Conducted Emissions for Different Conversion Ratios of GaN-Based Synchronous Buck Converter

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***Abstract*—Large voltage conversion ratios of the switching DC-DC converters are difficult to achieve at high switching frequencies due to the short pulses of the control signals for the FET switches. To overcome this, multiple stages of the DC-DC converters with smaller conversion ratios can be used. A synchronous buck converter based on the gallium-nitride FET switches is designed to analyze the impact of the different voltage conversion ratios on the power efficiency and differential-mode conducted EMI at the input of the converter. The conducted EMI and power efficiency are measured for duty ratios of 10% to 50% and for switching frequencies up to 5 MHz. The input and output voltage and power levels are set to reproduce the operating conditions of the front-end and load converter in the multi-stage step-down switching DC-DC converter topology.**

***Index Terms*—conducted EMI, duty ratio, gallium-nitride FET, power efficiency, switching DC-DC converter.**

I. Introduction

Switching DC-DC converters are more attractive for modern power electronic applications than the linear converters, primarily due to their higher power efficiency [1]. However, due to their switching operation, switching DC-DC converters are a major source of conducted and radiated emissions, which is the main downside of these power supply circuits [2].

The lower parasitic capacitance of gallium-nitride (GaN) FETs compared to those of silicon MOSFETs shifts the operation of the switching DC-DC converters to higher frequencies [3]. One of the typical problems of the high-frequency switching DC-DC converters is that it is difficult to achieve large voltage conversion ratios due to the short pulses of the control signals for the FET switches. The common solution to overcome this problem is to use more DC-DC converter stages that have the smaller voltage conversion ratios in order to achieve the large conversion ratio of the whole converter.

The multi-stage switching DC-DC converters are investigated in many papers in terms of high-voltage operation [4], stability analysis [5] or ease of implementation [6]. However, there is a lack of papers that investigate the impact of the voltage conversion ratio of the switching DC-DC converter on the conducted electromagnetic interference (EMI) and the power efficiency of the converter. Furthermore, different converters used in the step-down multi-stage topology operate at various input/output voltages and power levels, and impact of the duty ratio on the performance of the converter can depend on their position in the multi-stage converter chain.

In this paper, a designed synchronous buck converter using the GaN FET switches is analyzed in terms of generated conducted EMI and power efficiency for different voltage conversion ratios and at various switching frequencies and power levels. The GaN-based switching DC-DC converter is designed to investigate the operation of the converter at frequencies up to 5 MHz and output power levels up to 4 W for constant input voltage and output power (front-end converter) and constant output voltage and output power (load converter).

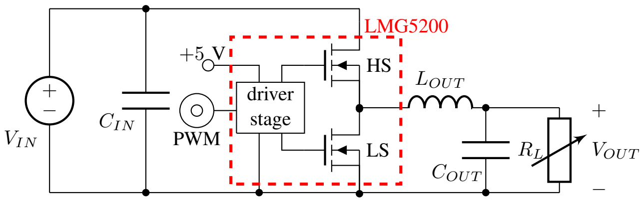


Fig. 1. The simplified model of a synchronous buck converter.

The device under test and measurement setup are described in Section II. Section III shows the measurement results, while Section IV concludes the paper.

II. Device Under Test and Measurement Setup

A. Device under test and characterization circuit

The simplified schematic of the synchronous buck converter used for characterization of the device under test (DUT) is shown in Fig. 1. The DUT is LMG5200 device from Texas Instruments that consists of a driver and GaN half-bridge power stage, i.e. high-side (HS) and low-side (LS) GaN FET switch [7]. The DUT, marked in red-dashed rectangle in Fig. 1, is used as a part of the analyzed synchronous buck converter. The FET switches are controlled using the two control signals (for HS and LS FET) from the dual-channel PWM signal generator. The output inductor, L_{OUT}, of 4.7 µH is used. The input capacitive decoupling network, C_{IN}, consists of 100-nF, 4.7-µF and 47-µF capacitor, while the output capacitive network, C_{OUT}, consists of 470-nF, 1-µF and 47-µF capacitor. The input and output capacitors are selected as described in [8]. The switching converter is designed on a dual-layer printed circuit board (PCB). An input low-pass LC filter is not used to ensure fair comparison of the results (the real filter does not attenuate all the harmonics equally). The filter design depends on the switching frequency, input voltage, output power level, required attenuation level, etc. [9], and the filter design is not in the focus of this paper.

