GALLIUM-NITRIDE INVERTER FOR ELECTRIC AIRCRAFT PROPULSION

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12

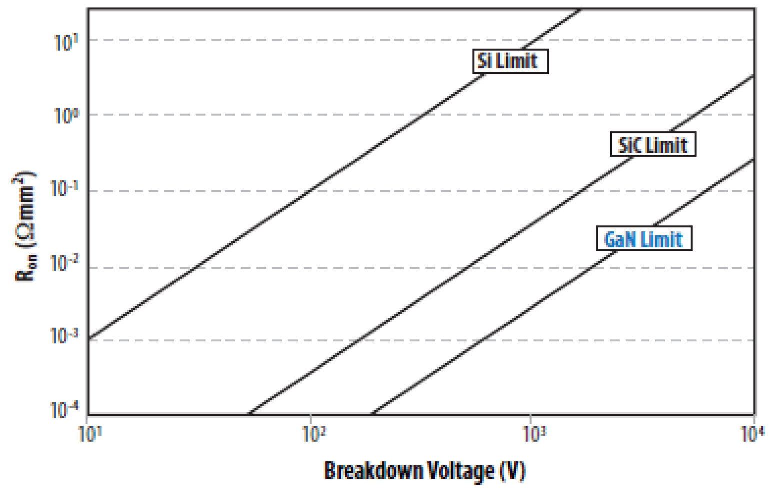
Amazon Prime Air – Electric Drone Delivery System

- Amazon Prime Air designs drones for delivery that operate using an electric propulsion system.
- Amazon would like to improve the efficiency and power density of these systems by using wide bandgap (WBG) devices in their motor drives, effectively increasing the drone's range.

[1]

GaN MOSFETs for Power Electronics Systems

- Why GaN for motor drives?
  - Faster switching frequency
  - Higher power density
  - No reverse recovery losses
  - Higher efficiency - low Rdson
- GaN devices have significantly lower on-resistance than their Si counterparts at the same operating voltage, making them a more efficient alternative.



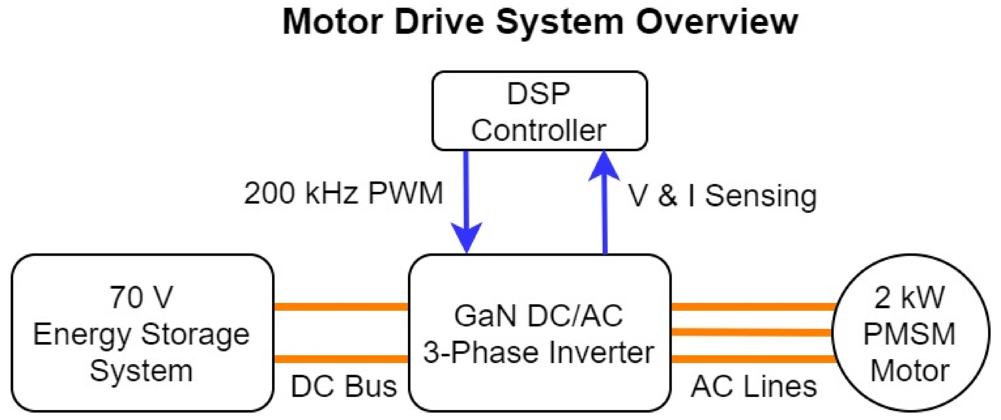
[2]

- The power electronics of an electric propulsion system are currently the limiting factor in achieving higher voltages and efficiency. Therefore, improving inverter performance will yield the largest system benefits.

GaN Inverter Features

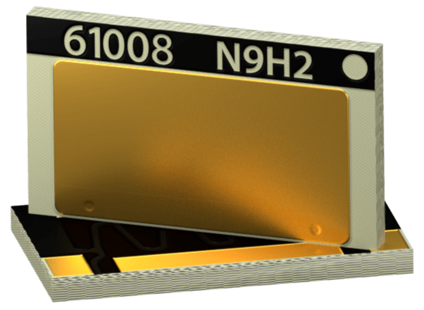
- The team-designed inverter is intended to operate with a 70 V ESS and 2 kW electric motor.

