High Power Density Modular Converter

VESI Theme 3

Demonstrator 2

18th March 2016

The University of Nottingham

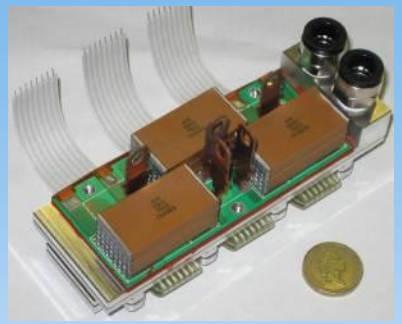
UNITED KINGDOM · CHINA · MALAYSIA

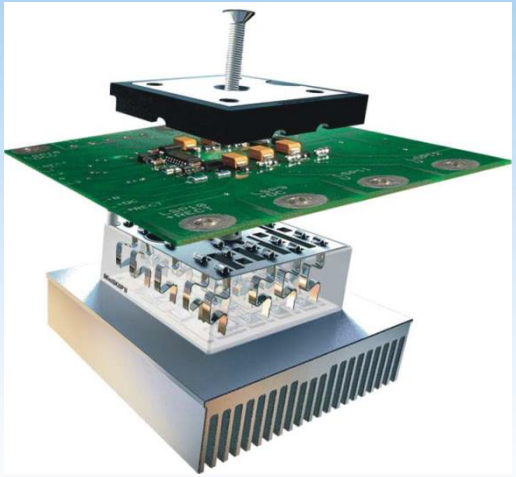
Historical Perspective

- Typical power converter consists of
  - semiconductor power modules
  - a physically separate DC-link
  - a separate input and/or output filter
  - EMI filters
  - gate drivers
  - controllers and sensors
- Demarcation of technological disciplines means electrical, mechanical and thermal aspects are treated separately by separate teams
- Each component is designed separately, cooled separately and has its own operational requirements

Integrated Assemblies

- Meeting the challenges through concurrent electrical, thermal and reliability design
- Reduced weight and volume (fewer interconnections, less “dead” space)
- Reduced cost (smaller bill of materials)
- Optimised thermal management (not limited by standard component footprint/construction)
- Passive components located close to active devices (layout optimised for reduced parasitic inductance and low EMI)
- Integrated control and protection functions (optimised system performance and health management)
- Suited to wide band gap semiconductors (SiC, GaN etc.)





VESI Building Block Targets

- Modular approach – flexibility in topology and power levels
- Increased power density
- Without compromising on efficiency
- Use of Wide band-Gap (SiC/GaN) devices
- Reduced EMI
- Integrated filtering (inductors and capacitors)
- Integrated control (gate drives, sensors)
- Integrated thermal management

