

Shimul Dam¹, Ching-Hsiang Yang¹, Zhou Dong³, Dehao Qin², Ruirui Chen¹, Fred Wang^{1,4}, Hua Bai¹, and Zheyu Zhang⁵
¹ The University of Tennessee, Knoxville ² Clemson University ³ ABB US Research Center
⁴ Oak Ridge National Laboratory ⁵ Rensselaer Polytechnic Institute

INTRODUCTION:

- The future Electrified Aircraft Propulsion (EAP) systems are expected to use medium voltages at MW power levels [1].
- Fast solid-state circuit breaker (SSCB) is needed for low-inductance MVDC system [2].
- Future EAP will also use cryogenic fluids for fuel and cooling superconducting machines.
- Cryogenic fluid can be utilized to achieve higher efficiency and power density.

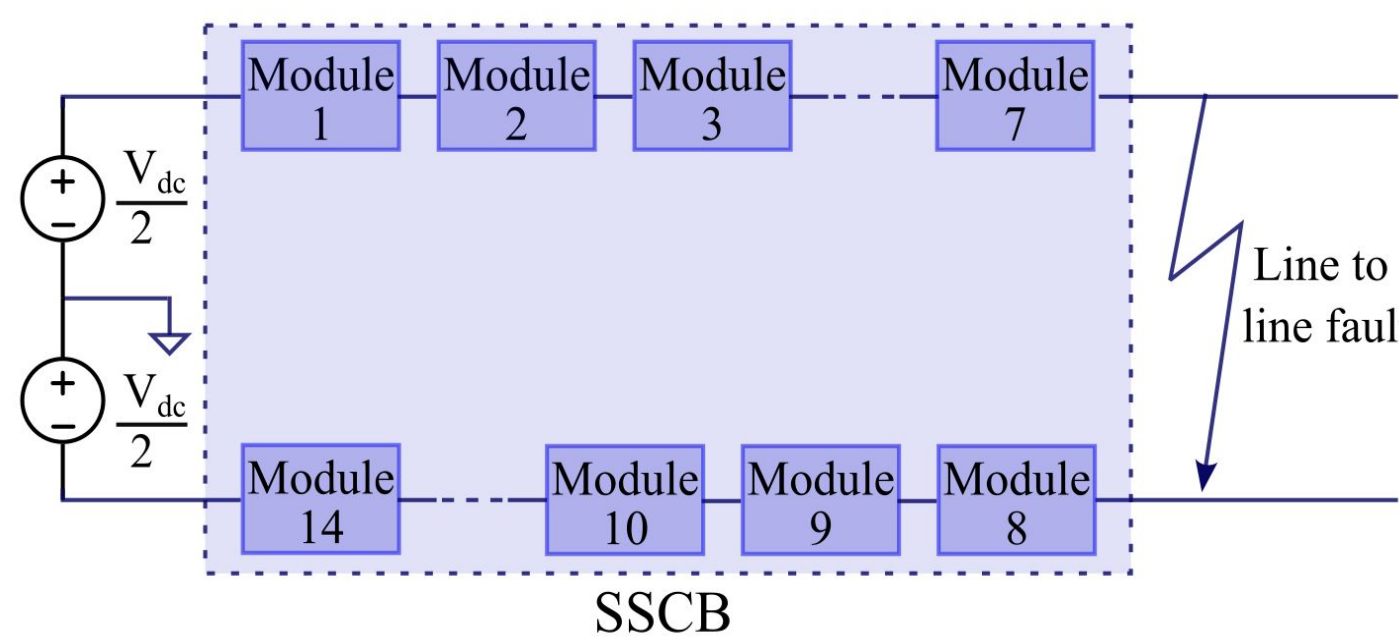


Figure 1. Modular SSCB for a bipolar 10 kV MVDC system.

- A 750V, 100A SSCB module is developed with liquid Nitrogen (LN₂) cooling.
- The 10 kV, 100A SSCB is consist of 14 such modules.
- GaN dies are selected due to their superior characteristics at cryogenic temperatures [3].

SSCB MODULE STRUCTURE

- Each module has a main board and an auxiliary board for electrical components and a cold plate for LN₂ cooling.
- The main board has GaN dies with their gate drivers and is placed closer to the cold plate.
- The module is attached to cold plate through a DBC for electrical insulation.
- Two such modules are placed on either sides of a cold plate to improve power density.

