A Cryogenic Gallium Nitride Full Bridge for Use in a Thermally Insulating Dual Active Bridge

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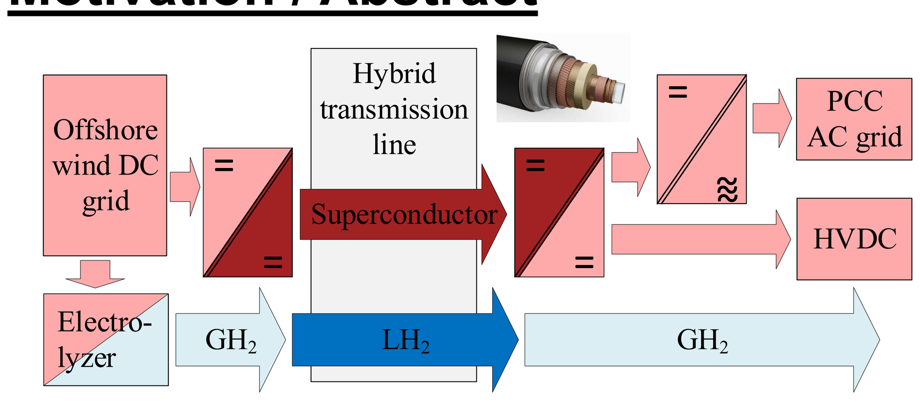
ECCE 2024 – IEEE Energy Conversion Congress & Expo, Phoenix, Arizona, USA, Oct. 20-24

Karlsruhe Institute of Technology – ETI Elektrotechnisches Institut

Sponsored by the Federal Ministry of Education and Research – Flagship Project TransHyDE

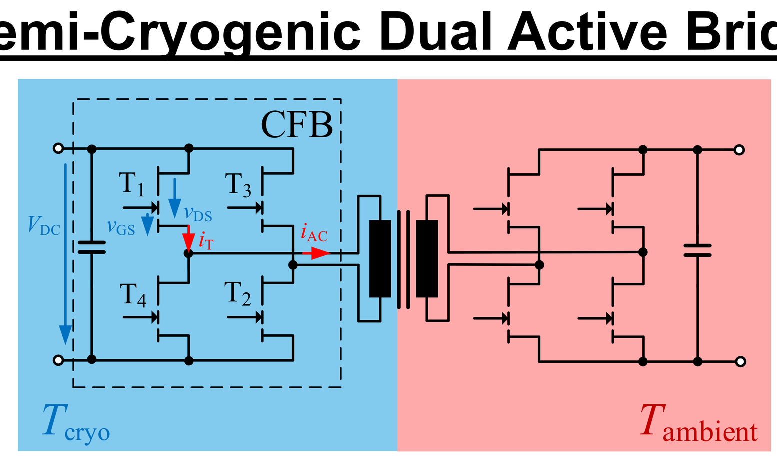
Motivation / Abstract



Hybrid transmission line for offshore wind DC grid connection

In this paper, a Liquid Nitrogen (LN_2) cooled Gallium Nitride (GaN) Cryogenic Full Bridge (CFB) is presented as part of a Dual Active Bridge (DAB) for use in a hybrid Liquid Hydrogen (LH_2) High Temperature Superconductor (HTS) transmission line. The concept of a 20 kW DAB with cryogenic parts is outlined and the design of the CFB as one of the cryogenic parts is presented.

