



HAL
open science

SiC and GaN boost convert with or not cryogenic coil comparison

Tanguy Phulpin, Louis Dupont, Amandine Marret, Samir A Mussa, Loïc Quéval

► **To cite this version:**

Tanguy Phulpin, Louis Dupont, Amandine Marret, Samir A Mussa, Loïc Quéval. SiC and GaN boost convert with or not cryogenic coil comparison. EUCAS, Sep 2025, PORTO, Portugal. <hal-05460722>

HAL Id: hal-05460722

<https://hal.science/hal-05460722v1>

Submitted on 15 Jan 2026

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



HAL Authorization

SiC and GaN boost convert with or not cryogenic coil comparison

T. Phulpin, L. Dupont, A. Marret, S. Ahmad Mussa, L. Quéval

Abstract—Cryogenic power converters present a compelling opportunity for superconducting power conversion chains, where multiple components operate at cryogenic temperatures while power electronics typically remain at room temperature. Integrating power electronics directly into the cryogenic environment could reduce the need for complex thermal interface components, leading to significant savings in space and weight. Additionally, cryogenic operation offers inherent benefits, such as best efficiency, enhanced power density, and a reduction in heat sink volume. In this study, a boost converter topology is evaluated under both ambient and cryogenic conditions (open liquid nitrogen bath at 77 K). The investigation focuses on the comparative performance of switching technologies: silicon carbide (SiC) vs. gallium nitride (GaN), in addition of inductor materials: copper at cryogenic temperature and high-temperature superconductors (HTS). Experiments are conducted at several switching frequencies such as 10kHz, kHz and 100kHz, with a varying duty cycle. The results indicate that GaN technology exhibits superior efficiency at cryogenic temperatures. Additionally, cryogenic copper inductors enhance performance, whereas high-temperature superconducting inductors yield mixed results. Furthermore, cold driver operation is demonstrated to be feasible. These findings are particularly relevant for embedded power conversion chains with high frequency, where compactness and weight reduction are critical design constraints.

Index Terms— Boost, Cryogenic converter, Gan, SiC, Voltage Gain, superconducting coil

This work was supported by academic institution. *Corresponding author: T. Phulpin*

First T. Phulpin is with the Electrical and Electronic Laboratory of Paris (e-mail: tanguy.phulpin@centralesupelec.fr).

Second L. Dupont is with the Electrical and Electronic Laboratory of Paris

Third A. Marret is with the Electrical and Electronic Laboratory of Paris

Author S. Ahmad Mussa is with UFSC, Brazil

Author L. Quéval is with the Electrical and Electronic Laboratory of Paris (e-mail: loic.queval@centralesupelec.fr)

I. INTRODUCTION

Over the years, new component technologies have emerged to address societal challenges as well as performance, power efficiency and environmental constraints. For several decades, silicon has been the most widely used semiconductor due to its excellent electrical properties and abundance. However, our interest today lies in gallium nitride (GaN) and silicon carbide (SiC) components, which offer several advantages over silicon. Article [1] notably highlights respectively the advantages of SiC and GaN devices for high voltage and high frequency application. This increase in switching frequency for GaN transistors, according to article [2], represents a major technological advancement by reducing the size, weight, and volume of conversion structures — an especially attractive feature in the

aerospace sector. Furthermore, according to the device structure called HEMT device, and due to the reduced structure of SiC MOSFET, the R_{dson} of these devices is drastically lower than Si MOSFET. Articles [1] and [3] conclude that GaN and SiC devices enable the design of converters with higher efficiency, higher operating temperatures, and higher voltage capabilities.