Motor Drive System Overview



Features & Specifications:

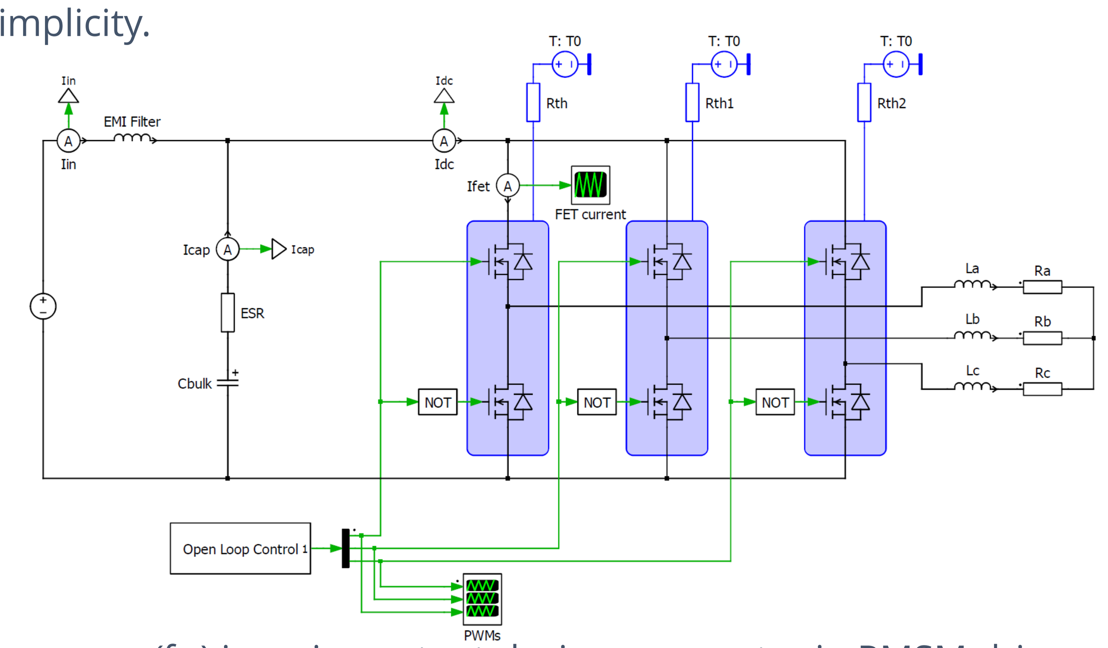
- 100 V , 90 A GaN MOSFETs
- 200 kHz switching frequency for initial design
- 250 μF bulk capacitance to reduce ESS current ripple
- Top-side air-cooled MOSFET design
- Onboard auxiliary power conversion
- Onboard DSP microcontroller for open loop operation
- Small footprint for high power density



GaN Systems 61008T MOSFET [3]

Inverter Modeling & Simulation

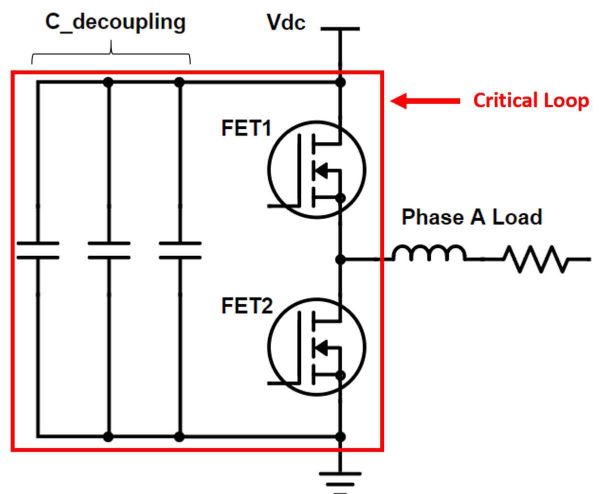
- During the design process, the software PLECs was used to model the inverter, specify circuit components, and simulate performance metrics.
- The system was modeled and will be tested using an RL load instead of a PM motor for design and validation simplicity.

