Fabrication of a novel multi-layer electric vehicle half-bridge inverter module

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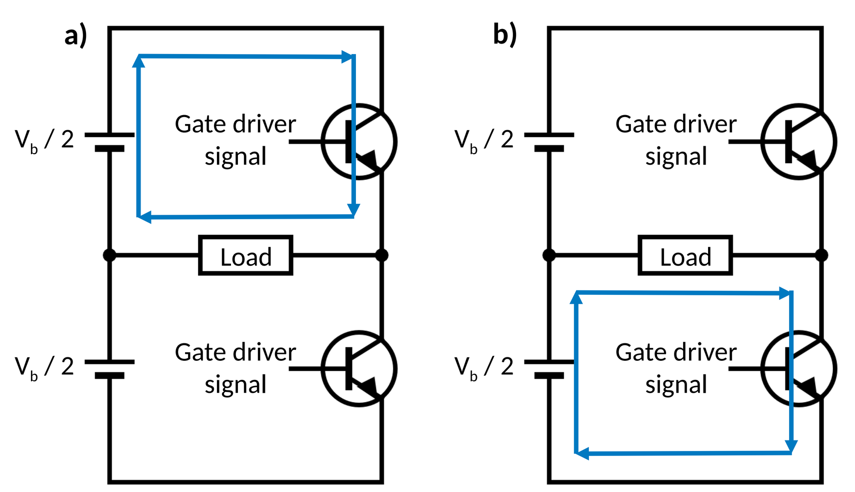
Introduction

Maximizing efficiency in electric vehicles (EVs) is critical to fully replacing gas-powered vehicles. A key focus area for improving efficiency in EVs is in the components responsible for electricity transmission throughout the vehicle, especially the **power inverter.**

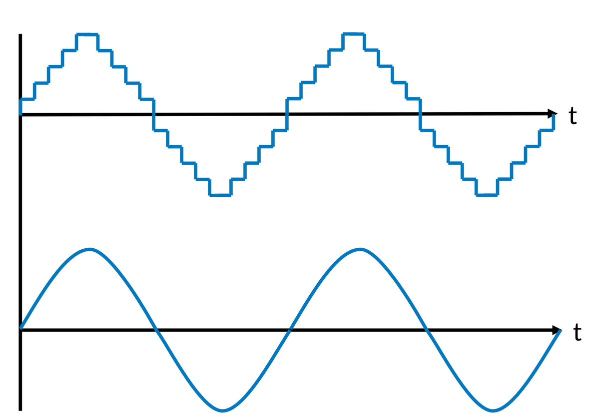
What does an EV inverter module do?

- Converts DC power from the batteries into AC, used by the high-current induction motors
- One half-bridge inverter module uses at least one pair of Silicon Carbide (SiC) Metal Oxide Semiconductor Field Effect Transistors (MOSFETs) to convert battery DC to AC



Current flow through half-bridge inverter circuit when a) the upper and b) the lower MOSFETs are closed, producing an alternating signal at the load