The use of semiconductors at cryogenic temperatures offers several advantages depending on the application [4]. It notably reduces the resistivity of semiconductors at low temperatures, which decreases Joule losses, as stated in article [5]. It is also well established that the leakage current in transistors decreases significantly under these conditions, thereby improving their energy efficiency. Another key advantage of using semiconductors at cryogenic temperatures is better control over heat dissipation, allowing operation at very high-power levels without risk of damage [6]. Finally, the reduction in thermal noise, highlighted in article [7], is a major benefit for applications requiring high precision. Several papers already mention the benefit of GaN devices at cryogenic temperature [8] [9] but their operation into a power converter remains challenging because of the operation of several other devices in this specific environment.

The objective of this study is therefore to compare the performance of two semiconductor technologies, GaN and SiC, for several frequencies, with a copper coil and a superconducting coil at both ambient and cryogenic temperatures reached by nitrogen liquid (77K). The impact of a cryogenic coil is also investigated in comparison with a classical copper coil. The objectives are to obtain results that could optimize power circuits in terms of efficiency, thermal dissipation, and converter miniaturization. Our tests will focus on power measurements and voltage gain as a function of the duty cycle of transistor switching.

II. CONFIGURATION OF BOOST CONVERTER EVALUATION

A. Protocol of test

In order to compare the two types of components, they are used in a boost converter [10], a classical DC-DC structure amplifying the voltage level. The principles of operation are the same for the two converters with for the GaN converter, a switch that replaces the diode, and which is forced to conduct current when the main switch is open. For the boost converter, the transfer function is given by the following equation, when series resistance of the inductance is neglected: α is the duty cycle of the switch (single switch for SiC board, main switch for GaN board). Without considering the series resistance of the inductance R_L , in continuous conduction mode, the transfer function or voltage gain is given by:

$$\frac{V_{\text{out}}}{V_{\text{in}}} = \frac{1}{1 - \alpha} \quad (1)$$

With (1), we can obtain the theoretical gain of the boost converter considering the duty cycle and also several values of R_L as plotted in Fig.1. As this resistance increases, especially for duty cycle near unity, the gain will decrease: It is therefore not possible to reach an infinite gain, as the simplified formula (2) suggests but gain with high or low duty cycle are possible if the internal resistance of the coil becomes negligible.

$$\frac{V_{out}}{V_{in}} = \frac{1}{1-\alpha} \cdot \frac{1}{1-(1+\frac{R_L}{R_{out}(1-\alpha)^2})} \quad (2)$$

Considering this formula, we can plot on Matlab the usual gain characteristic of a boost converter applied to a 100Ω load. We show that as soon as a load is connected, the gain is reduced for high duty cycle, because of the current level and losses in transistors. In this paper, the gain is measured and suggests the efficiency measurement of the converter [11] related to the voltage drop into the devices.

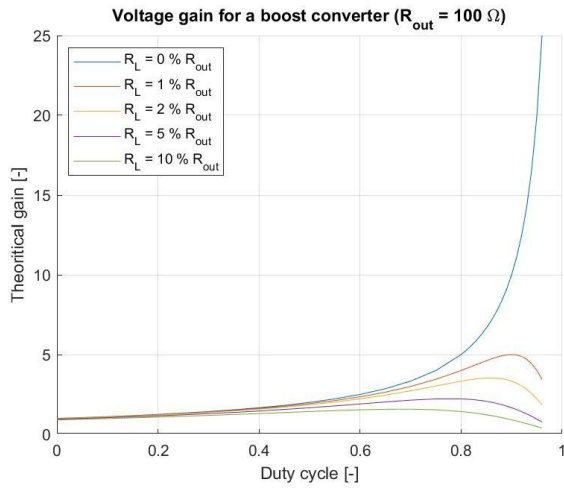


Fig. 1. Voltage gain simulation

B. Presentation of the boost

Technologies of the converter used are presented in the following part: a synchronous boost converter is used in case of GaN, using two switches whereas a simple boost is used with only one MOSFET and one diode in case of SiC.



