Development of SiC Inverter for a Formula Student Race Car

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INTRODUCTION

Formula Student is a series of international competitions where university students design, manufacture and compete with open wheel electric race cars [1]. Monash Motorsport has participated for over 20 years, and are at the peak of their vehicle development with their All Wheel Drive (AWD) electric race car.

Monash Motorsport (MMS) has a taken a significant leap in advancing their EV technology by developing a custom Silicon Carbide (SiC) inverter. However, this first iteration contained many inefficiencies, and did not take advantage of benefits that a custom package can offer. Wide Bandgap semiconductors such as the SiC MOSFETs, switch at higher frequencies, and have greater efficiency and power density [2].

A new system will be developed for the 2025 MMS vehicle, with the aim of optimising and resolving issues of the older iteration, and achieving the performance potential. This project aims to develop a system focusing on reduced mass, increased serviceability, and effective vehicle integration, such that performance is enhanced in multiple areas.

DESIGN PROCESS

Key steps listed below were taken towards optimising and future proofing the system, and resolve issues seen with previous solutions.

1. Review previous SiC inverter design
2. Simulation and testing of DC link capacitance requirements
3. Testing of reduced 2-Parallel SiC MOSFETs configuration
4. Simulation and bench testing of Gate Driver with desaturation protection
5. Verification of small footprint manufacturing i.e. BGA, for future designs
6. Design implementation with schematic and layout of PCBs

RESULTS AND DISCUSSION

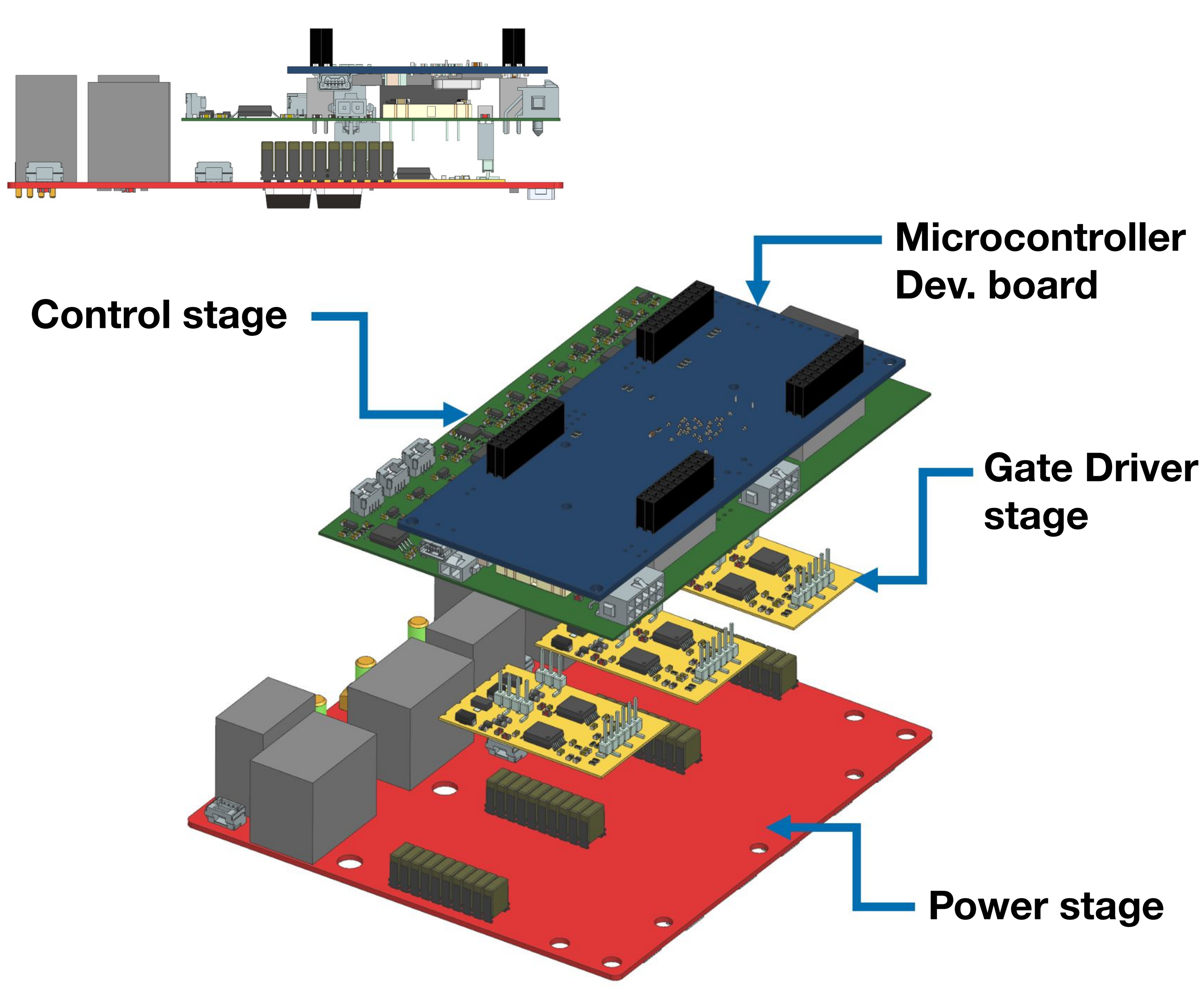

Figure 1: Board configuration for single inverter

- Compact Power Stage PCB with optimised switch and DC link capacitor configuration
- Gate Driver PCBs mounted on the Power stage board; one per phase achieving minimised gating loop
- Control PCB connected on top of Gate Driver boards, with communication protocol module and microcontroller development board