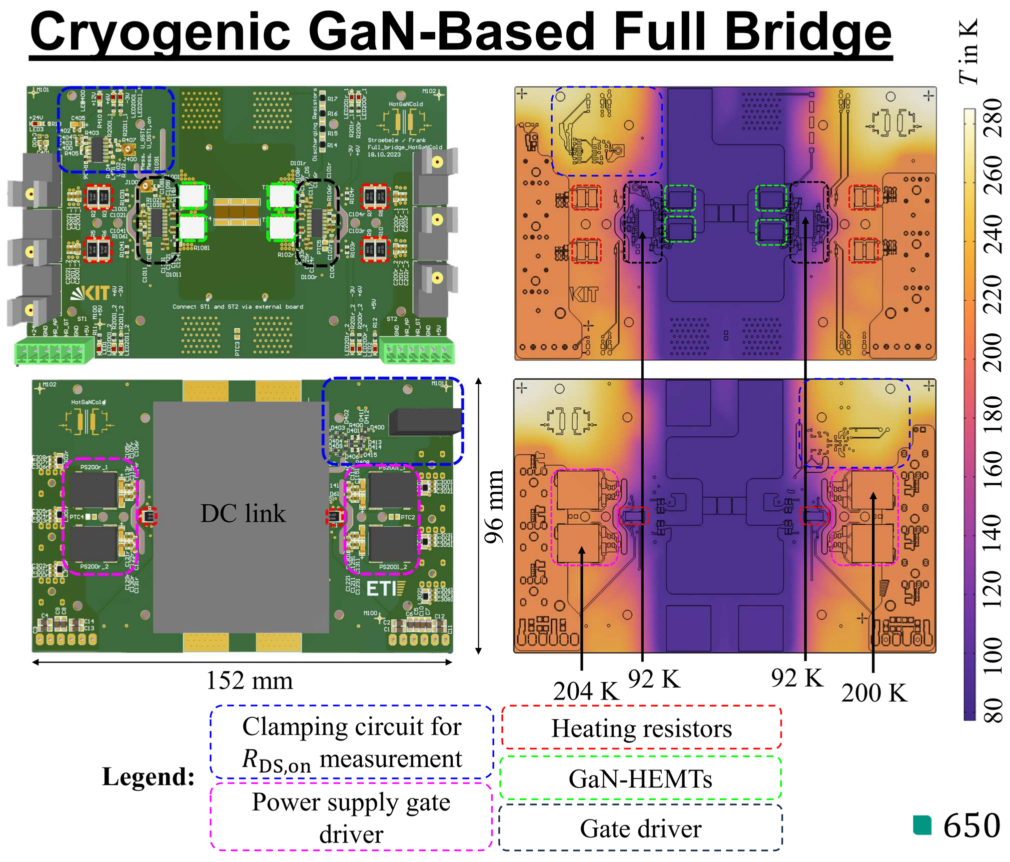
Semi-Cryogenic Dual Active Bridge



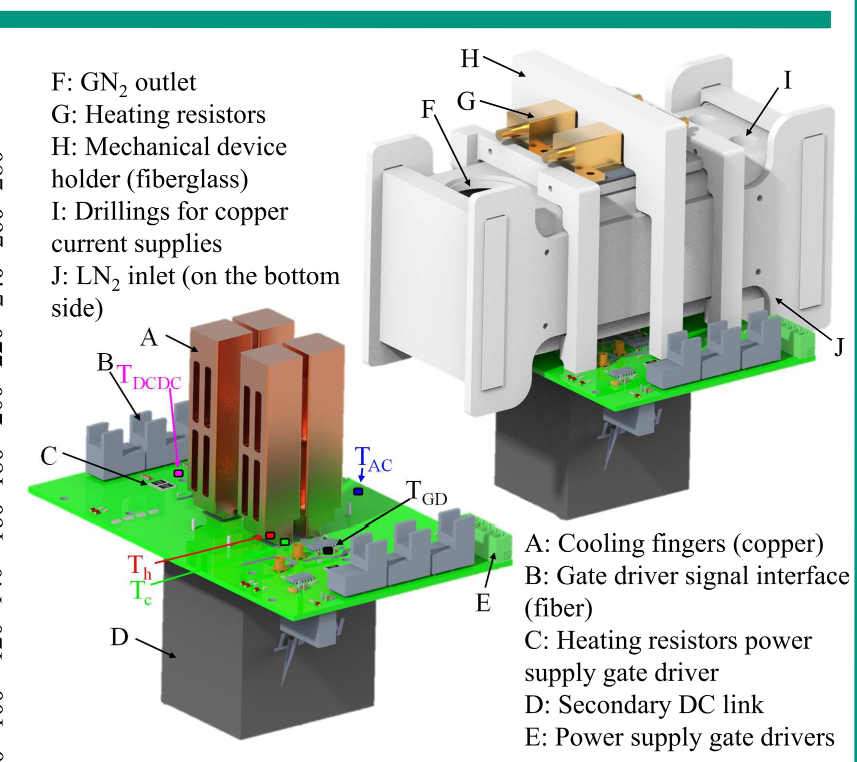
Semi-cryogenic converter topology

- Galvanically isolated converter (DAB, LLC)
- Thermally isolating medium frequency transformer
- Electrically identical warm and cold full-bridges
- Cold converter parts are LN_2 cooled (77 K)
- Warm converter parts are water-cooled
- 20 kW rated power at $V_{DC} = 400$ V
- 100 kHz switching frequency

