Design and Realization of a Interleaved Boost Converter with GaN FETs and SiC Diodes

Zoran Živanović, *Member*, *IEEE* and Vladimir Smiljaković

***Abstract*—This paper presents two hard switching boost DC/DC converters, one made with GaN FETs and SiC diodes and the other with MOSFETs and fest recovery epitaxial diodes (FRED). Both converters achieved 1200W of continuous output power operating at relatively high switching frequency of 167 kHz. Input voltages from 180 V to 240 V corresponding to the battery bank or photovoltaic power generation system, are boosted to 400V. The idea was to demonstrate the performance of GaN transistors in order to show their significant advantages over silicon MOSFETs.**

***Index Terms*—Boost, FRED, GaN, MOSFET, SiC diode.**

I. INTRODUCTION

A basic BOOST converter shown in Fig. 1, also known as a step-up converter is a non-isolated topology which means that the input and the output voltage use the same ground. The output voltage is higher than the input voltage keeping the same polarity. The input current is continuous and it is the same as the inductor current. On the other hand the output current is pulsating, because the output diode conducts only during the off time of the power switch. The output capacitor provides the load current during the power switch conduction.

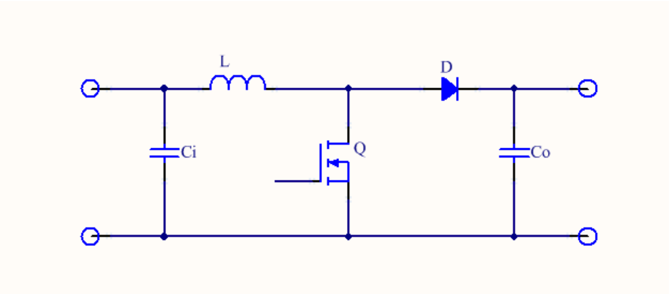

Fig. 1. Basic BOOST converter

II. INTERLEAVED BOOST CONVERTER BASICS

Interleaved BOOST converter shown in Fig. 2 is practically made from two boost converters (channels) operating at the same frequency but 180° out of phase. Both channels use the same input and output capacitor and as a result the effective ripple frequency is doubled. By splitting the current into two paths, the conduction losses of power switches Q_1 and Q_2 and inductors L_1 and L_2 are reduced. All of that makes the efficiency of the interleaved boost converter higher, input current ripple and output voltage ripple lower compared to the conventional boost converter. The performances are improved at the cost of additional power switches, inductors and output diodes. Due to the fact that both inductors are identical, both channels behave identically sharing the current equally. If only part of the energy stored in inductor is delivered to the load, the converter operates in continuous conduction mode (CCM). Opposite to that, if all stored energy is delivered to the load then the converter operates in discontinuous conduction mode (DCM). The peak currents are higher when the converter operates in DCM mode resulting in higher dissipation and higher electromagnetic interference (EMI). On the other hand converters operating in CCM mode have a stability problem caused by the right half plane zero in the transfer function, but they can achieve higher power density.

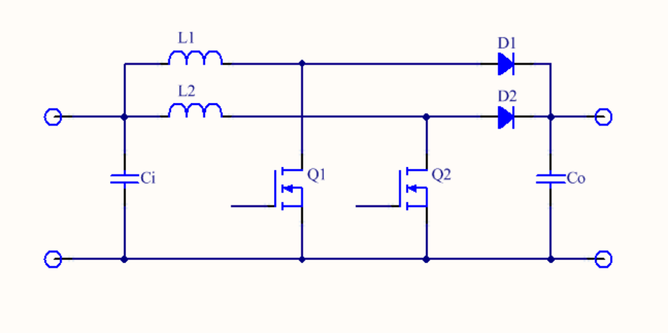

Fig. 2. Interleaved BOOST converter

III. DESIGN AND ANALYSIS

To evaluate the electrical and thermal performance we have designed two 1200 W interleaved boost converters – one with silicon MOSFETs and FRED diodes and the other one with GaN FETs and SiC diodes. Design specifications are given in Table I.

TABLE I
DESIGN SPECIFICATIONS

		Min	Typ	Max	
Input voltage	V_{IN}	180	200	240	V
Output voltage	V_O		400		V
Output current	I_O		3		A
Output current limit	I_{OCL}		3.3		A
Full load efficiency	η	95			%
Switching frequency	f_{SW}		167		kHz

Zoran Živanović is with the IMTEL KOMUNIKACIJE AD, Bul. Mihajla Pupina 165b, 11070 Belgrade, Serbia (e-mail: zoki@ insimtel.com).