Fig. 2. GaN converter photography

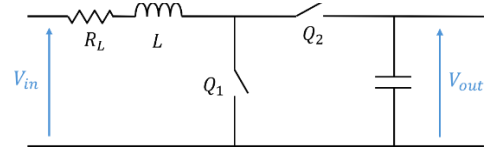


Fig 3. Electrical schematic of GaN converter

The GaN power board used in this system is the “GSP65RxxHB-EVB 650V” [12] as represented in Fig.2 and Fig.3. The IMS evaluation modules are configured as half-bridge. The driver circuit is Si82771 based on silicon devices with 4 ceramic capacitors in parallel of 1 μF in output of the circuit as represented in Fig.2.

A SiC-based electronic board is used. This board consists of two capacitors, a MOSFET with reference “C3M0045065K”, a silicium diode and a gate driver with reference “CGD15SG00D2” as represented in Fig.4 and Fig.5. It presents 2 film capacitors of 10 μF in output of the circuit.

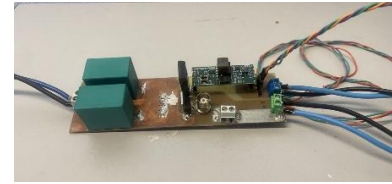


Fig. 4. SiC schematic

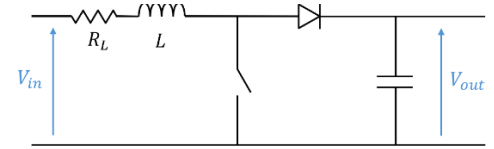


Fig. 5. Electrical schematic of the SiC converter

C. Presentation of the coil system

A PWM control signal is generated and applied to the board via a microcontroller (C2000 Delfino MCU F28379D). The air-core inductance value and its resistivity are measured with the following protocol at 60Hz: through a power amplifier, a GBF signal is applied to the gate via a driver. Measurements are made on current I_a and voltage V_a through the coil, giving the power P_a . Maximum voltage of the GBF is used to set maximum current in the coil, as the following test of the boost converter will imply medium high current (around 10 Amps). Then, as active power is only dissipated in the resistance, the resistivity is then given by (3):

$$R_L = \frac{P_a}{I_a^2} \quad (3)$$

And as reactive power is only dissipated by the inductance, we can measure the inductance value (4):

$$L = \frac{X_a}{w} = \frac{X_a}{2.\pi.f} = \frac{\sqrt{(V_a I_a)^2 - P_a^2}}{2.\pi.f.I_a^2} \quad (4)$$

A copper air-core coil is evaluated in addition to a superconducting coil. The goal is to identify the optimal configuration based on the desired operating mode. To do this, we designed a superconducting coil that matches our use case, with a similar value than the air-core copper coil. The material of this coil is BSCCO, a High-Temperature Superconducting (HTS) material, working properly in an open liquid nitrogen

bath, at 77K. The superconducting material is implemented in a silver matrix.

Before using the superconducting coil, we checked that it was still in a superconducting state at cryogenic temperature. To process, we completely disassembled it and carried out some adjustments. Specifically, we cut the oxidized ends of the conductor and added two braided cables to measure the voltage and current of each coil individually in order to characterize its superconductivity in Liquid Nitrogen (LN2) bath at 77K. Initially, we conduct tests at room temperature. The measured resistances were relatively high for a superconducting coil, so we verify its behavior at cryogenic temperature, only for the superconducting part of the coil. Indeed, the resistance could be due to the copper connector of the coil. The goal was to observe a typical characteristic curve for this type of coil. We then measured the voltage (on the superconducting conductor and not from the connector) and current through each winding (top/bottom) as observed in Fig.6.