Cryogenic GaN-Based Full Bridge



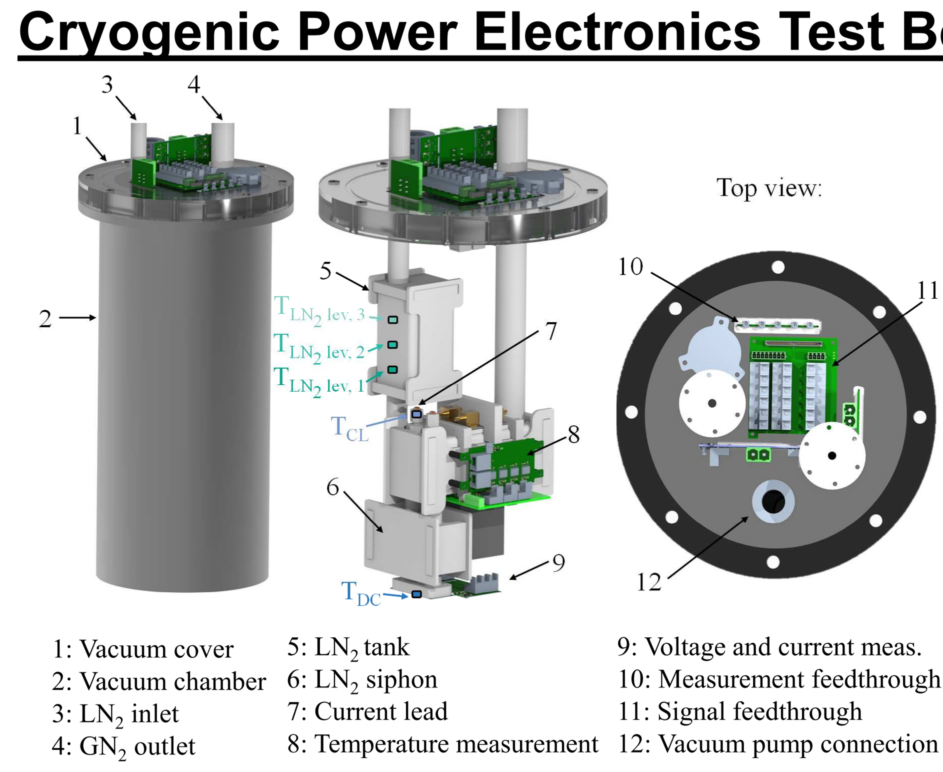
3D CAD PCB rendering and thermal simulation



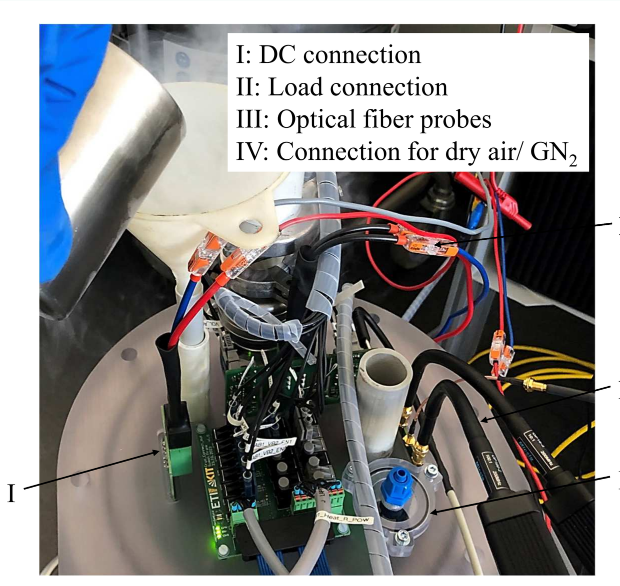
3D CAD rendering of the cryogenic heatsink

- 650 V, 60 A *GS66516T* GaN HEMTs from *GaN Systems*
- Thermally isolating PCB design ensures safe operation