Proposed solution: Modular Approach

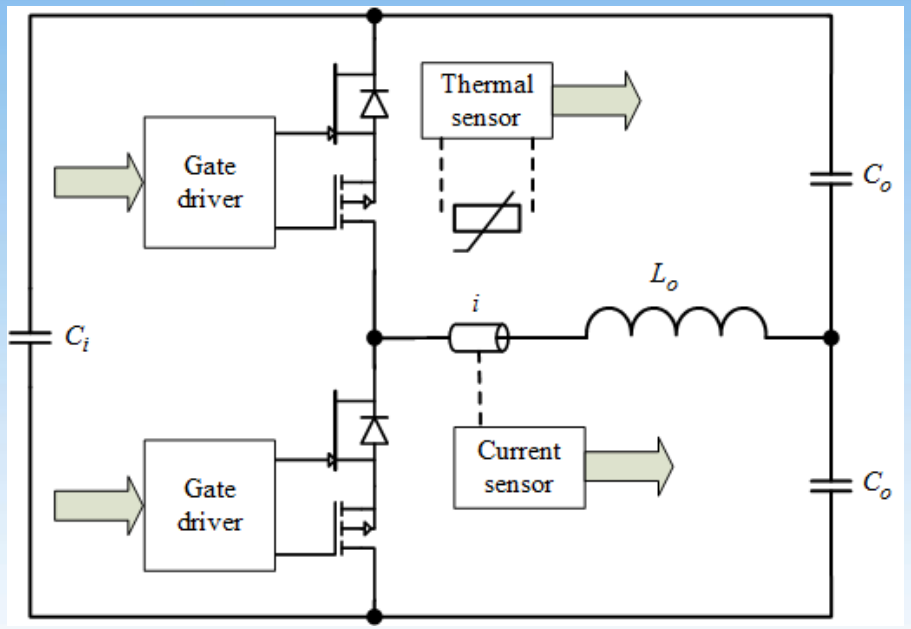
- odules in parallel to create high

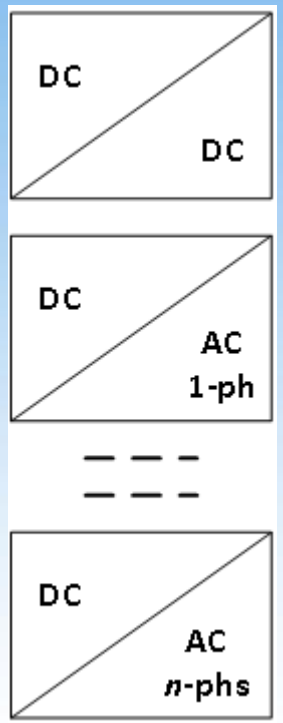
n paths – reduced parasitics

  - Certification of different converters simplified

- Standard Approach
- Modular Approach

Building Block Concept



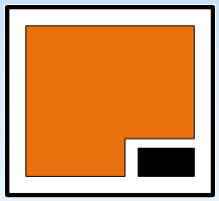


- Half bridge circuit
- Combined in multiples to achieve higher current/multi-phase operation
- Different topologies
  - » DC/DC converter
  - » *n*-phase converters

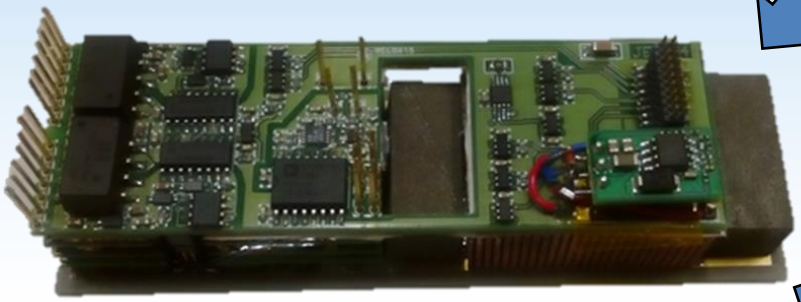
Power Cell Realisation

- JFET SiC semiconductors
- Switching frequency 143 kHz
- Passive elements integrated
- Sensor integration

inductors



JFET die

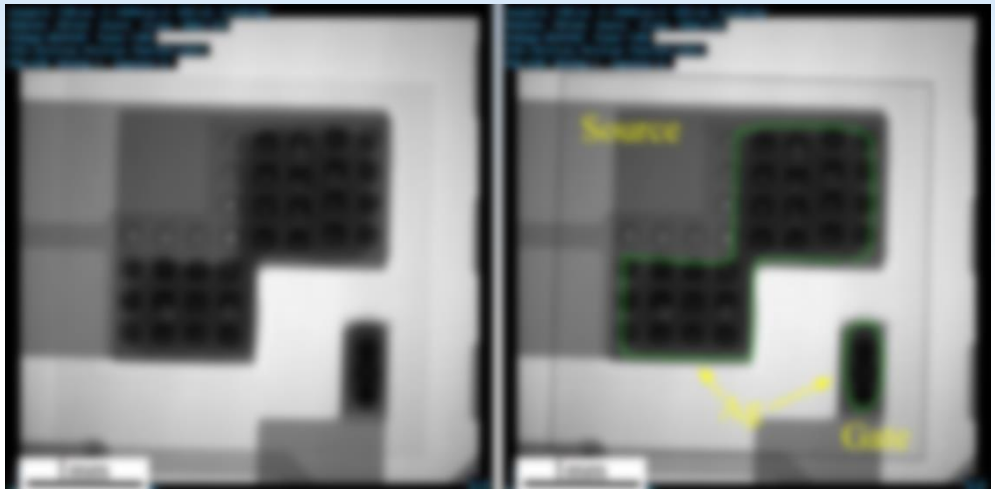


Gate drivers and sensors transducers

Direct Chip-On-Board Assembly

- Dies flip-chip sintered to flex
- Minimises commutation inductance
- Flex mounted to DBC substrate for cooling