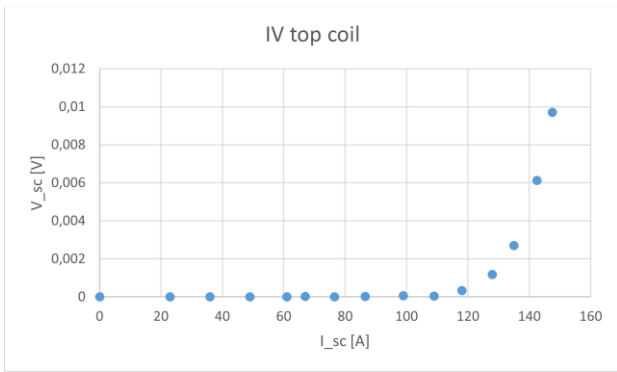


Fig. 6. Characteristic of the superconducting coil

Through these curves, we can identify three distinct phases:

- A conducting state of both coils up to 130 A, corresponding to the critical current.
- A transition phase.
- A resistive state.

These results allow us to confirm that this assembly of series-connected coils is indeed superconducting. We will therefore use it in our converter.

For the considered coil, tests are performed at two different temperatures: at room temperature (around 292K) and at cryogenic temperature (around 77K). Results of respective inductance and internal resistance R_L are compiled in Table 1.

A converter integrating sequentially the two coils permits the technological impact in function of the frequencies (GaN/SiC) and in function of the coil conductor.

III. COMPARISON RESULT

For the gain measurements we implement a protocol focusing on experimental tests and evaluation of the converter voltage gain in function of the duty cycle. It is important to note that all measurements will be carried out under the same conditions for comparison.

For the gain test protocol, a constant input voltage of 10 V is applied to the converter, and a load of 100 Ω is connected to the output of the converter inducing a current around 1A. Throughout the simulation, the duty cycle is varied with the externalized microcontroller:

- From 0 to 0.8 in steps of 0.2
- From 0.8 to 0.96 in steps of 0.1

Parameter	Value at AT° (292°K)	Value at CT° (77°K)
L	641 μ H	637 μ H
R	428 m Ω	60 m Ω
L	675 μ H	640 μ H
R	596 m Ω	6 m Ω

TABLE I. Characteristic of the superconducting coil

The input (V_{in}) and output (V_{out}) voltages of the system are recorded at each duty cycle variation to calculate the voltage gain, as follows in (5).

$$\text{Experimental Voltage Gain} = \frac{V_{out}}{V_{in}} \quad (5)$$

This measured gain is then compared to the theoretical gain using only the copper coil for two switching frequencies (10kHz and 100kHz) as calculated earlier in (2). This protocol highlights the difference between experimental gain and theoretical gain as a function of the duty cycle and the chosen structure. The experiments were done several times in order to ensure a reproducibility of the results. The prototype under test is shown in Fig.7.

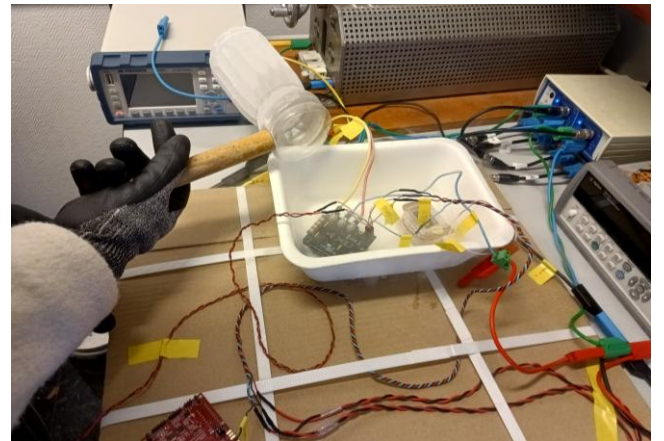


Fig.7. Gain measurement for boost converter immersed in LN2 bath at cryogenic temperature (77K)

In this section, we have chosen to highlight certain curves to compare the different configurations used and the operating conditions of the technologies. The first analysis on a SiC converter at ambient temperature focuses on the impact of the switching frequency on the gain characteristic (Fig.8 and Fig.9). The conclusion is that the gain is better at 10kHz than at 100kHz. This is probably due to more switching losses at 100kHz which is logical although the increase of the switching frequency will modify the coil design and improve the power density, but this

aspect is not considered presently with one unique coil for all experiments.