Cryogenic Power Electronics Test Bench



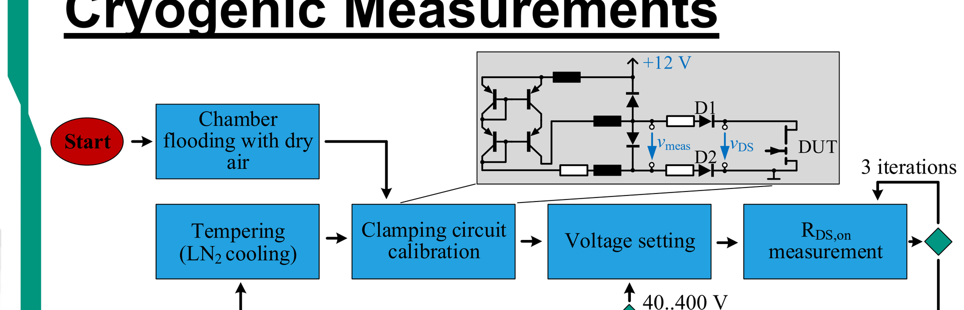
3D CAD rendering of the cryogenic test bench



Top view test bench during cryogenic measurement

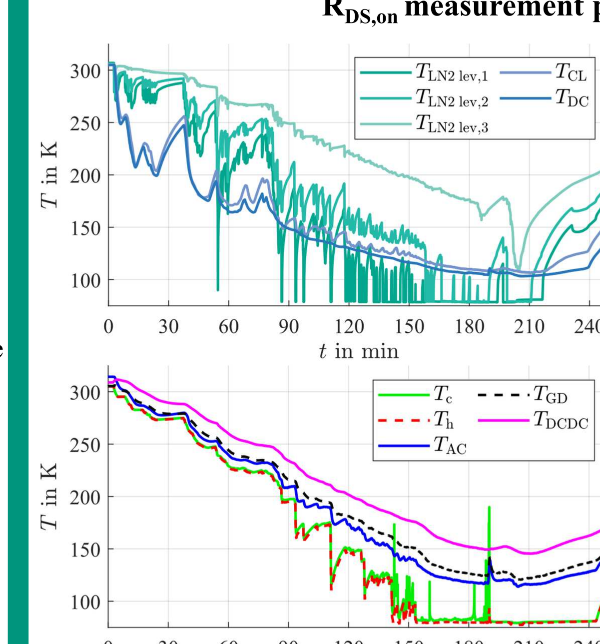
- Hermetical chamber (vacuum or dry air operation)
- Fiberglass-based LN_2 pipe system
- In-house developed vacuum feedthroughs

Cryogenic Measurements



$R_{DS,on}$ measurement procedure

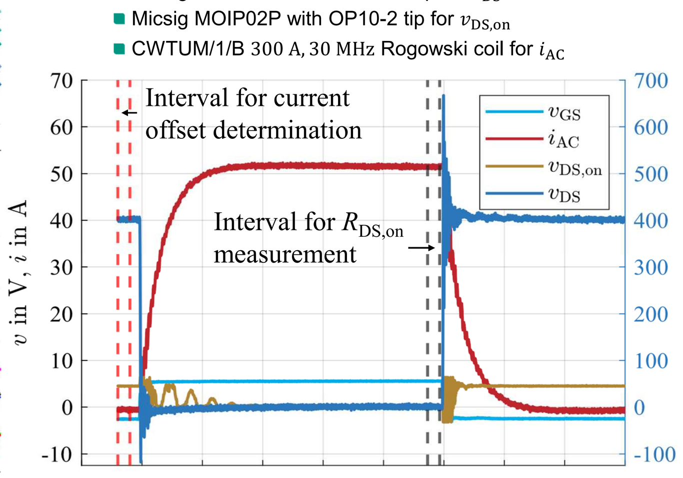
- Cryogenic $R_{DS,on}$ measurement in single-pulse operation
- 7.5 Ω and 15 Ω load resistors
- $R_{DS,on}$ is reduced by a factor of approx. 5 at cryogenic temperatures
- Continuous buck-mode operation was tested with reduced power