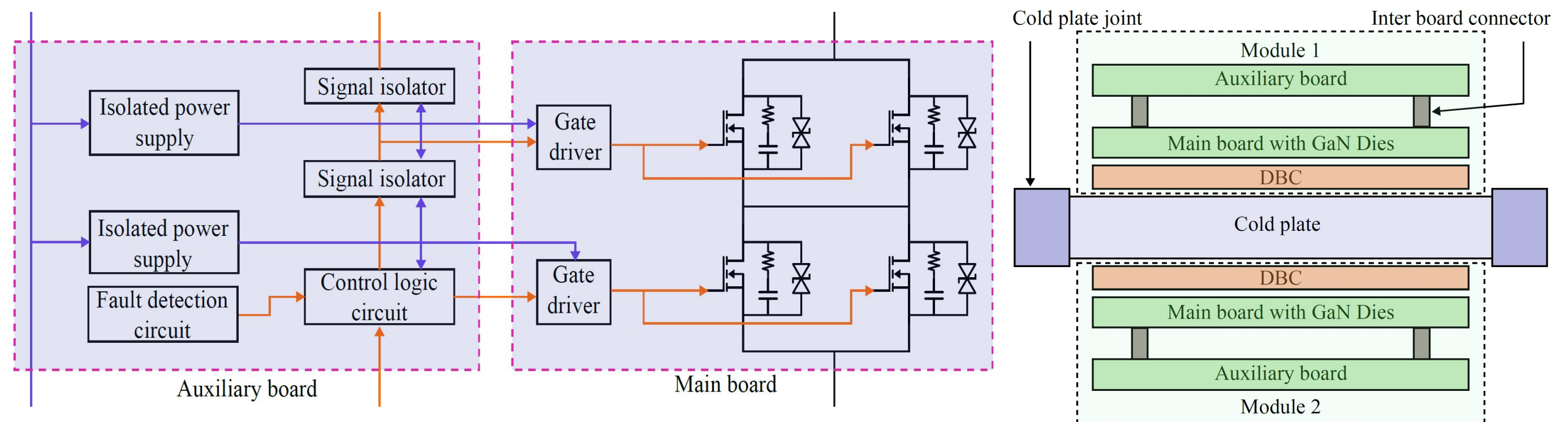


Figure 2. Structure of a 750V, 100A SSCB module: electrical design and mechanical structure.

COLD PLATE AND INSULATION DESIGN

- Thin-walled aluminum cold plate designed to improve specific power density.
- Cold plate design is modular, allowing each module with its own cold plate.
- Cold plates are joined by heat-shrink method, which is reliable at cryogenic temperatures.

