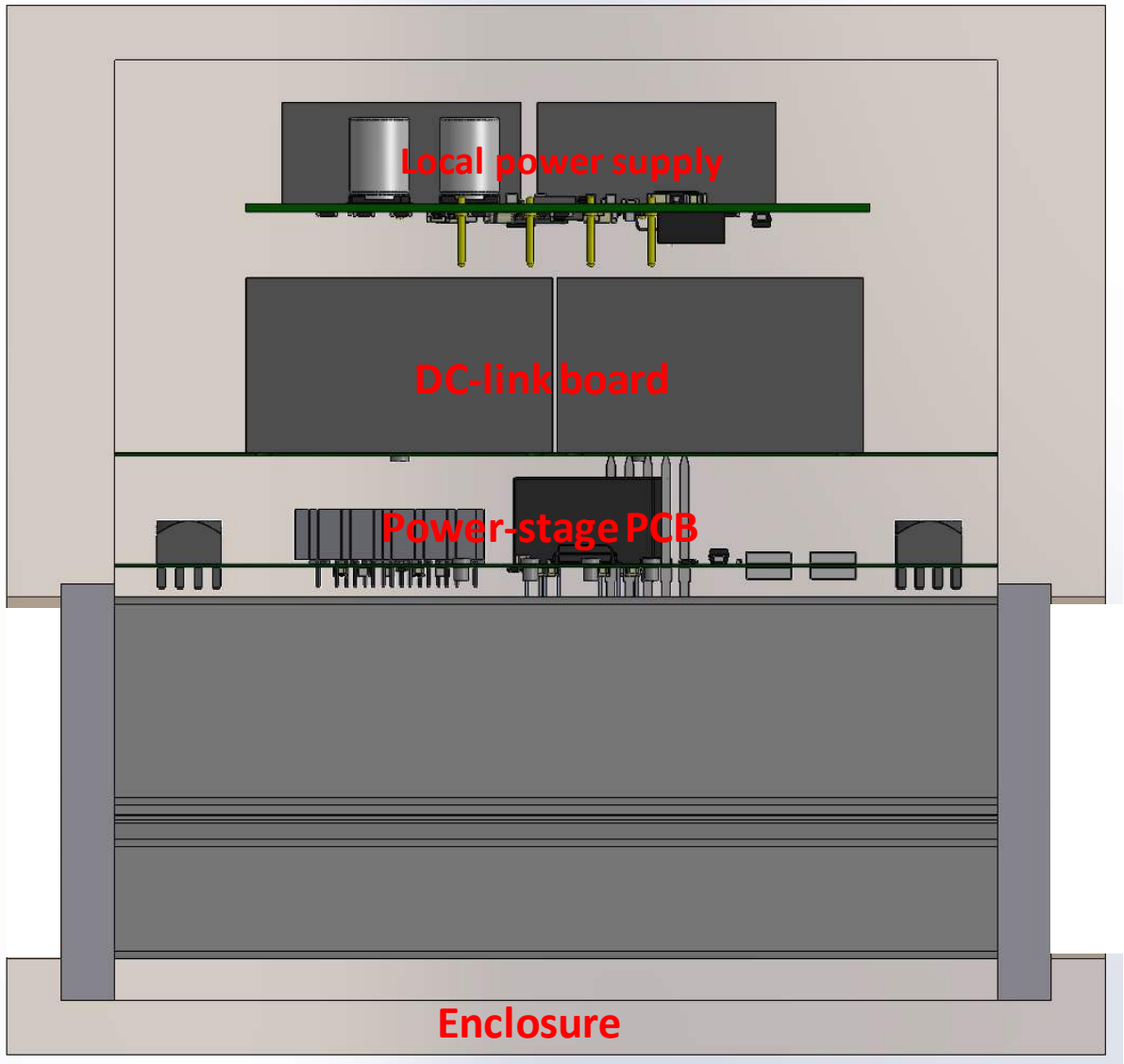
3D Packaging of Single Building Block



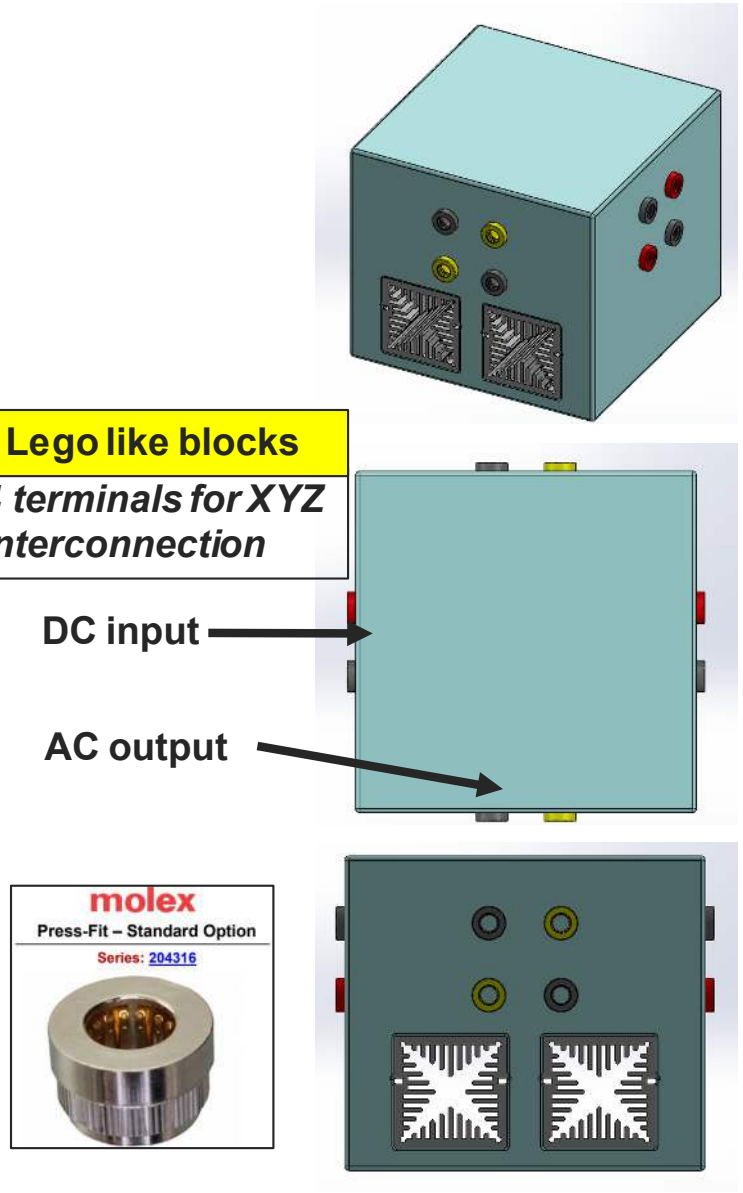




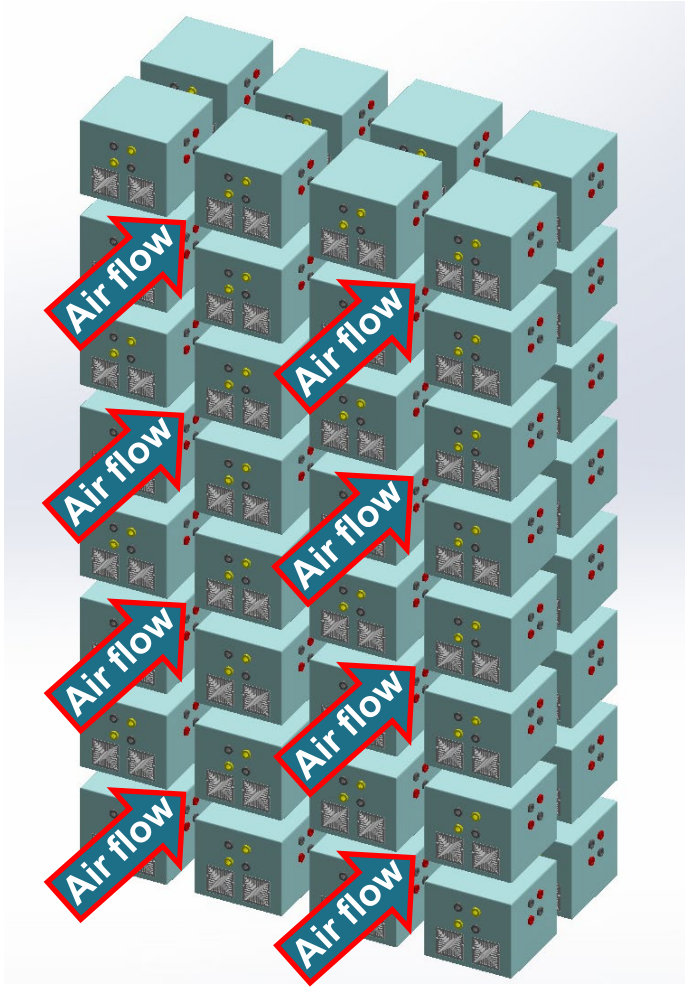




Modular SST 3D Conceptual Design: From Single Block To System Level



- **Flexible interconnect enables efficient usage of available space**
  - Electric terminals connected in parallel or in series along XYZ
  - Cooling channels connected in parallel (Preferred) or in series
  - Fiber optics connected in parallel or in chain structure



Summary and Future Work

❑ Major Accomplishments

- Fiber controlled 3.3kV SiC MOSFETs with self-power enables modular SST with scalability up to 66 kVac
- Modulation method with 2-independent-input was simulated for proposed AC-AC SST and DC-DC SST
- Discrete 3.3kV SiC MOSFETs with the patented structure simplifies the SST building block design
- Sealed cooling channels are pre-defined to ensure cooling performance and contamination free

❑ Future Work

- To finalize conceptual 3D design
- Hardware and software development of modular DC-DC or AC-AC SST
- Possible innovative design of the transformers with ultra-high partial discharge inception voltage


Thank you!
Any Comments, Suggestions,
or Questions?