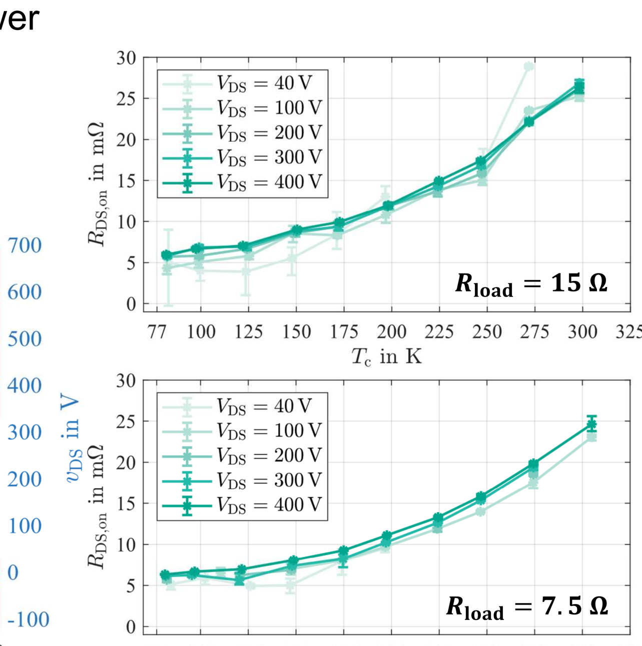
Temperatures during cryogenic measurement

Measurement Setup

- LeCroy Wavesurfer 4104HD, 12bit, 1 GHz oscilloscope
- PMK Firefly FF-1500 with FF-MMCX-25V tip for v_{GS}
- Micsig MOIP02P with OP500-2 tip for v_{DS}
- Micsig MOIP02P with OP10-2 tip for $v_{DS,on}$
- CWTUM/1/B 300 A, 30 MHz Rogowski coil for i_{AC}



Waveforms at $T_c = 99$ K, $R_{load} = 7.5$ Ω



$R_{DS,on}$ at different temperatures

References

[1] P. Alvarez et. al., *Design of a HTS 2 MW Electric Motor for Single-Aisle Regional Aircraft*
[2] Y. Wang et. al., *Feasibility Study of High Temperature Superconducting Machines for Electric Aircraft*
[3] S. Miura et. al., *Lightweight Design of Tens-MW Fully-Superconducting Wind Turbine Generators With High-Performance REBa2Cu3Oy Wires*
[4] S. Lengsfeld et. al., *Comparing Armature Windings for a 10 MW Fully Superconducting Synchronous Wind Turbine Generator*
[5] M. Stemmle et. al., *Superconducting MV cables to replace HV cables in urban area distribution grids*
[6] A. Allais et. al., *SuperRail World-First HTS Cable to be Installed on a Railway Network in France*
[7] H. Gui et al., *Review of Power Electronics Components at Cryogenic Temperatures*
[8] V. Vysotsky et. al., *Energy Transfer with Hydrogen and Superconductivity - The Review of the First Experimental Results*
[9] H. Sicius, *Handbook of the Chemical Elements*. Springer, 2024.
[10] R. De Doncker et al., *A three-phase soft-switched high-power-density DC/DC converter for high-power applications*
[11] P. C. Saha et. al., *CLEAN: Cryogenic Link for Electric Aircraft Propulsion*
[12] R. Chen et. al., *SiC and GaN Devices with Cryogenic Cooling*
[13] A. Deriszadeh et. al., *Cryogenic Operation of Enhancement-Mode GaN HEMTs*
[14] R. Ren et al., *Characterization and Failure Analysis of 650-V Enhancement-Mode GaN HEMT for Cryogenically Cooled Power Electronics*
[15] A. Wadsworth et al., *GaN-based cryogenic temperature power electronics for superconducting motors in cryo-electric aircraft*
[16] Top-side cooled 650 V E-mode GaN transistor, GaN Systems, 2021, rev. 210727.
[17] Mustafeez-Ul-Hassan et al., *Investigation about Operation and Performance of Gate Drivers for Power Electronics Converters for Cryogenic Temperatures*
[18] M. u. Hassan et. al. *Development of Gate Drive Configuration for GaN Based Cryogenic Power Electronics Converters*
[19] R. Gelagaev et. al., *A Fast Voltage Clamp Circuit for the Accurate Measurement of the Dynamic ON-Resistance of Power Transistors*