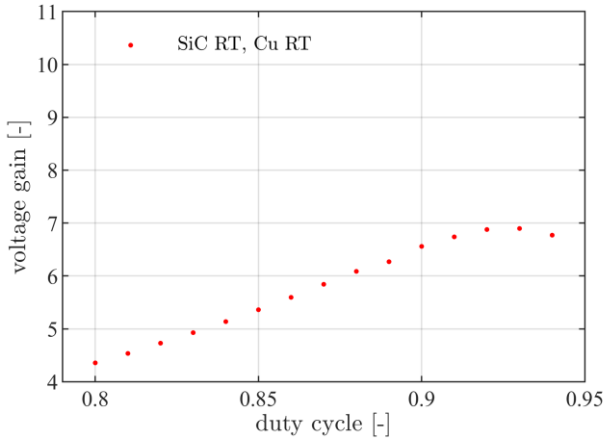


Fig. 8. Gain measurement in SiC boost at 10kHz

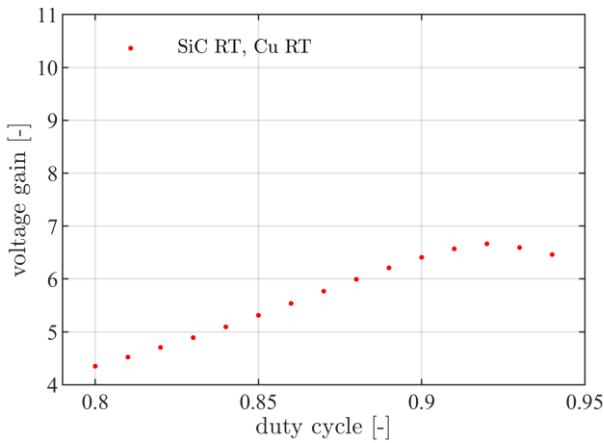


Fig. 9. Gain measurement in SiC boost at 100kHz

We then use the same SiC converter with a coil under specific conditions while maintaining a constant switching frequency of 10 kHz as shown in Fig.10 and Fig.11: the copper coil at ambient temperature, the copper coil at cryogenic temperature and the HTS coil at cryogenic temperature. The comparison shows the gain interest of the cryogenic temperature. As the internal coil resistance is decreased R_L , it becomes possible to reach high gain with higher duty cycle than at ambient temperature. This benefit corresponds to the mobility increase at 77K, traduced in case of copper coil, into a resistivity reduction. We were, however, surprised to observe that the copper coil presents a higher gain than the HTS coil at cryogenic temperature at 10kHz and that this result is inverted at 100kHz. Usually, HTS coil losses increase with the frequency, and we were expecting the contrary phenomenon. This is probably provided by the skin effect resistance in the copper conductor because we can globally observe a reduction of the gain, and the copper conductor is not optimized for this frequency. The HTS coil seems to support 100kHz, probably because of the low magnetic field induced by air-core magnetic circuit. Besides the skin effect doesn't impact the HTS because of its low thickness.

