GaN based DC-DC converters for high energy physics applications

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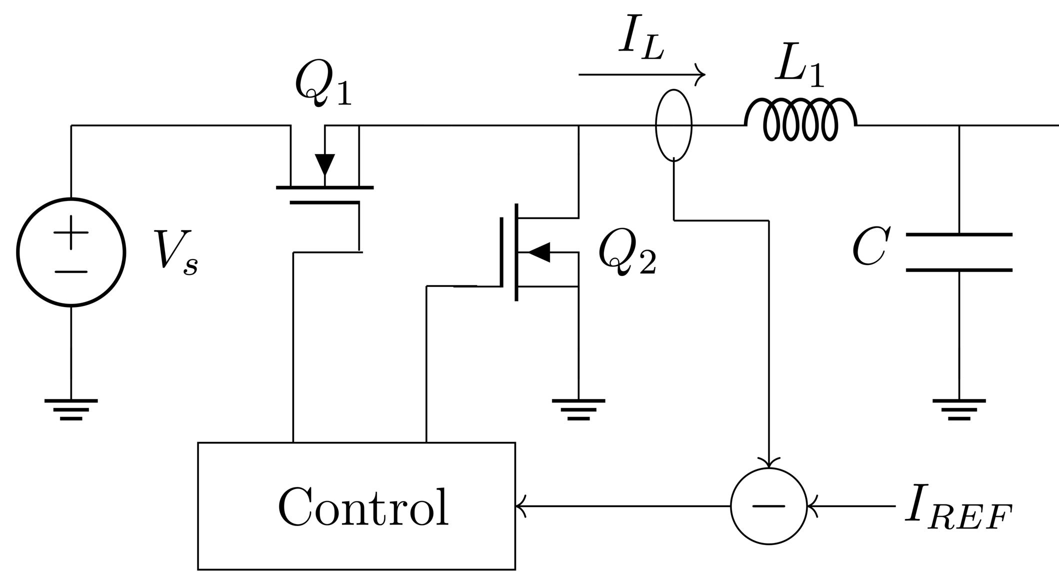
Abstract **- This paper introduces a prototype of a GaN FET based 200W DC-DC converter. Its design has been carried out to evaluate power density (or power dissipation and volume) and ensure minimal electromagnetic interference (EMI) issues that are commonly associated with the high switching frequency converters. To achieve this 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.**

1. What is the purpose of this GaN FET Converter?

To validate the GanFET technology for high-energy physics environments, where high power density and radiation tolerance are critical, the Advanced Electrical Technologies at ITAINNOVA has developed a GanFET current source (DC/DC converter) prototype for serial powering purposes.

- GaN FET Technology allows commuting at high frequency due to low switching losses.

Small Passives { ♦Low Weight ♦Low Volume } → High-Density Power



Current Source Prototype Specifications:

⇒ 12V to 24V Input Voltage (V_s)

⇒ 2MHz Max Switching Freq.

⇒ 200W Output Power

⇒ Up to 10A Output Current (I_{OUT})

2. High-Frequency Simulation Model

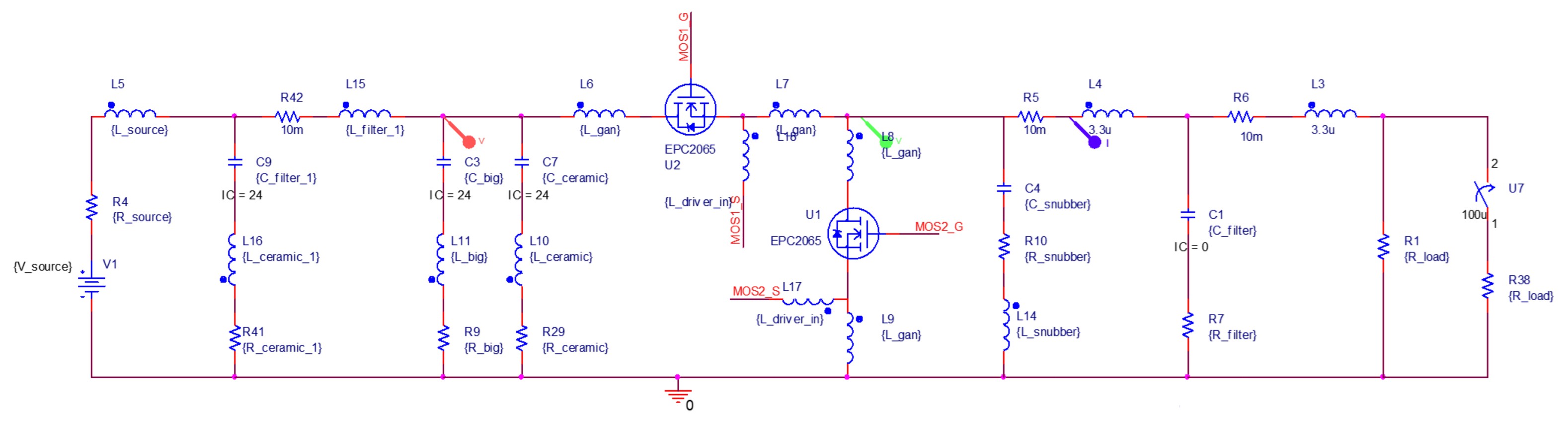
The aim of the high-frequency simulation is:

⇒ Optimize the layout of the PCB (Gate Drivers and Power Stages)

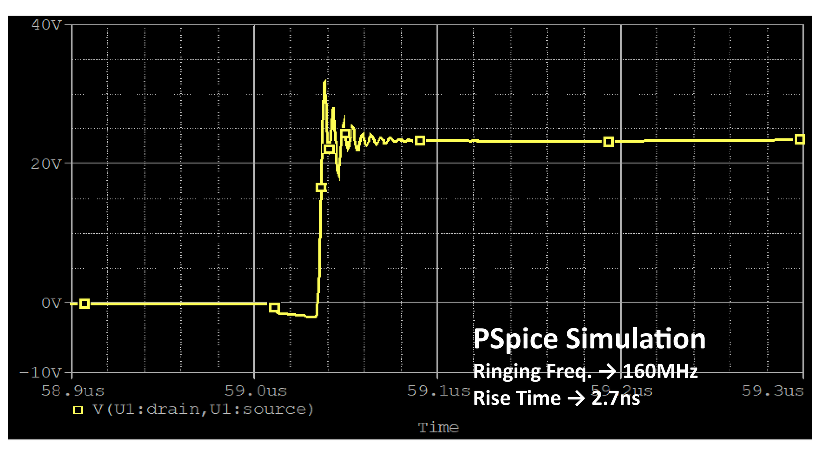
⇒ Better understand the effects of parasitic elements of PCB design on robustness and potential EMI issues

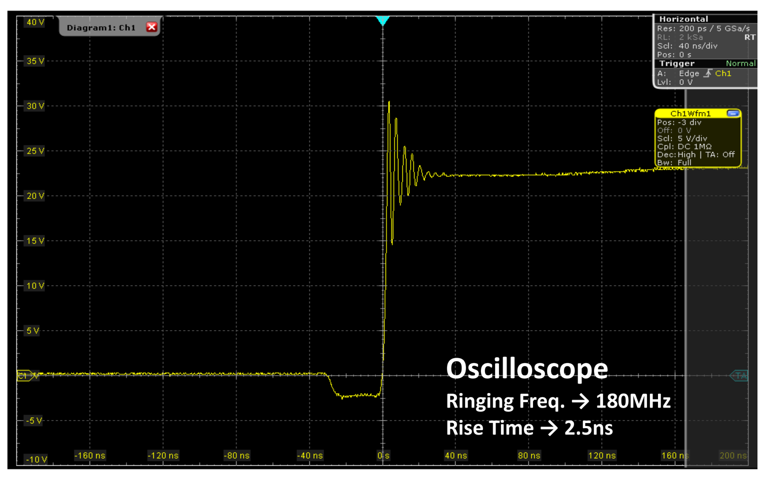
⇒ Fine-tuning of drivers' components, snubbers circuits, in/output filter design

SPICE-based software (Cadence Orcad) and Finite Element models (ANSYS) are the simulation types used.



The results of Prototype Testing stage has been used to validate and improve the high-frequency simulation models.