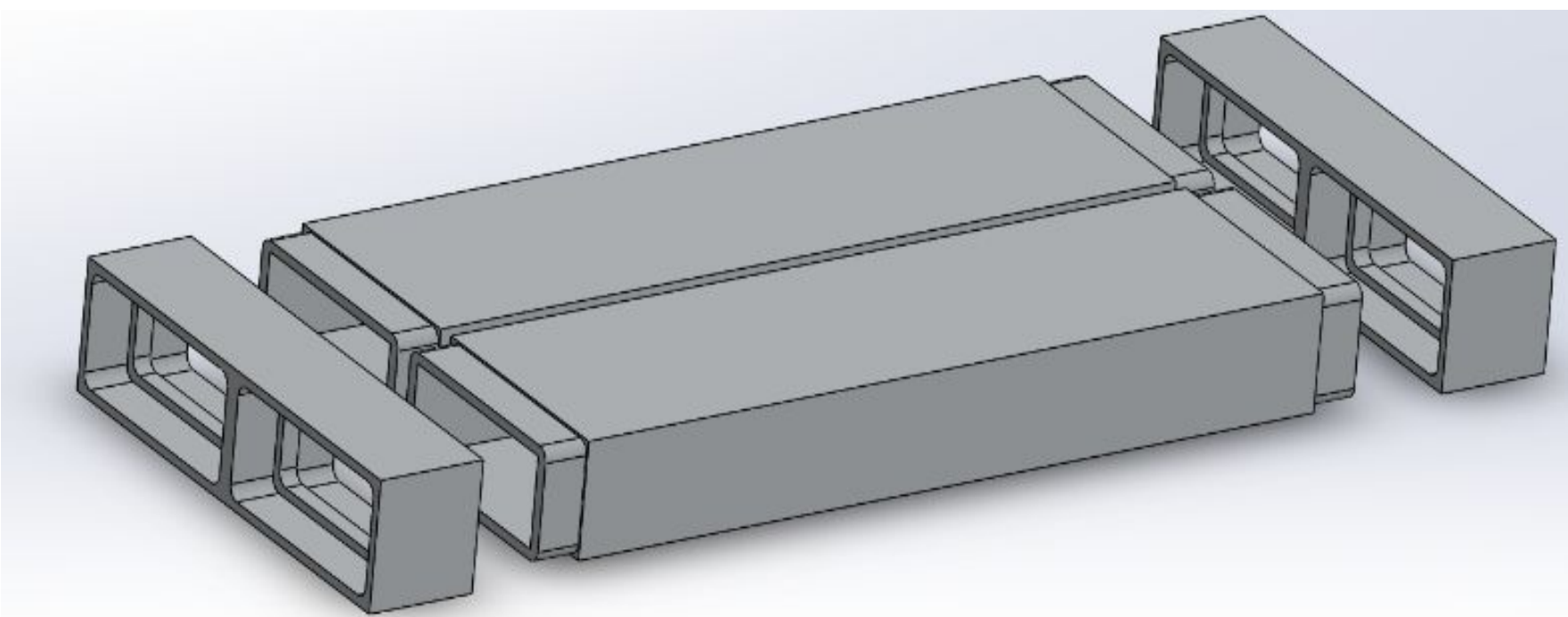


Figure 3. Modular cold plate of the SSCB.

- Cold plates are grounded. Each module is subjected to 5 kV insulation stress in a 10 kV bipolar DC system.
- DBC is designed with adequate thickness. Edges of DBC and exposed parts of the cold plate are coated with epoxy resin.

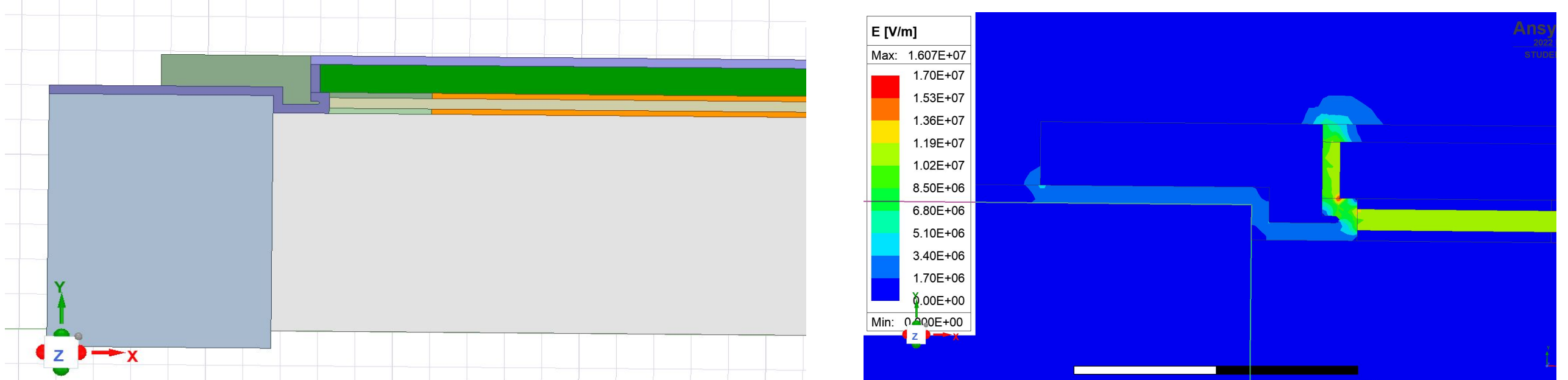


Figure 4. Electrostatic simulation model of the module insulation design and simulation results in Ansys.

- An Ansys model of the designed insulation is simulated with 8 kV between cold plate and module.
- The simulation result shows that the peak electric field is 16 kV/mm in epoxy and 11.9 kV/mm in ceramic material, both within their limits.