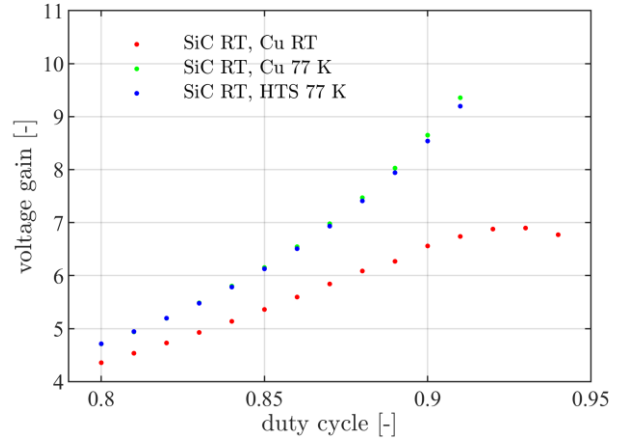


Fig. 10. Gain measurement in SiC boost at 10kHz

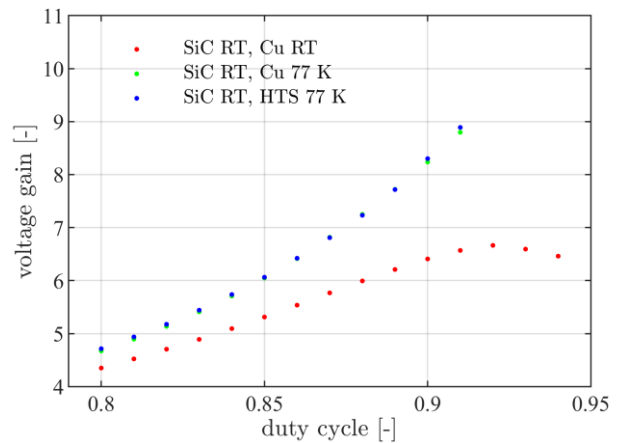


Fig. 11. Gain measurement in SiC boost at 100kHz

At the end, we include (Fig.12 and Fig.13) the converter into the LN2 bath with an established process for being certain that the cryogenic temperature is established for the whole converter [6]. The first teaching is that the driver and the full converter succeed in operating and that the conversion is made possible. We observe in addition that the gain is higher than the full prototype at ambient temperature but is reduced in comparison to only the coil at cryogenic temperature. This behavior is similar for both frequency.

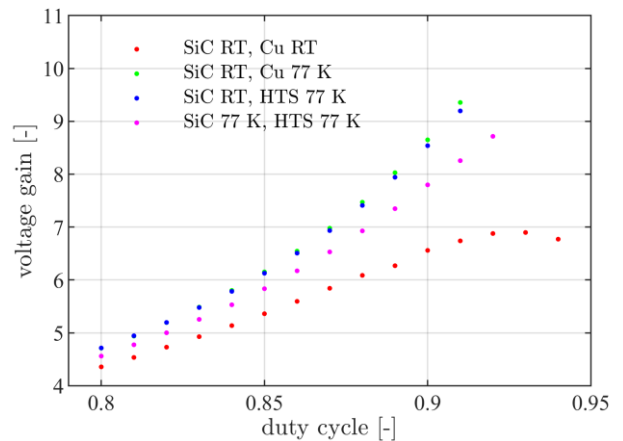


Fig. 12. Gain measurement in SiC boost at 10kHz

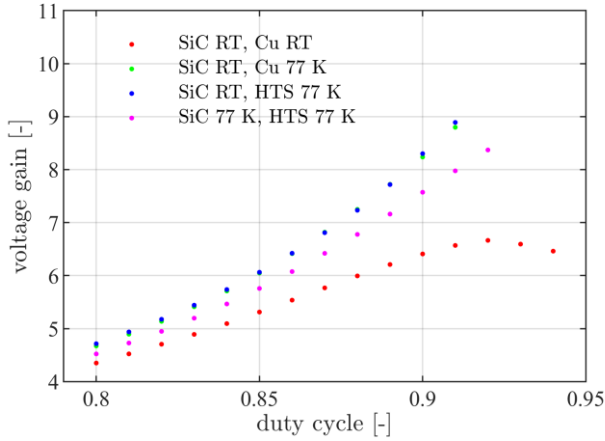


Fig. 13 Gain measurement in SiC boost at 100kHz

As shown in the literature, performances of GaN transistors are improved in cryogenic environment but few publications refer on the global converter. As performances of a unique transistor are improved in comparison to those of SiC, we compare with the GaN boost converter gain (Fig.14 and Fig.15). As estimated, results are coherent and better for GaN converter. Tendences are similar than the previous ones observed in SiC but whereas the maximum gain was estimated at 9.4 for SiC, the boost gain value is estimated at 9.8 for the GaN converter. It demonstrates the interest of using GaN converter for reaching high gain value and high duty cycle with simple converter topology.