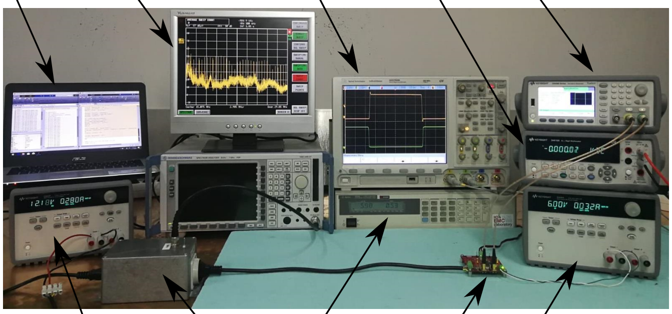


Fig. 2. Photo of the measurement setup.

B. Measurement setup and method

The photo of the setup used to measure the conducted EMI and the power efficiency is shown in Fig. 2. The dual-channel PWM signal generator is used to generate the control signals for the DUT, while the DC voltage sources provide the input voltage for the converter and 5-V supply for the driver stage of the DUT. The electronic load is used to set the output current for the defined output voltage that is measured using the voltmeter. The dead times between the generated control signals are set to 10 ns for all measurements and they are measured using the oscilloscope at the highest possible horizontal resolution (2 ns/div).

The designed converter is a non-isolated switching DC-DC converter, which uses two lines at the input port (between the DC voltage source and the converter) and two lines at the output port (between the converter and the electronic load). The conducted EMI is measured at the input of the designed converter using the line impedance stabilization network (LISN) (described in [2]) and spectrum analyzer. The settings of the spectrum analyzer used for monitoring the conducted EMI are: frequency range from 150 kHz to 30 MHz, 9-kHz RBW filter, average detector and 8000 sweep points with 10 sweep counts.

The power efficiency and conducted EMI are measured for different voltage conversion ratios (i.e. duty ratios of 10%, 20%, 30%, 40%, 50%) at switching frequencies of 800 kHz, 1 MHz, 3 MHz and 5 MHz. The impact of the duty ratio of 10% for the switching frequency of 5 MHz is not analyzed due to the too short pulse of the control signal for the proper operation of the designed synchronous buck converter. A personal computer (PC) with GPIB interface is used for setting the parameters of the converter operation and post-processing of the measured data.

The conducted EMI and the power efficiency of the designed GaN-based DC-DC converter are measured for two independent test cases:

1) $V_{IN} = 12$ V (const.), output power: 2 W and 4 W,
2) V_{OUT} = 2 V (const.), output power: 2 W and 4 W.

The first test case imitates the operation of the first (front-end) converter in the multi-stage step-down topology that reduces the input fixed DC voltage to an intermediate voltage level. The second test case reproduces the last stage (load converter) in the multi-stage chain that provides the desired output voltage at defined output power level.

III. Measurement Results

A. Test case 1: Front-end converter

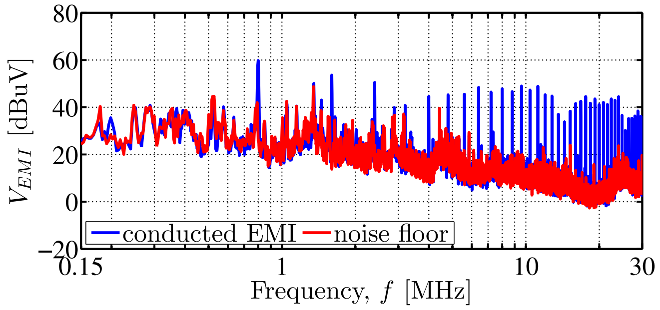
The measured conducted EMI for all four analyzed switching frequencies of the designed converter at conversion ratio of 50% for the output power of 2 W is shown in Fig. 3. The amplitudes of the harmonics of the conducted EMI for duty ratios of 10% and 50% and output power levels of 2 W and 4 W are shown in Fig. 4. The measured conducted emissions increase with the output power level due to the larger current at the input of the converter (V_{IN} = const.). The larger duty ratios lead to the larger output voltages, V_{OUT}, and lower input currents (to keep P_{OUT} = const.), which causes the lower measured conducted EMI. The noise floor that represents the sum of all the noise sources within the measurement setup is shown in red in Fig. 3.