2D XCT projection showing positioning of SiC device

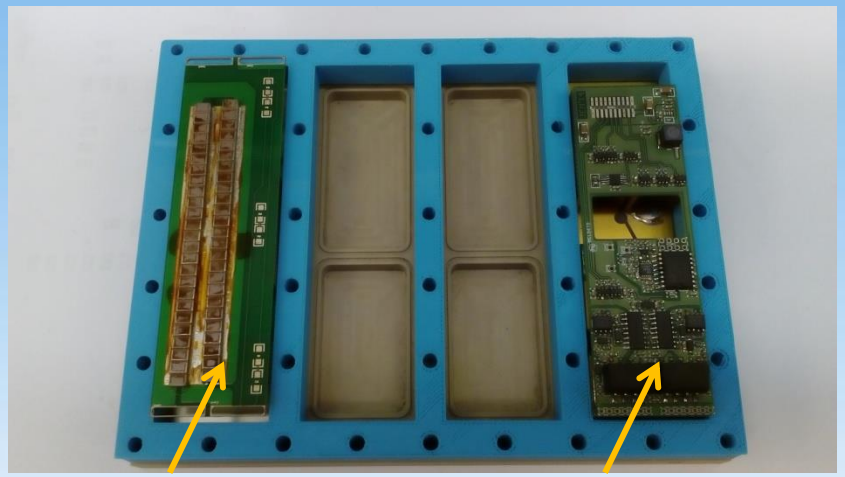


Green lines represent the JFET connection

Integrated Modular Converter

- Integrated, flexible platform for implementing multi-phase inverters and dc-dc converters
- Housing has multiple stations for half-bridge cells, input filter etc. with integrated liquid cooling
- Half-bridge cells: SiC JFETs with integrated dc-link decoupling, gate drives and output LC filter
- Cell interconnections, control and input filtering on separate power plane – different configurations to suit application