Vladimir Smiljaković is with the IMTEL KOMUNIKACIJE AD, Bul. Mihajla Pupina 165b, 11070 Belgrade, Serbia (e-mail: smiljac@ insimtel.com).

The most of the losses are generated by the inductors, power switches and output diodes.

Starting from design specifications we will now calculate the basic parameters of the each converter channel (Table II).

TABLE II
BASIC PARAMETERS OF THE EACH CONVERTER CHANNEL

		Max	Typ	Min	
Duty cycle	D	0.55		0.40	
Average ind. current	I_{AVG}	3.33			A
Inductor ripple current	I_{PP}		3.33		A
Peak ind. current	I_{LP}	5.00			A
RMS ind. current	I_{LRMS}	3.47			A
Inductance	L		178		µH
RMS FET current	I_{RMS}	2.47			A
Peak diode current	I_{DPK}	5.00			A
Average diode current	I_{DAVG}		1.5		A

Due to high switching frequency, the inductance of the boost inductor is relatively low (178 µH), so we will use a PQ32/30 core, material N97 from TDK. We will use two bundles of seven enamelled copper wires, 0.3 mm in diameter, in order to minimize copper losses due to the skin effect. Boost inductor parameters are given in Table III.

TABLE III
BOOST INDUCTOR PARAMETERS

Core effect. volume	V_E	10.4	cm^3
Specific core losses	P_V	0.12	W/cm^3
Number of turns	N	31	
Winding resistance	R	44	mΩ
Core loss	P_{CORE}	1.25	W
Copper loss	P_{CU}	0.53	W
Total loss	P_{TOT}	1.78	W

As a power switch we have chosen a MOSFET SPP20N60C3 and GaN TPH3206S whose characteristics are given in Table IV. GaN FET has a better figure of merit (FOM) given by

$$FOM = (Q_{GD} + Q_{GS}) * R_{DS} \tag{1}$$

TABLE IV
POWER SWITCH CHARACTERISTICS

	Q_{GD}	Q_{GS}	C_{OSS}	R_{DS}	FOM
SPP20N60C3	33nC	11nC	83pF	160mΩ	7040
TPH3206S	2.2nC	2.1nC	64pF	150mΩ	645

Power switch losses can be broken down as

$$P_{FET} = P_{COND} + P_{ON} + P_{OFF} + P_{QOSS} \tag{2}$$

P_{COND} is the conduction loss given by

$$P_{COND} = I_{RMS}^2 R_{DS} \tag{3}$$

P_{ON} is turn-on switching loss given by

$$P_{ON} = \frac{V_{DS} I_P (Q_{GS} + Q_{GD}) f_{SW}}{2 I_G} \tag{4}$$

P_{OFF} is turn-off switching loss given by

$$P_{OFF} = \frac{V_{DS} I_P (Q_{GS} + Q_{GD}) f_{SW}}{2 I_G} \tag{5}$$

Finally, P_{QOSS} is drain capacitance charge loss given by

$$P_{QOSS} = \frac{Q_{OSS} V_{DS} f_{SW}}{2} \tag{6}$$

The losses for both FET types are given in Table V.

TABLE V
FET LOSSES

	SPP20N60C3	TPH3206S	
P_{CON}	1	0.94	W
P_{ON}	0.55	0.05	W
P_{OFF}	0.99	0.09	W
P_{QOSS}	1.1	0.85	W
P_{TOT}	3.64	1.93	W

The boost diodes are hard commutated at a high current and the reverse recovery can cause significant loss. For the FET converter we will use fast recovery diode DSEI 08-06A and for GaN converter the silicon carbide Schottky diode C3D08065I.

Conduction losses for both diode types can be calculated as

$$P_{DCOND} = V_F I_O \tag{7}$$

Switching losses for fast recovery diodes can be calculated as

$$P_{SWFR} = \frac{V_O t_{RR} I_{OFFSET} f_{SW}}{2} \tag{8}$$

For the silicon carbide diodes switching losses can be expressed as

$$P_{SWSIC} = \frac{Q_C V_{DS} f_{SW}}{2} \tag{9}$$

The losses for both diode types are given in Table VI.