The comparison of the amplitude of the spectrum of the measured conducted EMI at the switching frequency, f_{SW}, against the duty ratio for different values of switching frequencies is shown in Fig. 5. The impact of the duty ratio on the measured conducted EMI is more pronounced when the switching frequency and output power level are increased because in both cases the current that flows into the converter and causes the conducted EMI is increased.

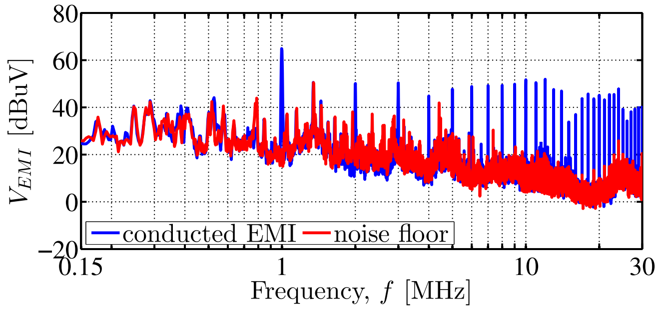
The power efficiency of the designed converter against the duty ratio for different switching frequencies is shown in Fig. 6. The efficiency drops as the switching frequency increases due to the larger switching losses of the power converter. Furthermore, the power efficiency gets higher as the duty ratio is being increased, which can be attributed to the lower conduction losses of the HS FET switch compared to the LS FET switch integrated in LMG5200.

B. Test case 2: Load converter

The impact of the duty ratio on the amplitude of the measured conducted EMI at the switching frequency, f_{SW}, for the output power levels of 2 W and 4 W is shown in Fig. 7. It is shown that the amplitude of the measured conducted EMI increases as the duty ratio increases for both output power levels. The output voltage is kept constant in this test case ($V_{OUT} = 2$ V) and the larger duty ratio leads to the lower input voltage and larger current at the input of the converter to ensure required output power level. The conducted EMI is only related to the current level, and not the voltage level at the input port. With the same output power level of the buck converter, lower input voltage means higher input current, thus worse input conducted EMI. The difference of around 6 dB between the duty ratio of 10% and 50% is observed for the output power of 2 W and almost 9 dB for the output power of 4 W. The impact of the duty ratio on the generated conducted EMI is the opposite of the previous test case. The conducted EMI at the input of the multi-stage DC-DC converter should



(a)



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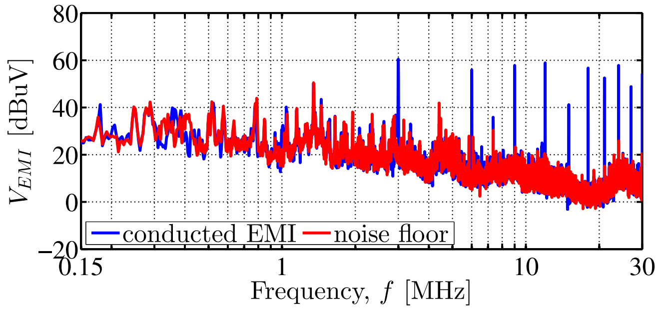