Besides as previously, the copper coil results are better due to the decrease in copper resistivity. However, we observe no improvement due to the HTS coil at both frequencies and the gain at 100kHz is slightly improved when the converter is immersed into LN₂ bath.

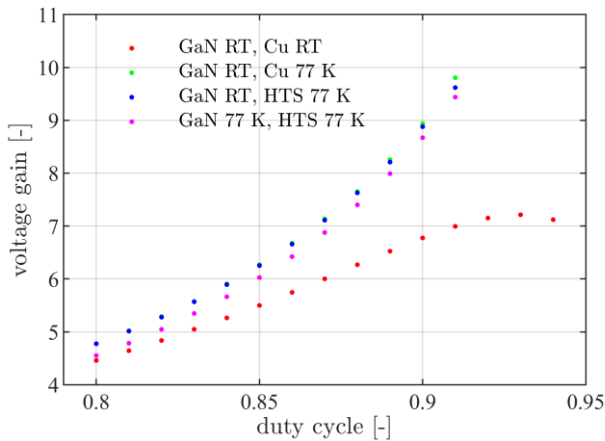


Fig. 14. Gain measurement in SiC boost at 10kHz

IV. CONCLUSIONS

This project provided an in-depth comparative study between GaN and SiC technologies—two wide bandgap semiconductors that are increasingly promising in power conversion applications. A key originality of this work lies in the experimental use of GaN and SiC power boards under cryogenic conditions, a setup that has rarely been explored in the literature. This approach enabled us to better understand the impact of extreme temperatures on component behavior, particularly regarding driver performance and results in terms of efficiency and voltage gain. It is promising result for expecting a high gain of boost converter and high duty cycle.

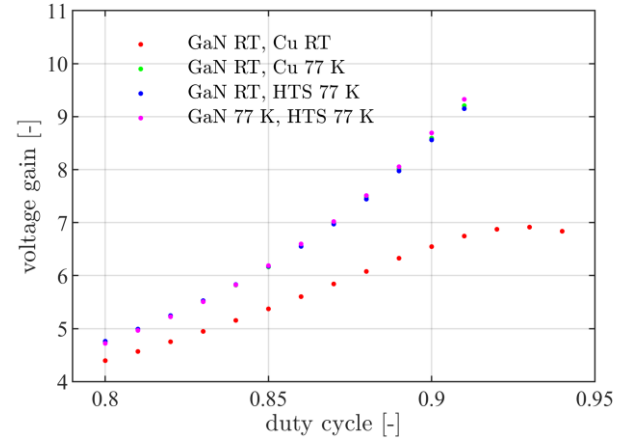


Fig. 15. Gain measurement in SiC boost at 10kHz

The results revealed also interesting trends: GaN components generally demonstrated better voltage gain, while SiC components proved more energy-efficient, especially at high switching frequencies and under constant power regimes. However, the influence of temperature on performance remains complex to interpret, notably due to unexpected behaviors observed at low frequencies, such as discontinuity operation with GaN transistors under cryogenic conditions. This reproducible and still poorly understood phenomenon presents a promising research avenue. It highlights the need for deeper analysis of GaN component robustness and the limitations of their gate drivers at very low temperatures.

Furthermore, the integration of superconducting (HTS) coils allowed us to question the real impact of series resistance in the conversion circuit, with results that were at times counterintuitively influenced by the physical configuration of connectors and the operating frequency.

In summary, this study, both experimental and exploratory, contributes new insights to the field of cryogenic power electronics. It can serve as a foundation for future investigations with more current, particularly regarding driver operations. The coil design at high frequency can be also easier with Litz wire than with superconducting cable but it surely depends on the required value of current for the application.