TABLE VI

DIODE LOSSES

	DSEI 08-06A	C3D08065I	
P_{CON}	1.5	1.5	W
P_{SW}	2.6	0.66	W

IV. REALIZATION

Both converters are built on FR-4 substrate with 70µm copper with footprint 160 x 110mm. The inductors are wounded according to calculations. Metalized polypropylene film capacitors (MKP) 22µF/450V are used as input and output power capacitors.

Using lab power supply 0-600V/8.5A and high power resistive load, we have measured efficiency of both converters at maximum input voltage and also recorded the waveforms at the point of interest.

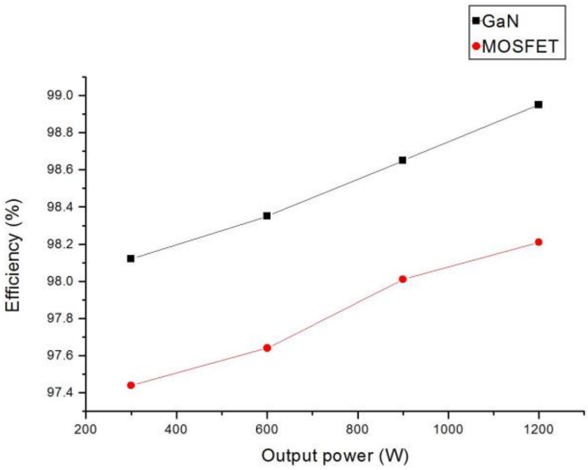

Fig. 3. Efficiency of GaN and MOSFET converters vs. output power

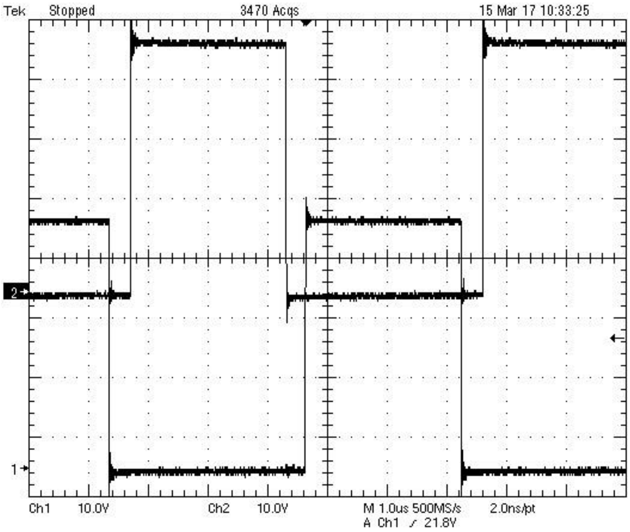

Fig. 4. Drain voltages waveforms at 180V input

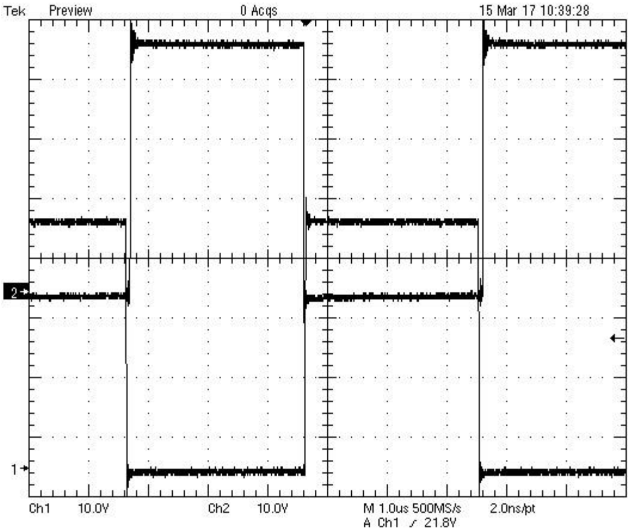

Fig. 5. Drain voltages waveforms at 200V input