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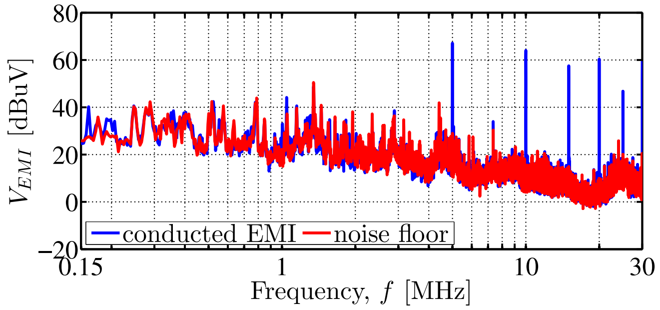
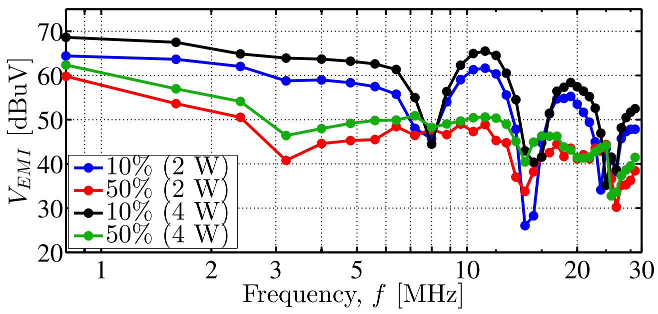
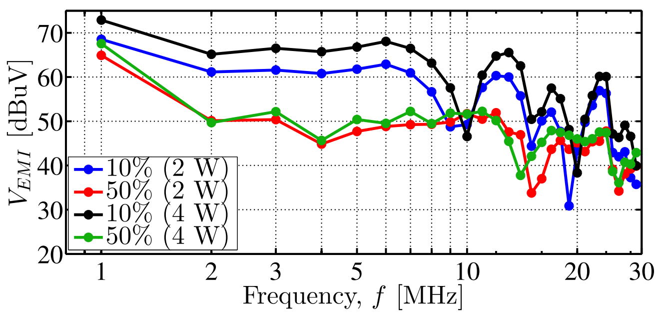


(d)

Fig. 3. Test case 1: conducted EMI for output power level of 2 W and voltage conversion ratio of 50% at switching frequencies: (a) 800 kHz, (b) 1 MHz, (c) 3 MHz and (d) 5 MHz. The noise floor is shown in red. The input voltage is constant, $V_{IN} = 12$ V.



(a)



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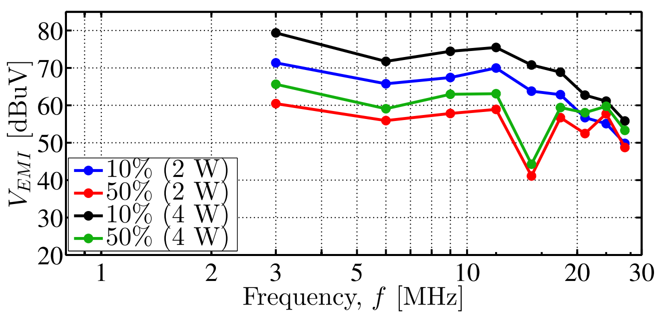

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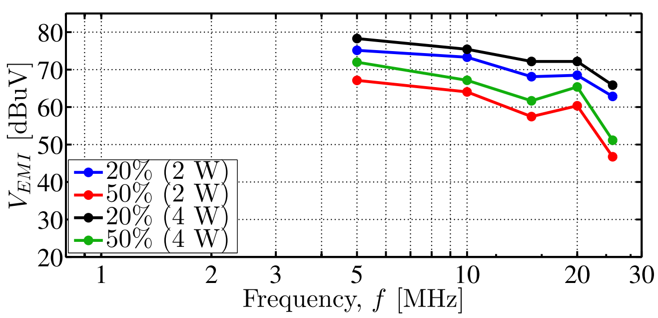
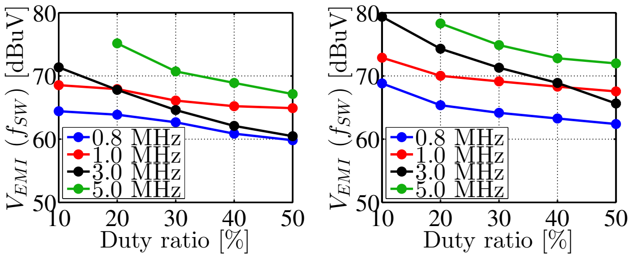


(d)

Fig. 4. Test case 1: amplitude of the harmonics of conducted EMI for voltage conversion ratios of 10% and 50% and output power levels of 2 W and 4 W at switching frequencies: (a) 800 kHz, (b) 1 MHz, (c) 3 MHz and (d) 5 MHz. The input voltage is constant, $V_{IN} = 12$ V.