- The MOSFETs rapidly switch on and off to produce a smooth sinusoidal AC signal

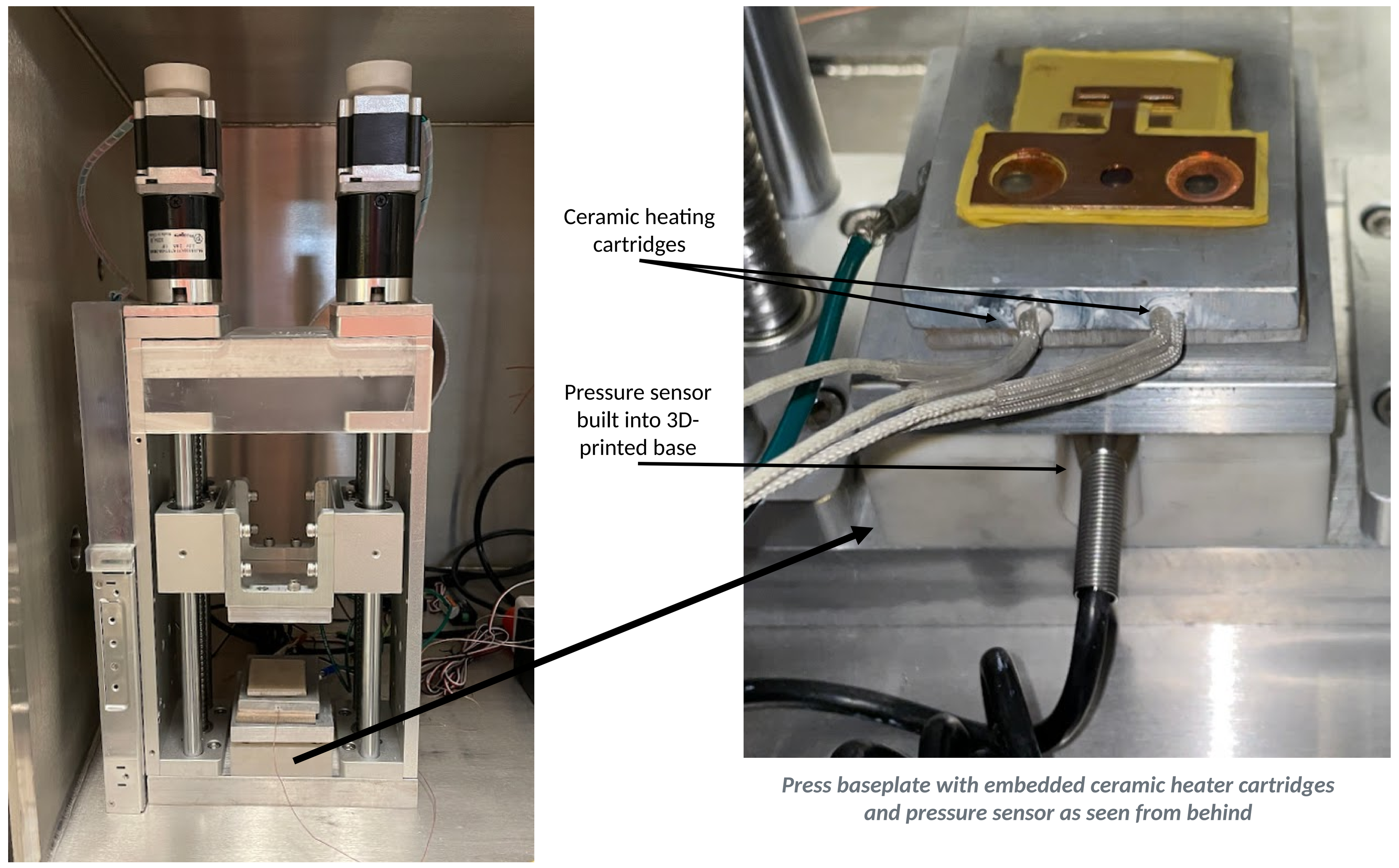


Graphical representation of how a sinusoidal AC waveform can be generated by rapid toggling of MOSFETs

- **Faster switching speed** improves motor efficiency and minimizes switching losses, but simultaneously introduces harmful parasitic inductance as a result of the rapid changes in voltage and current (dV/dt and dI/dt) [1]
- This unwanted inductance can cause damage to the inverter or other components and thus it is critical to **reduce this inductance** as much as possible

Project Goal: Design equipment and develop a control mechanism to facilitate the fabrication of novel power inverter modules with innovative designs and materials, allowing for rapid module prototyping and simulation validation.

Press Design



Press assembly

Press baseplate with embedded ceramic heater cartridges and pressure sensor as seen from behind

Key Features

- High-torque DC motors capable of supplying 5000+ Newtons of force
- Pressure sensor built into baseplate to monitor force reading and provide feedback to motor control
- Self-leveling baseplate to ensure even pressure distribution onto sample
- Custom-built temperature controller to heat baseplate to desired temperature
- Intuitive graphical Python program to control press operation and monitor program status
- Built-in redundant temperature safeties to ensure that baseplate temperature never exceeds user setpoint