4-station housing with integrated cooler

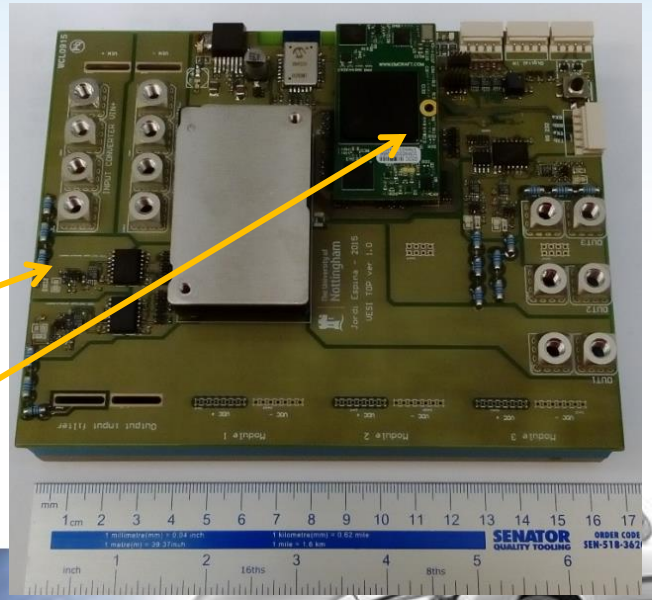


Input filter

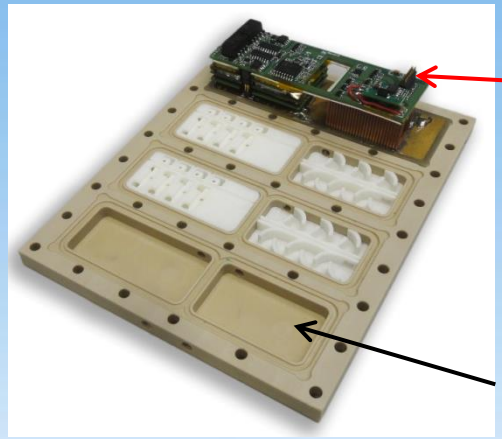
Half-bridge cell

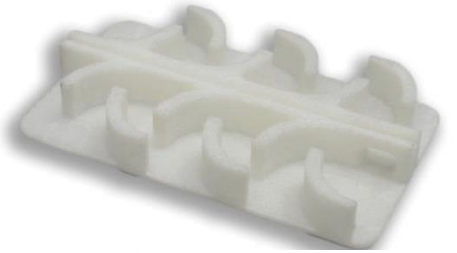
Interconnecting power plane

Controller



Integrated Thermal Management



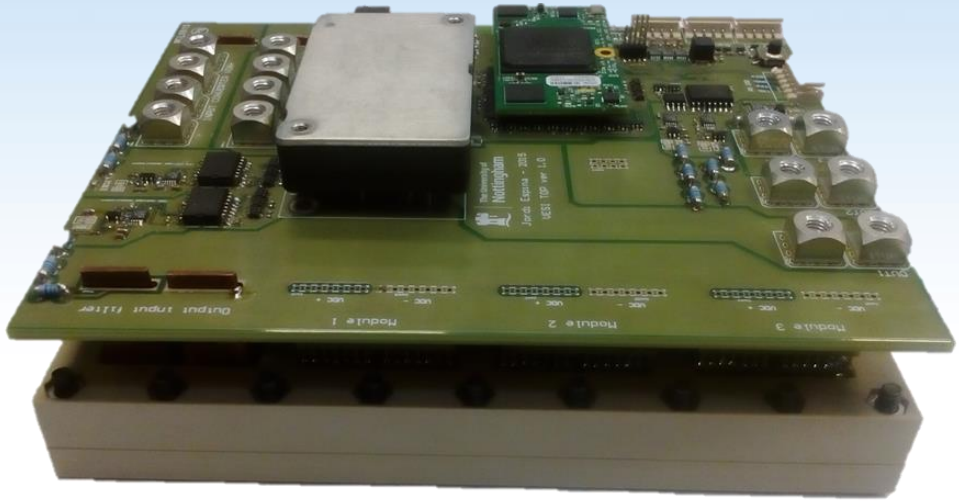


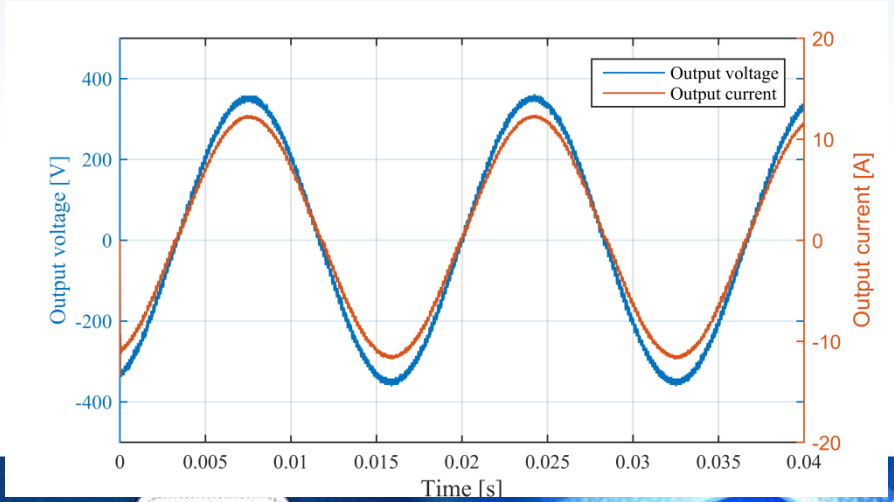
- Single cooler with multiple stations and reconfigurable flow characteristics
- PEEK base with wells and internal flow path connectors
- Printed/laser sintered inserts direct flow onto cooled surface:
  - Impingement cells for targeting hot spots
  - Turbulator cells for large area cooling
- Optimum trade-off between pumping power and cooling effectiveness

Modular Converter

- Example: Three phase converter

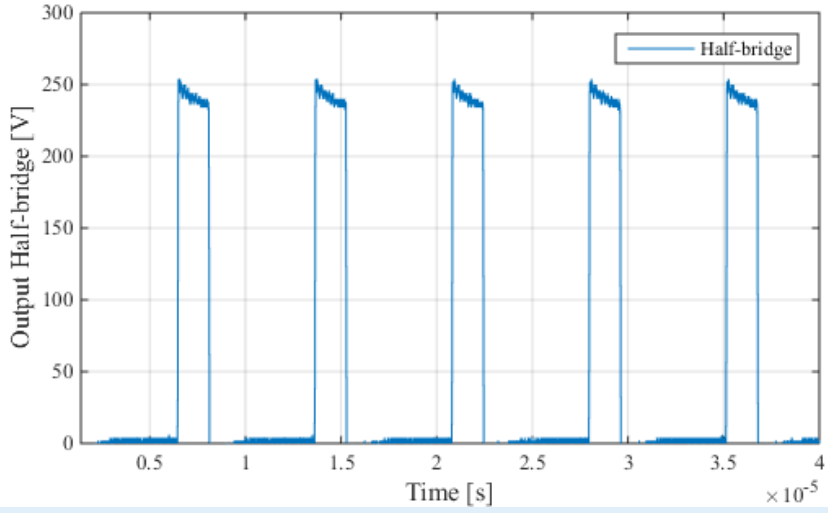
- Three modules
- Differential & common filter
- 240 V @ 50 A rms
- 26 kW / Litre