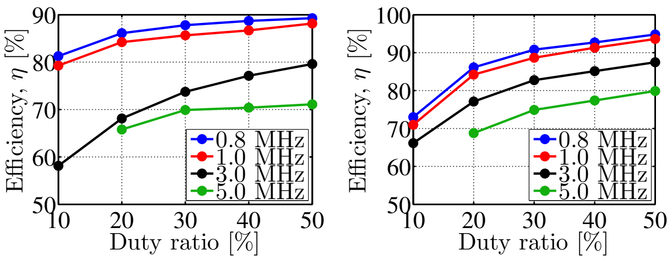
be mainly determined by the current flowing into the first stage of the converter cascade, i.e. the front-end converter, and the conducted EMI generated by the other stages are filtered out by the inductive elements at the output of the previous stage, as L_{OUT} in Fig. 1. However, if the load converter is used as a standalone switching DC-DC converter, than the test case 2 is crucial for estimation of the conducted EMI at the input.

The power efficiency of the designed switching converter against the duty ratio for different switching frequencies is shown in Fig. 8. The trend of the power efficiency against the



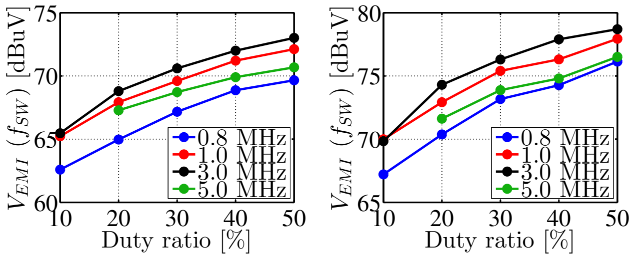
(a) (b)

Fig. 5. Test case 1 (V_{IN} = const.): amplitude of the EMI spectrum at switching frequency f_{SW} vs. duty ratio at different switching frequencies for the output power of: (a) 2 W and (b) 4 W.



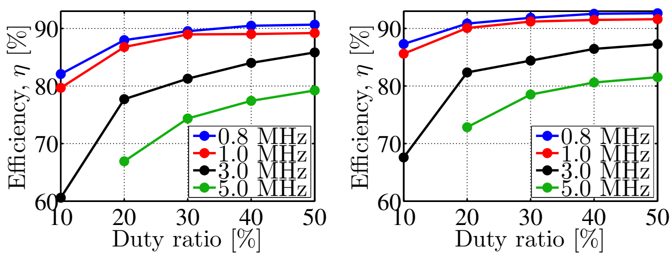
(a) (b)

Fig. 6. Test case 1 (V_{IN} = const.): power efficiency vs. duty ratio at different switching frequencies for the output power level of: (a) 2 W and (b) 4 W.



(a) (b)

Fig. 7. Test case 2 (V_{OUT} = const.): amplitude of the EMI spectrum at switching frequency f_{SW} vs. duty ratio at different switching frequencies for the output power of: (a) 2 W and (b) 4 W.



(a) (b)

Fig. 8. Test case 2 (V_{OUT} = const.): power efficiency vs. duty ratio at different switching frequencies for the output power of: (a) 2 W and (b) 4 W.

duty ratio and the switching frequency is the same as for the first test case.

IV. Conclusion

A GaN-based synchronous buck converter is designed to analyze the impact of the voltage conversion ratio on the conducted emissions at the input of the converter and the power conversion efficiency at switching frequencies up to 5 MHz and output power levels up to 4 W. The operating conditions of the designed converter are chosen to imitate the typical operation of the front-end (constant input voltage) and load converter (constant output voltage) of the multi-stage switching DC-DC converter. When the input voltage is constant, the conducted EMI reduces as the conversion ratio is increased (up to –8 dB between the duty ratio of 10% and 50%). When the output voltage is constant, the conducted EMI increases with the conversion ratio (up to 9 dB between the duty ratio of 10% and 50%). Therefore, the position of the converter in the multi-stage chain determines the trend of the conducted EMI against the voltage conversion ratio. The measured power efficiency of the designed converter increases with the duty ratio and decreases as the switching frequency gets higher. This trend of the power efficiency is the same regardless of the variation of input or output voltage levels.

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