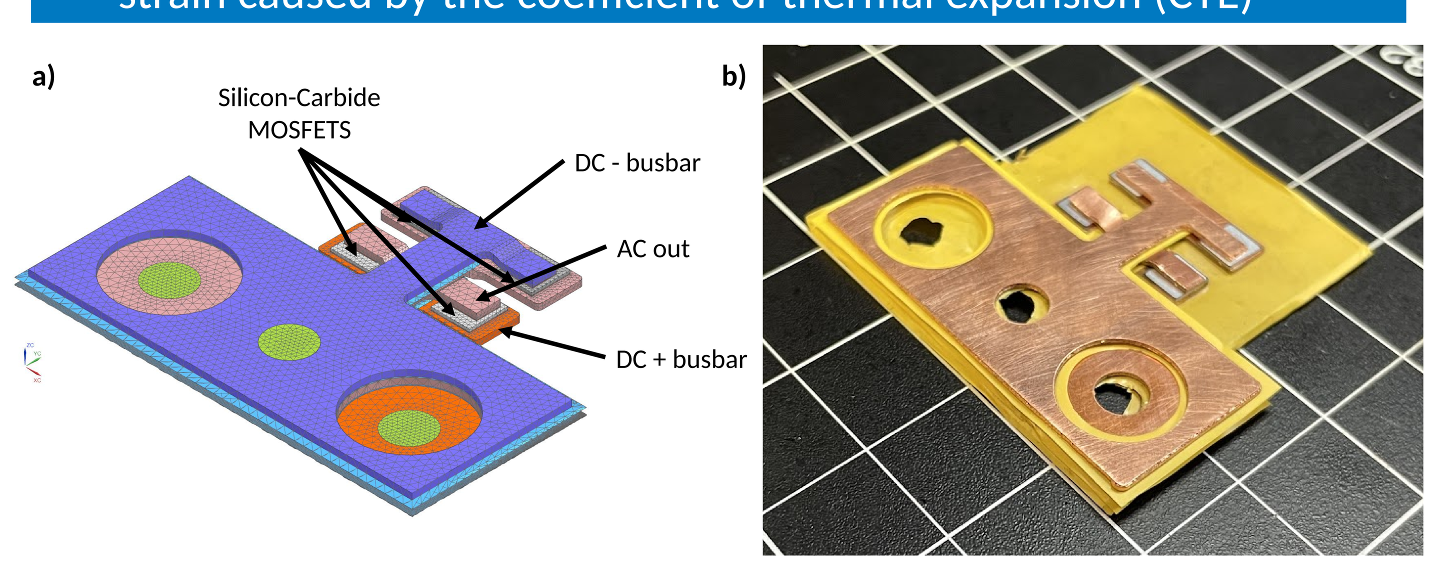
Module Design

Issues with traditional power inverter modules

- 2D layout with wire-bonded connections result in energy density limitations and minimal reduction in parasitic inductance
- Ceramic substrate is expensive and difficult to modify post-production, limiting module design possibilities

New inverter design

- Replacing ceramic substrate with **Dupont™ Temprion©** electrically insulating film
- Stacked module layout greatly improves energy density and reduces parasitic inductance [2] (based on simulation data)
  - Typical half-bridge module inductance: **20-25 nH**
  - Novel half-bridge module inductance: **8.2-9.5 nH**
- Improved reliability as the compliance of Temprion© reduces the strain caused by the coefficient of thermal expansion (CTE)



a) 3D CAD drawing of new half-bridge inverter module and b) early prototype module built using the updated press program