Table 1: Specification comparison between inverter packages

Specification	Bucher Mobile DCU 60/60 (Si-IGBT) [3]	Mini SiC DCI	SiC QCI 2025
No. channels	2	2	4
Switching frequency	4 / 8 / 16 kHz	20 kHz	> 20 kHz
Max (Peak) Output Current	102 / 73 / 41 A	140 A	120 A
Max input voltage	800 V	700 V	700 V
Efficiency	98 %	98.5 %	98.5 %
Mass	6.7 kg	4.6 kg	< 6 kg
Dimensions	310 x 355 x 81 mm	313 x 321 x 65 mm	~ 310 x 355 x 81 mm

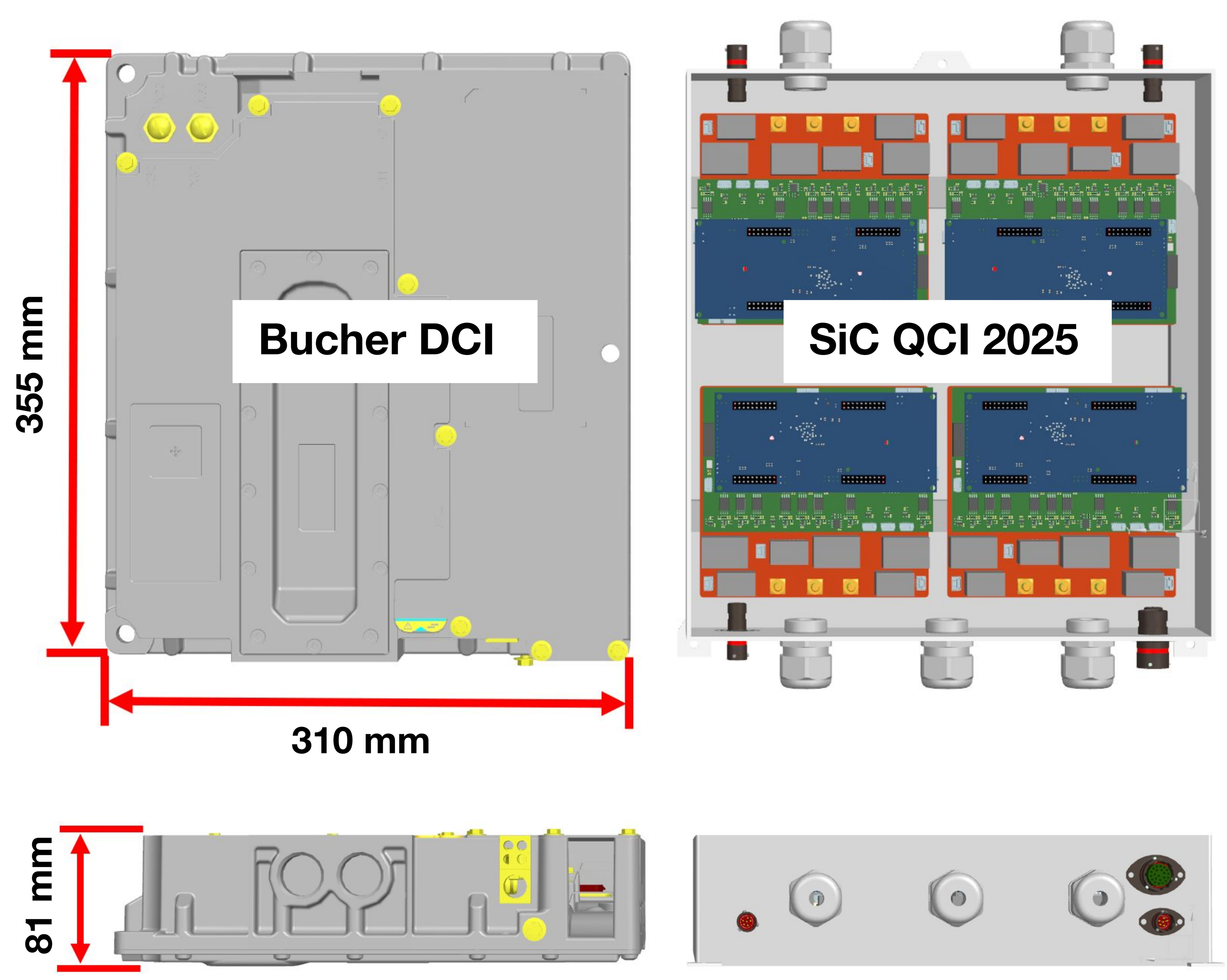

Figure 2: Packaging comparison with preliminary enclosure design

Efficient three layer stack-up forms a compact single inverter. Packaged side by side for a Quad Channel Inverter (QCI), this design takes up the same volume as the previous Dual Channel Inverter (DCI).

CONCLUSIONS

Development has resulted in a motor drive package ideal for use on a Formula Student race car. This design has twice the kW/kg of previous solutions, retains performance afforded by SiC technology, and is less prone to failure.

Future work to implement this design on the 2025 vehicle:

- Finalise designs for outsourcing
- Manufacturing and verification
- Implementation of integrated microcontroller

REFERENCES

[1] "Formula SAE Knowledge," 2024. [Online]. Available: https://www.sae.org/attend/student-events/formula-sae-knowledge/about
[2] M. Beheshti, "Wide-bandgap semiconductors: Performance and benefits of GaN versus SiC," 2020.
[3] "Bucher MOBILE DCU Double Inverter," 2024. [Online]. Available: https://www.bucherdrives.com/64827/Prodcuts/MOBILE-DCU/index.aspx