Further work is expected with higher current value, the integration of the microcontroller in the cryogenic bath or the comparison between cold plate or immersion. Is there a necessary interest of a cryogenic command circuit.

V. REFERENCES

- [1] P. Palmer, X. Zhang, E. Shelton, T. Zhang and J. Zhang, "An experimental comparison of GaN, SiC and Si switching power devices," *IECON 2017 - 43rd Annual Conference of the IEEE Industrial Electronics Society*, Beijing, China, 2017, pp. 780-785, doi: 10.1109/IECON.2017.8216135.
- [2] M. T. Bektas, O. Aytar, M. Coban and M. Fidan, "Analysis of the Performance of MOSFET, IGBT and GaN FET Power Switches Used as Switching Elements on Buck Type DC-DC Converter," *2024 4th International Conference on Electrical, Computer, Communications and Mechatronics Engineering (ICECCME)*, Male, Maldives, 2024, pp. 1-5, doi: 10.1109/ICECCME62383.2024.10796825.
- [3] L. Zhang, P. Liu, S. Guo and A. Q. Huang, "Comparative study of temperature sensitive electrical parameters (TSEP) of Si, SiC and GaN power devices," *2016 IEEE 4th Workshop on Wide Bandgap Power Devices and Applications (WiPDA)*, Fayetteville, AR, USA, 2016, pp. 302-307, doi: 10.1109/WiPDA.2016.7799957.

- [4] K Rajashekara and B Akin, "Cryogenic Power Conversion Systems: The next step in the evolution of power electronics technology," *IEEE Electrific. Mag.*, vol. 1, no. 2, pp. 64–73, Dec. 2013.
- [5] A. Wadsworth, D. Thrimawithana, L. Zhao, M. Neuburger, R. Oliver, and D. Wallis. Gan-based cryogenic temperature power electronics for superconducting motors in cryo-electric aircraft. *Superconductor Science and Technology*, 36, 07 2023
- [6] Yasmine Baazizi, Lauro Ferreira, Simon Meunier, Tanguy Phulpin, Loïc Quéval. Experimental Study of a Three-Phase Diode Rectifier Operating at Cryogenic Temperature. *IEEE Transactions on Applied Superconductivity*, 2024, 34, pp.1 - 5. ([10.1109/tasc.2024.3365427](https://doi.org/10.1109/tasc.2024.3365427)). ([hal-04920876](https://hal.archives-ouvertes.fr/hal-04920876))
- [7] R Chen and F F Wang, "SiC and GaN Devices With Cryogenic Cooling," *IEEE Open Journal of Power Electronics*, vol. 2, pp. 315-326, 2021.
- [8] Z Zhang et al., "Characterization of Wide Bandgap Semiconductor Devices for Cryogenically- Cooled Power Electronics in Aircraft Applications," *2018 AIAA/IEEE Electric Aircraft Technologies Symposium (EATS)*, Cincinnati, OH, 2018, pp. 1-8.
- [9] H Gui et al., "Review of Power Electronics Components at Cryogenic Temperatures," *IEEE Trans. Power Electron.*, vol. 35, no. 5, pp. 5144-5156, May 2020.
- [10] P.A.A. Honadia, F.I. Barro, and M. San´e. Performance analysis of a boost converter with components losses. *Energy and Power Engineering*, 10:399–413, 2018.
- [11] P. A. A. Honadia, F. I. Barro, et M. San´e, « Performance Analysis of a Boost Converter with Components Losses », *EPE*, vol. 10, n° 09, p. 399-413, 2018, doi: [10.4236/epe.2018.109025](https://doi.org/10.4236/epe.2018.109025).
- [12] GSP65RxxHB-EVB 650V, High Power IMS Evaluation Platform, Technical Manual, <https://www.infineon.com/cms/en/product/power/gallium-nitride/?redird=294997>, view the 04/2/2025