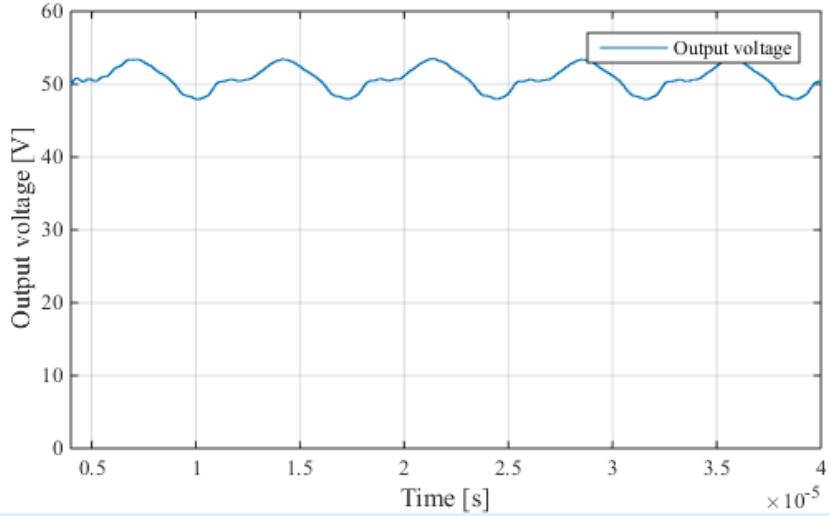


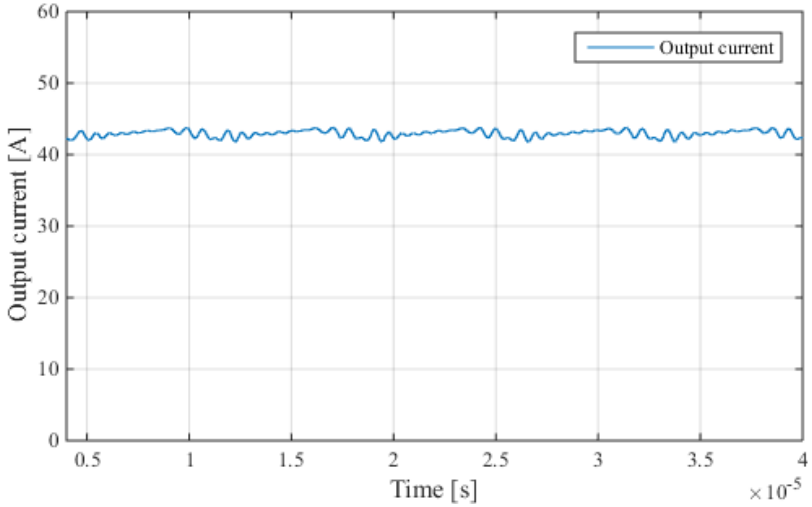


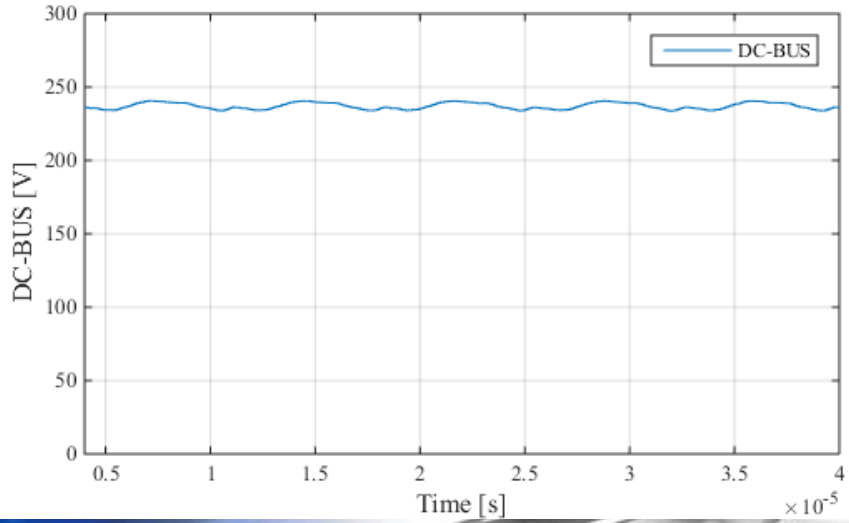
Sinusoidal outputs

DC-DC Converter









Summary

- Integrated modular approach
- Large size reduction
- No electrolytic capacitors
- Gate drivers integrated
- Sensors integrated
- ARM + FGPA control
- Output filter and DC-link passive components integrated
- High energy density inductors through enhanced cooling
- Integrated EMI filtering and controlled dv/dt at output
- High power density (up to 200 kW/litre)

Future Plans

- Refinement of assembly processes
- Optimisation of filter components for EMI/application specific requirements
- Extend concept to GaN devices
- Exploitation:
  - Patents in preparation
  - Incorporate into higher TRL/MRL automotive projects
  - Commercialisation