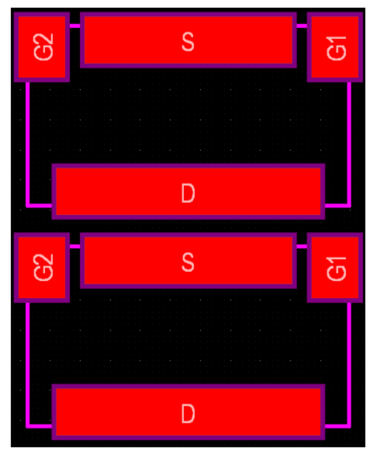


- The switching frequency (f_{sw}) is an important design parameter in PMSM drives, as there are multiple design trade-offs to consider. Increasing the switching frequency generally leads to:
  - Higher inverter losses and worse EMI/EMC.
  - Improved torque ripple, motor efficiency, and motor control.
- The team's model only considers inverter efficiency and not the overall system as motors may change.
- Predicted average efficiency of the inverter @ 200 kHz f_{sw}:
  - 96.45 %
- Predicted peak efficiency of the inverter under full load @ 200 kHz f_{sw}:
  - 98.7 %

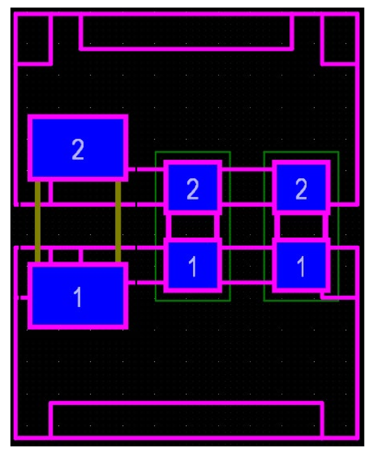
Circuit & Critical Loop Design Considerations

- GaN devices are significantly more sensitive than their Silicon counterparts.
- Minimizing parasitics and large voltage/current changes is extremely important to consider in design.
- Primarily, the critical loop between the half-bridge MOSFETs and their decoupling capacitors must be as tight as possible.