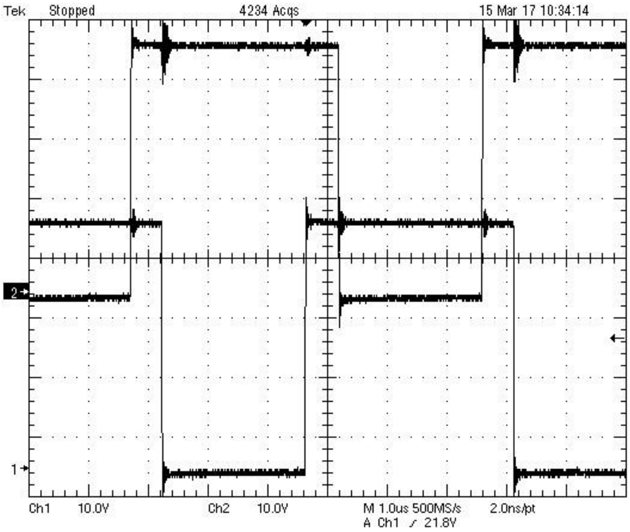

Fig. 6. Drain voltages waveforms at 240V input

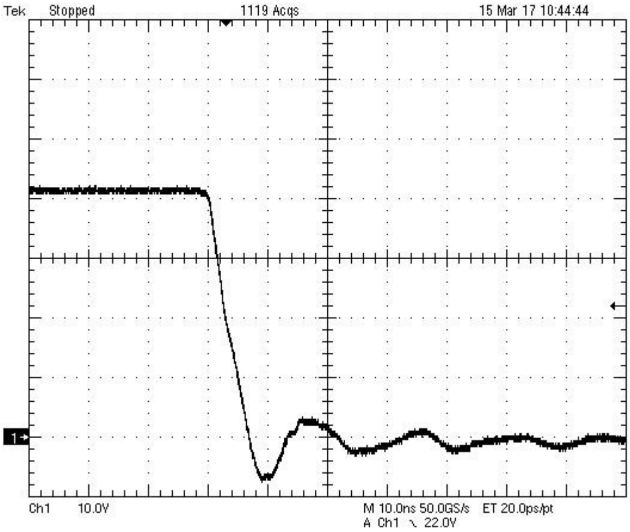

Fig. 7. GaN FET turn-on waveform at 240V input

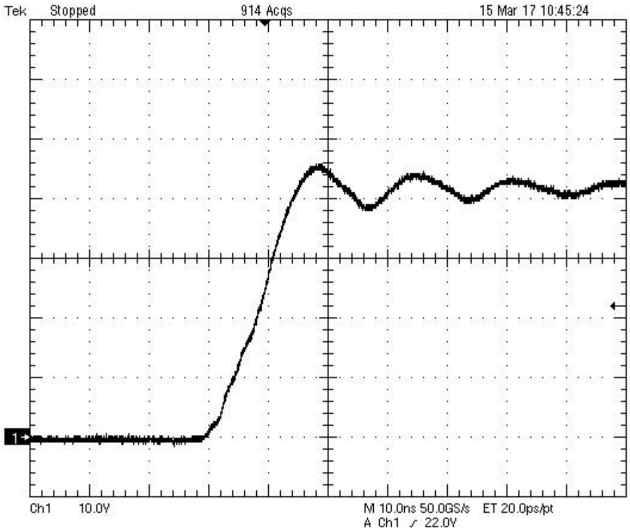

Fig. 8. GaN FET turn-off waveform at 240V input

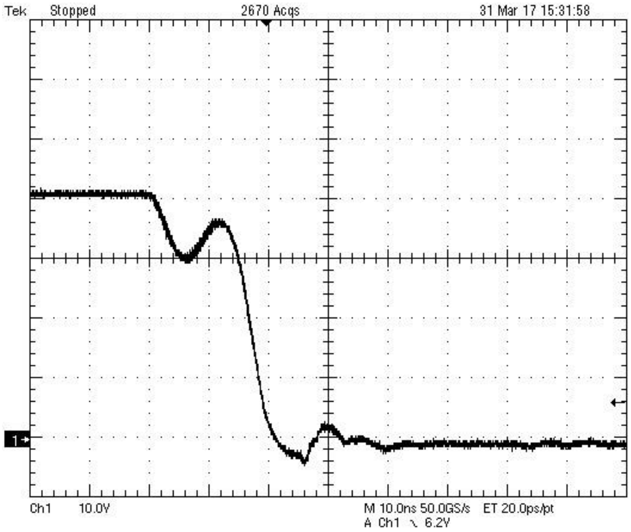

Fig. 9. MOSFET turn-on waveform at 240V input

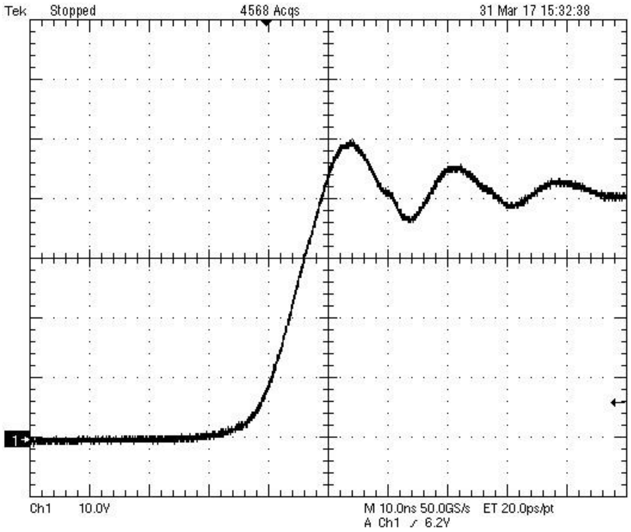

Fig. 10. MOSFET turn-off waveform at 240V input

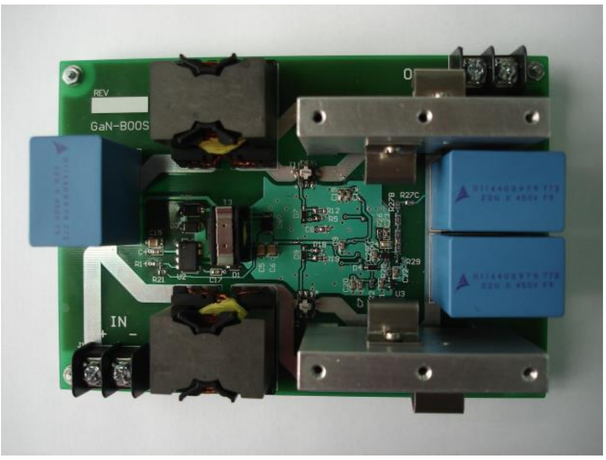

Fig. 11. Boost converter prototype

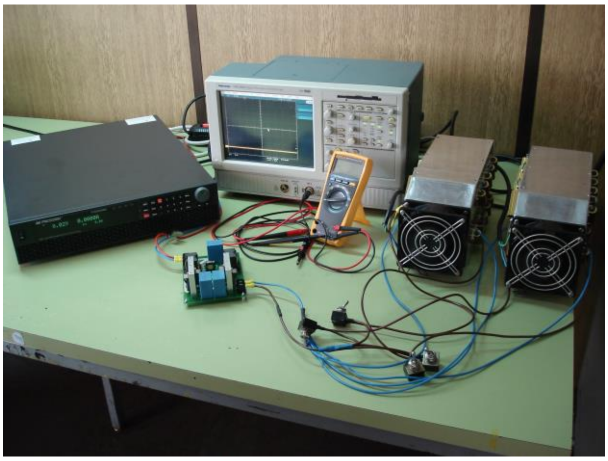

Fig. 12. Experimental setup in the lab

V. CONCLUSION

In this paper the design and realization of 1200W BOOST converters are presented. The prototypes are built and tested. The results confirmed the higher efficiency of the GaN converter made with GaN FETs and SiC diodes.

ACKNOWLEDGMENT

The work is partially supported by the Serbian Ministry of Education and Science (Project III-45016). The authors would like to thank Texas Instruments for providing BOOST controller and GaN driver samples.

REFERENCES

[1] R.W. Ericsson, D. Maksimovic, "Fundamentals of power electronics", Kluwer Academic Publishers, 2001.
[2] Zoran Zivanovic, Vladimir Smiljakovic, “Design and Realization of a eGaN FET DCDC Converter”, TELFOR2014 Proceedings, pp. 637-640
[3] Zoran Zivanovic, Vladimir Smiljakovic, Sinisa Jovanovic “Analysis and Design of a Resonant Reset GaN Forward Converter with Self-Driven Synchronous Rectifiers”, ICEST2015 Proceedings, pp. 275-278
[4] Texas Instruments, “LM5032 High-Voltage Dual Interleaved Current Mode Controller ”, Data sheet, www.ti.com