EXPERIMENTAL RESULTS

- A 750V, 100A module prototype developed with power density of 329 kW/kg.
- The module is tested in a thermal chamber at cryogenic temperatures.
- Module insulation is tested up to 8kV between module and cold plate. The observed leakage current is 40 nA.
- Module is successfully tested to interrupt 10x fault current at -180°C with LN₂ cooling.
- Good current sharing in paralleled dies.

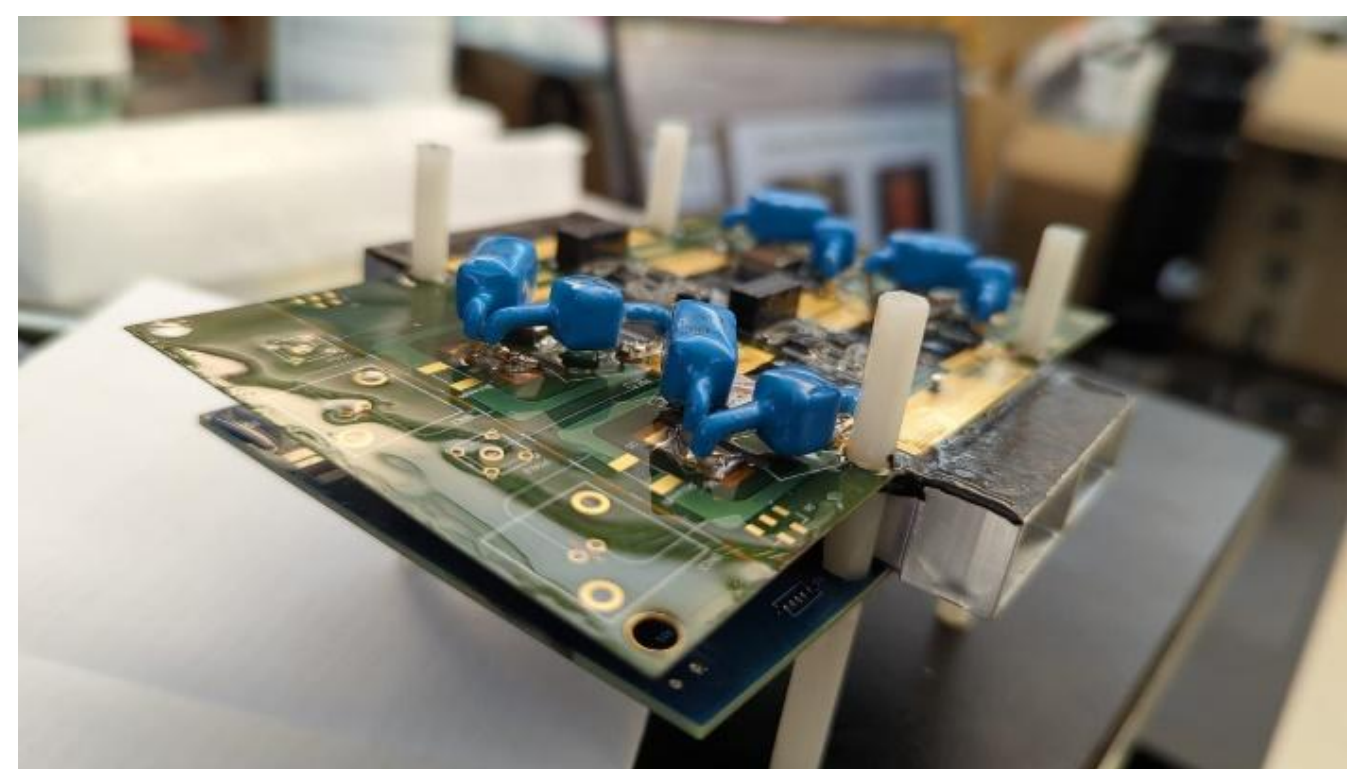
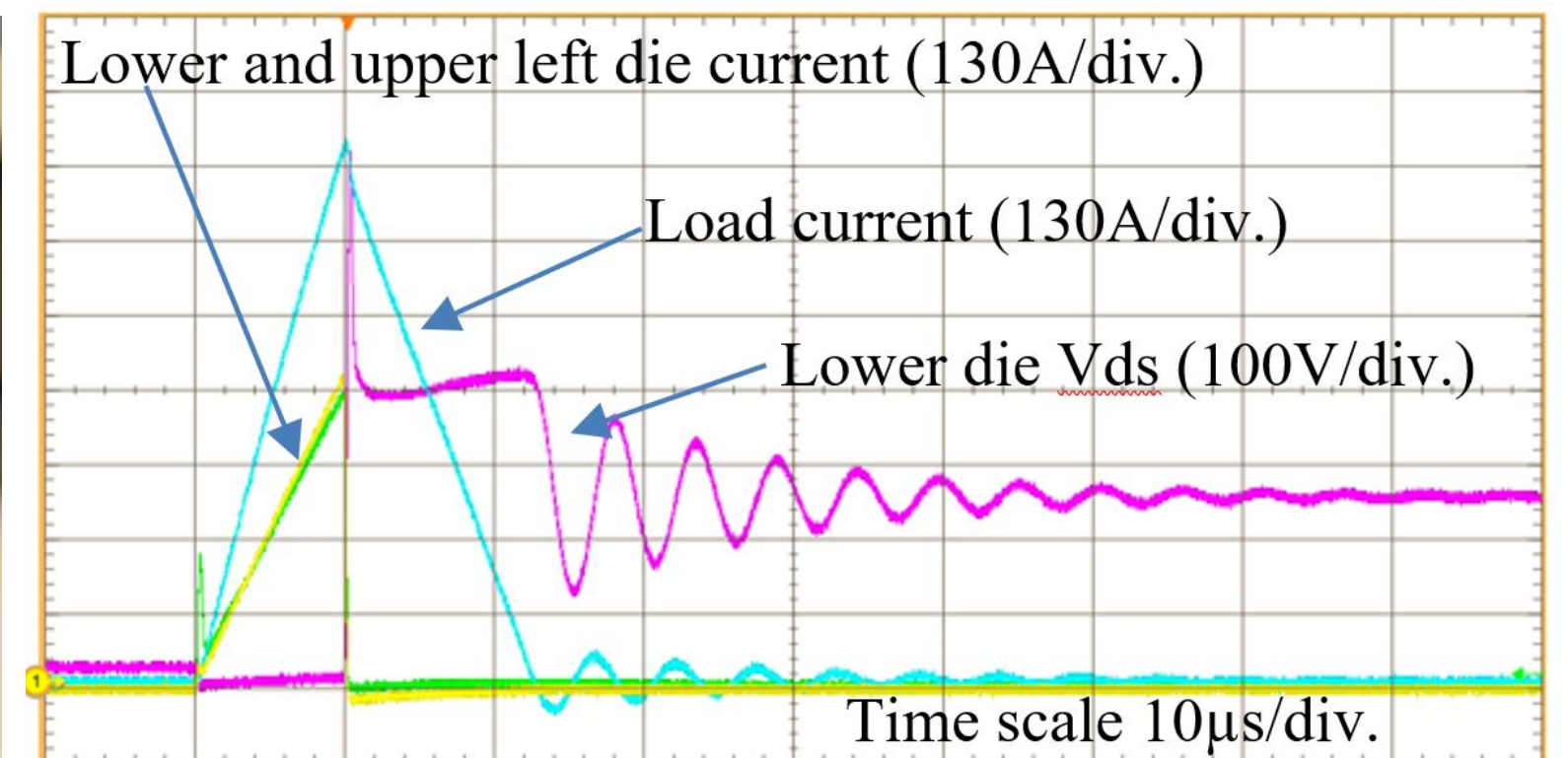


Figure 5. Developed SSCB module and test result of 1 kA fault interruption.



CONCLUSION

- The design of a 750V/100A cryogenic SSCB module is presented, which utilizes the superior characteristics of GaN at cryogenic temperatures.
- A reliable and low-weight modular cold plate design is discussed.
- The developed SSCB module prototype has a power density of 329 kW/kg and can withstand 8kV insulation stress.
- The 10x fault current interruption capability of the module is verified.
- Feasibility of cryogenically cooled GaN based SSCB modules for MVDC application is demonstrated.

REFERENCES

1. R. Jansen, et. al., "Overview of NASA electrified aircraft propulsion (EAP) research for large subsonic transports," in 53rd AIAA/SAE/ASEE Joint Propuls. Conf., 2017.
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3. Z. Zhang, et. al., "Characterization of high-voltage highspeed switching power semiconductors for high frequency cryogenically-cooled application," in Applied Power Electronics Conference and Exposition, Tampa, FL, 2017.