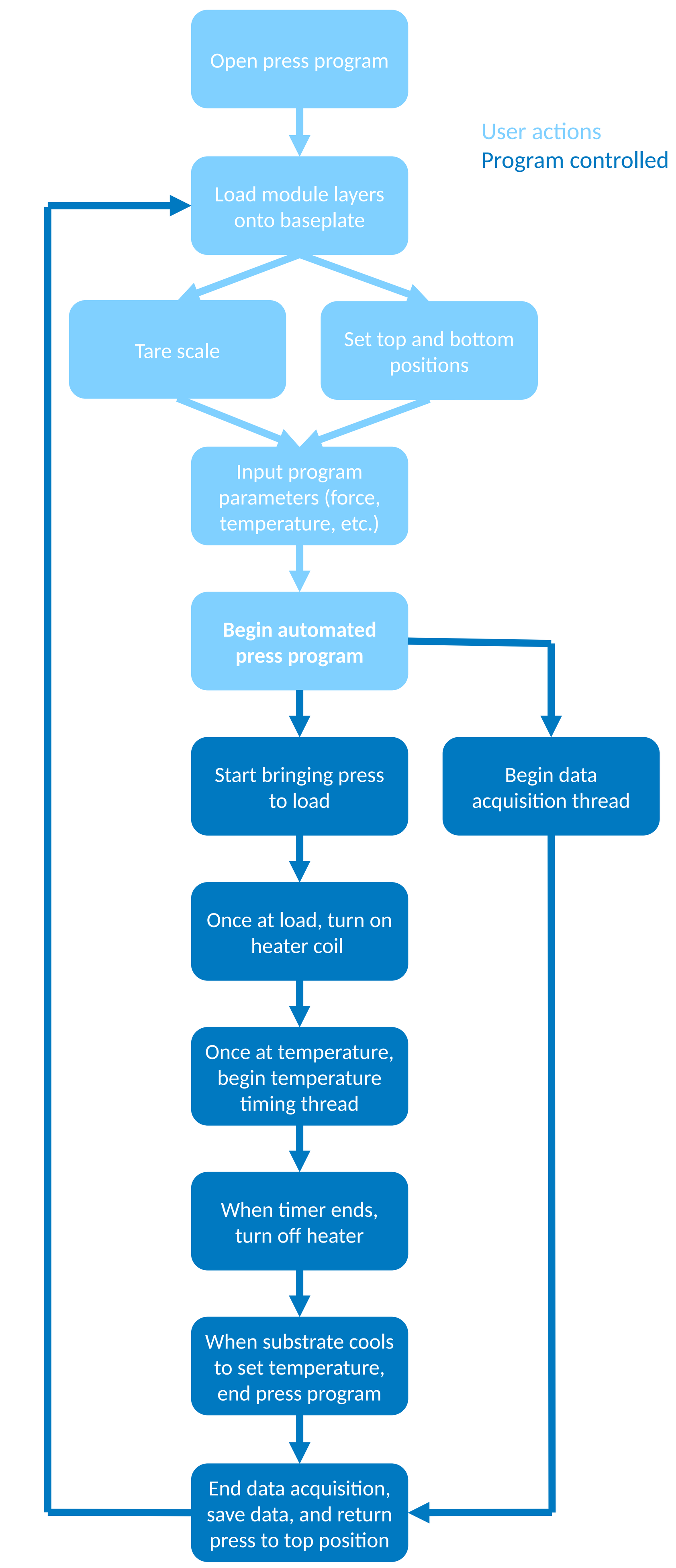
Conclusion

- Press is working as desired for fabrication of new modules utilizing Temprion© as an insulating substrate material
- Speed of construction of new modules allows for rapid verification of simulation data
- Relatively inexpensive component costs and ease of fabrication have promising potential for widespread adoption of this material and process into a variety of research areas

Future Work

- Develop a method of consistently placing and aligning layers within press stack to ensure repeatability of module fabrication
- Incorporate heating element into top plate of press to allow for double-sided heating and decrease module fabrication time
  - Press currently contains heating only in the baseplate, limiting the rate of bonding to one layer at a time
  - Double-sided heating could allow for the entire module to be pressed at once
- Implement control of vacuum chamber into press program to allow for fabrication of modules under varying environmental conditions
- Characterize electromagnetic properties of new inverter module to direct future research focus

Program Workflow



Press program workflow, where actions in light blue are performed by the user and dark blue are completed by the program

Acknowledgements

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References

[1] S. Wang, R. Pollock, N. McNeill, D. Holliday, K. Ahmed, and B. Williams, "Realising SiC MOSFET switching speed control based on a novel series variable-resistance gate driver", in 11th international conference on power electronics, machines and drives (PEMD 2022), Vol. 2022 (June 2022), pp. 588–592.

[2] H. Gui, R. Chen, J. Niu, Z. Zhang, F. Wang, L. M. Tolbert, D. J. Costinett, B. J. Blalock, and B. B. Choi, "Design of low inductance busbar for 500 kVA three-level ANPC converter", in 2019 IEEE energy conversion congress and exposition (ECCE), ISSN: 2329-3748 (Sept. 2019), pp. 7130–7137.

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