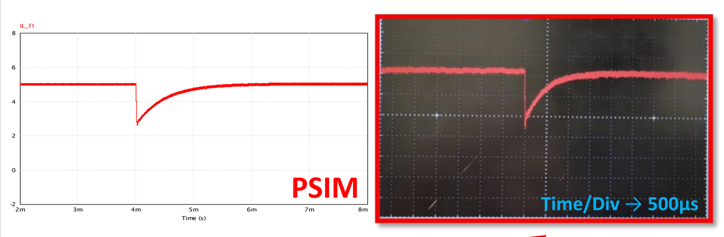
3. Simulation, Control Programming and Testing

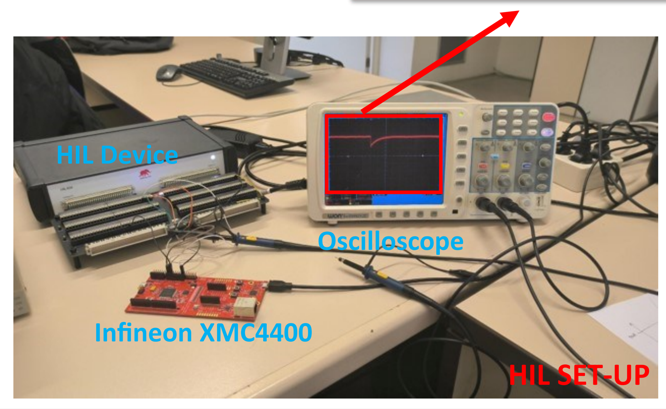
After designing the power converter and the feedback control, the system was tested using a simplified simulation model in PSIM, (with this solver, the system can be simulated for a longer time because it does not focus on temporal transitions as much as SPICE solver).

The control has been implemented using XMC4400 Infineon Microcontroller to use its High Resolution Pulse Width Modulation (PWM) functionality.

The controller was debugged and tested using Hardware-In-the-Loop (HIL) before it was used in the power converter prototype.

Load Step Current Output I_{OUT} Response

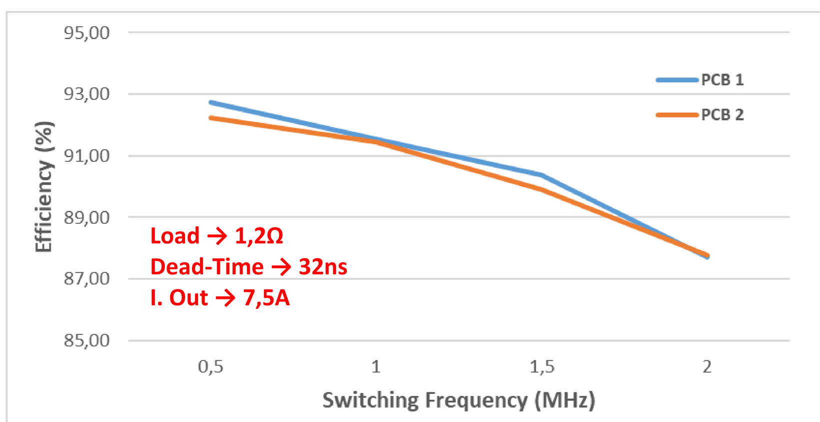




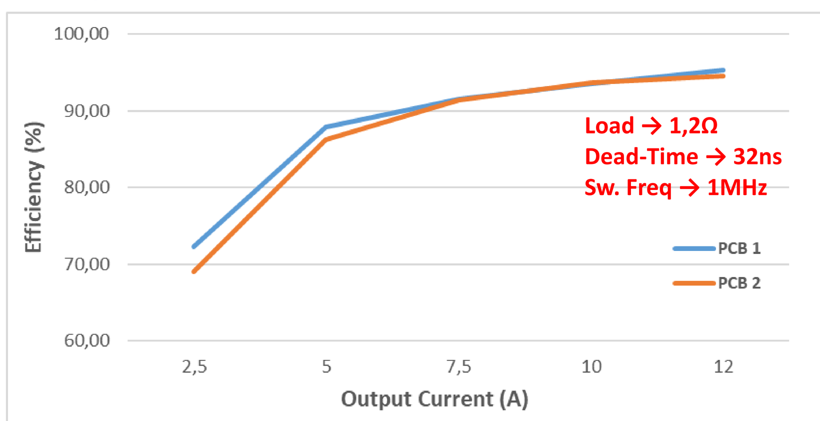
4. Current Source Prototype Testing

⇒ Characterization of power dissipation and efficiency of the current source prototype based on:

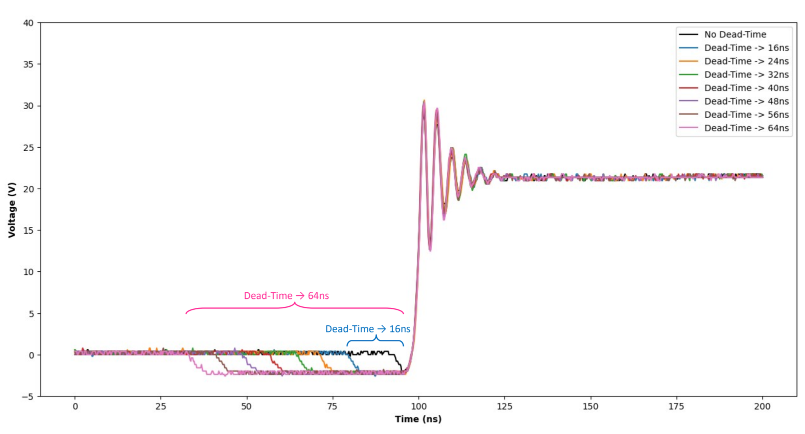
♦ Switching Frequency:

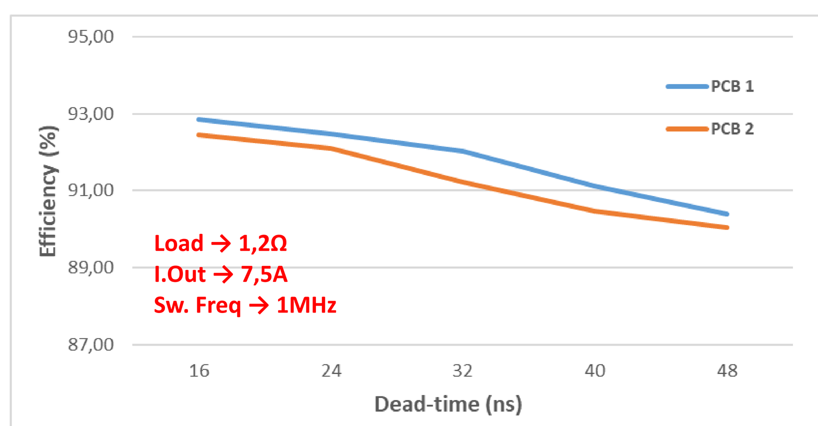


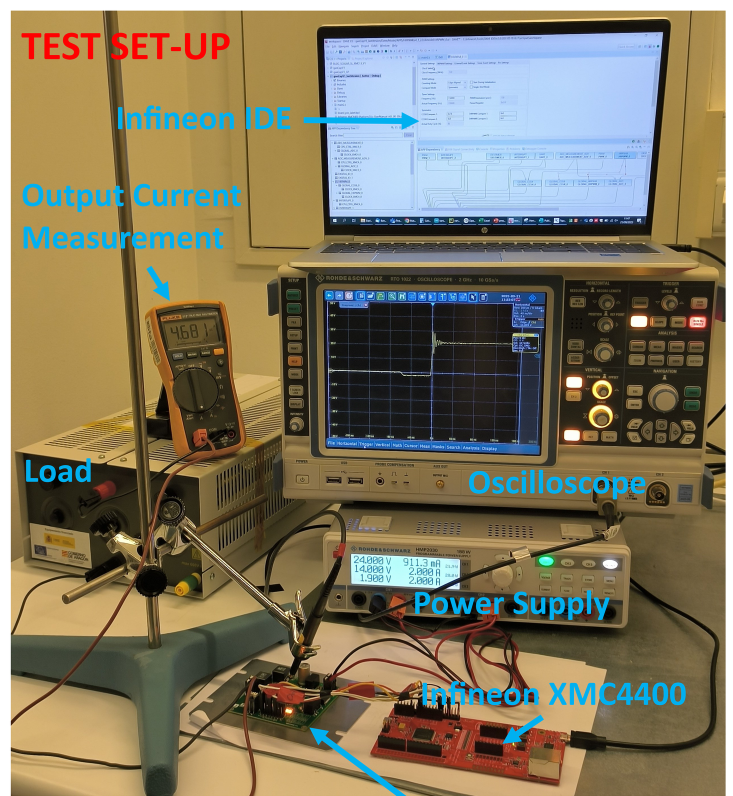
♦ Output Current:

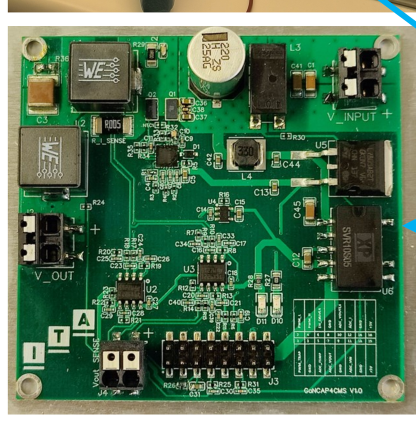


♦ Dead-Time:



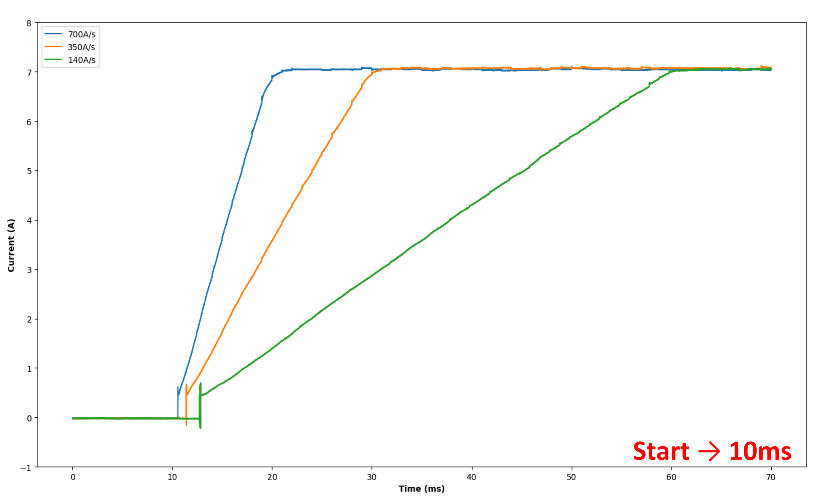




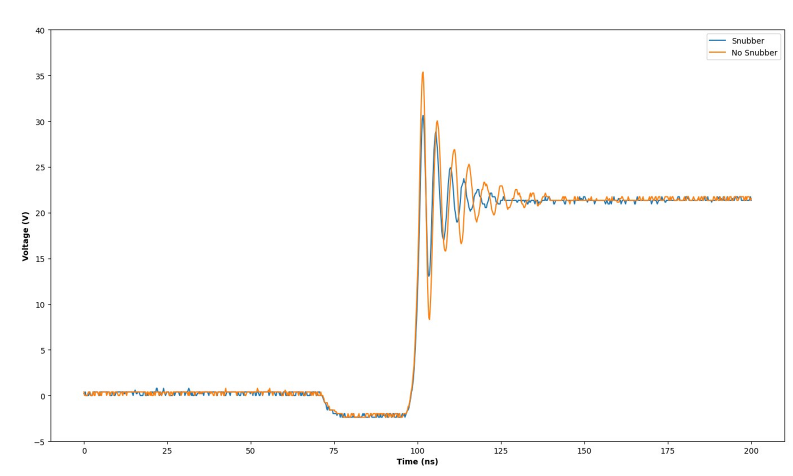


Current Source Prototype

⇒ Start-up of the current source:



⇒ Effect of Snubber Circuit in the switching behavior:



5.Summary and Future Work

The most revelant aspects observed during the designing and testing of the current source prototype:

⇒ Increasing the switching frequency reduces the size of the power converter components but the switching losses are higher and the PCB parasitic elements have a more significant impact

⇒ Optimal PCB layout is critical to minimize the parasitic elements of the prototype

⇒ An excessive dead-time results in unnecessary greater losses

⇒ Commercial microcontroller introduces some limitations due to its PWM resolution and clock speed

⇒ Importance of simulation models for analysing and improving the performance of the current source prototype

Next steps in the development of the current source are:

⇒ Adjust the snubber components to improve the switching behaviour

⇒ Maximize the converter power density using planar inductors and integrated power GaN modules (Drivers and Transistors)

⇒ Study and improve the design of the heat dissipation of power devices and the power converter

⇒ Continue the prototype testing stage with CERN chips as load (Serial powering)

⇒ Work on communication interface to create a Modular System composed by multiple current sources

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