Contribution ID: **227** Type: **Poster**

GaN based DC-DC converters for high energy physics applications

Tuesday 3 October 2023 15:00 (20 minutes)

This paper introduces a prototype of a GaN FET based 200 W DC-DC converter. Its design has been carried out to ensure optimal efficiency and minimal electromagnetic interference (EMI) issues that are commonly associated with the high switching frequency converters. To achieve this, hardware-in-the-loop (HIL) techniques have been used to enhance the control at high switching speed, and ANSYS HFSS-SiWave models have been developed to assess noise emissions based on the parasitic elements of PCB layout. Prototypes performance have been evaluated through extensive testing. This work offers insight into the potential of this technology in future physics detectors.

Summary (500 words)

In recent years, the industry has identified GaN transistors as a pioneering technology to enhance high-density power modules that can augment efficiency, reduce weight, and shrink in size. The ECFA DRD roadmap has also recognized this technology as a promising candidate for overcoming limitations imposed by the higher power densities required for future physics detectors. Specifically, DRD7 of the ECFA roadmap has highlighted the importance of identifying synergies with the industry to assess and tailor this emerging technology to meet the requirements of physics detectors. The Advanced Electrical Technologies division at ITAINOVA has spent the last years developing power converters based on GaN transistors for both the automobile industry and physics detectors. One such project, GANCaP4CMS, has been dedicated to the design of a DC-DC utilizing GaN transistors for physics detectors.

This paper describes the development and testing of a GaN-based DC-DC power converter prototype intended for high-energy physics detectors. The converter delivers 200W output power and operates within a 12V to 24V input voltage range at a maximum switching frequency of 2MHz. It is a current source capable of providing 10A output for serial power testing applications. The primary objective of this prototype is to validate the technology for high-energy physics environments where high power density and radiation tolerance are critical.

The design of the converter comprises three main stages, which will be presented in this paper. The first stage involves using a simplified simulation model of the power elements and control loop to dimension and choose the main components based on the application requirements. The second stage involves programming and testing the control loop of the system on a Hardware in the Loop (HIL) platform using a microcontroller while running a real-time simulation of the power converter. This approach ensures reliable and stable control while implementing advanced techniques to reduce noise emissions. The third and final stage involves high-frequency simulations using both Spice-based software (Cadence Orcad) and finite element models (ANSYS) to optimize the layout of the gate drivers and power stages, and better understand the effects of parasitic elements of PCB design on robustness and potential EMI issues. This stage also enables fine-tuning of drivers' components, snubber circuits, and input/output filter design.

During prototype testing, the performance of the converter, efficiency, stability, step response, and current ripple, has been measured for all the range of input voltage and loads, and different switching frequencies. The switching behavior of the converter has been also characterized using different dead-times and driving circuitry configuration to validate and improve the high frequency simulation models.

Future work based on this paper includes full design optimization to maximize the converter power density, using integrated power GaN modules (modules that integrate drivers and transistors) and planar inductors. Also, higher voltage and power prototypes will be developed and studied for integration optimization purposes.

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Session Classification: Tuesday posters session

Track Classification: Power, Grounding and Shielding