Top Side MOSFETs

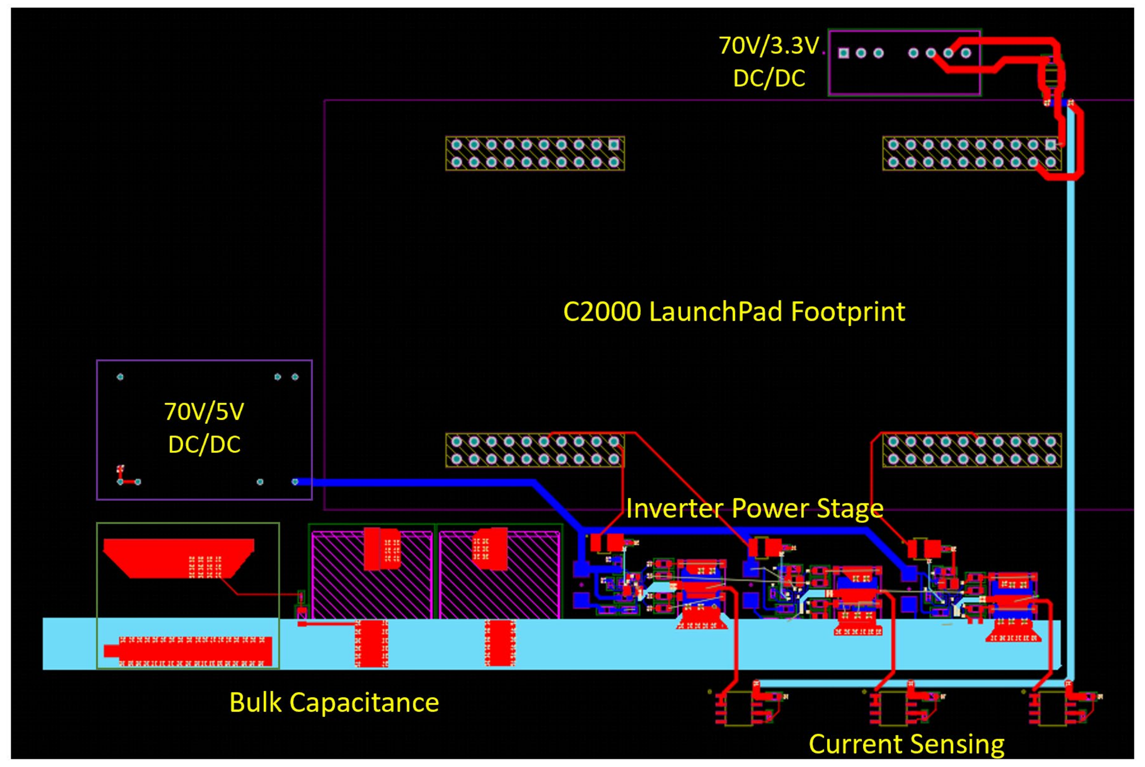


Bottom Side Caps

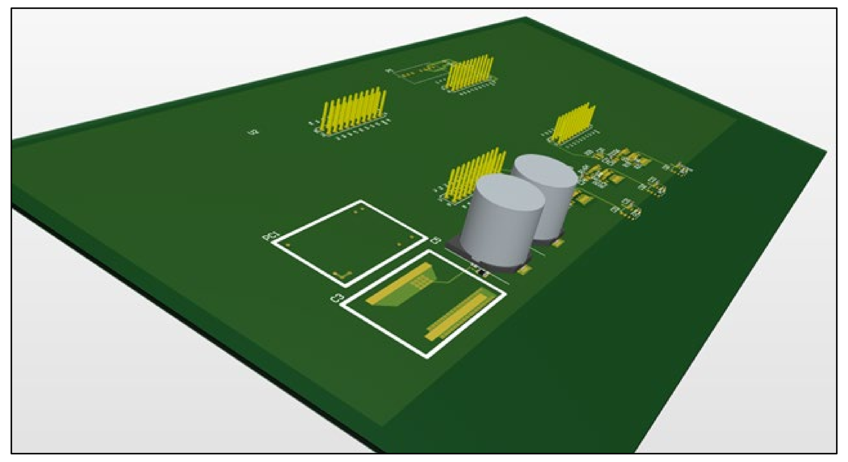
- To minimize this loop, the FETs were placed closely together as shown. The decoupling caps are placed directly below the transistors on the bottom side of the board.

Inverter PCB Design

- A 4-layer PCB prototype was developed for hardware tests to validate performance and efficiency metrics.
- The PCB includes a footprint to directly attach a TI C2000 LaunchPad microcontroller.
- Onboard current and voltage sensing for testing and future closed loop control.



- Overall Board Dimensions: 8 in x 4 in
- The microcontroller consumes the majority of the board space. The power stage itself uses about 7 in^2.



Future Work & References

- Performing hardware tests to compare efficiency against various switching frequencies.
- Improved thermal management design.
- Open loop motor testing to validate full system performance.
- Iterative improvements on PCB layout based on test results & feedback.
- EMI/EMC studies of the system.

[1] Amazon.com. 2020. [online] Available at: <https://www.amazon.com/Amazon-Prime-Air/b?ie=UTF8&node=8037720011> [Accessed 27 May 2020].

[2] Strydom, J., Reusch, D., Colino, S. and Nakata, A., 2020. AN003-Using Enhancement Mode Gan-On-Silicon Power Fets. [online] Epc-co.com. Available at: <https://epc-co.com/epc/DesignSupport/ApplicationNotes/AN003-UsingEnhancementMode.aspx> [Accessed 27 May 2020].

[3] GaN Systems. 2020. GS61008T | Gan Systems. [online] Available at: <https://gansystems.com/gan-transistors/gs61008t/> [Accessed 27 May 2020].

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