Characterization of Ground Bounce and Conducted Emissions of Integrated Isolated DC-DC Converter

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***Abstract* - Isolation is used in automotive industry for safety reasons to galvanically isolate different domains. Isolated DC-DC converters are used to provide power across the isolation boundary. Integrated isolated power converters provide simpler, smaller, and more robust solutions compared to discrete solutions such as push-pull converters. Integrated isolated DC-DC converters operate at switching frequencies in the range of tens of MHz which makes them potential sources of electromagnetic emissions. Ground bounce is the main cause of the electromagnetic emissions. A 5V-to-5V integrated isolated DC-DC converter based on ISOW774x with interlayer stitching capacitance is developed on a printed circuit board. The ground bounce is characterized by time-domain measurements. The conducted emissions of the converter are measured according to CISPR25 standard. EMI filtering design for the converter is discussed.**

***Keywords* – CISPR25, electromagnetic compatibility, electromagnetic interference, switched-mode power converter**

I. INTRODUCTION

Isolation technology protects parts of a system from high voltage surges and can also shield devices from signal interference. The most important role isolation has is safety. In the automotive industry isolation plays a vital role as electric vehicles are now running on 400 V or 800 V battery packs and it is necessary to isolate parts of the system that operate at a different voltage [1].

Isolated DC-DC converters are used to provide the necessary isolation and lower voltage levels. Integrated solutions for isolated power converters are smaller, simpler, and cheaper than converters with discrete components, such as push-pull converters. The downside of integrated isolated converters is they are operating at higher switching frequencies, in range of tens of MHz, which makes them potential sources of electromagnetic (EM) emissions of these frequencies and their harmonics.

For every electronic device, the allowed maximum levels of EM emissions are defined by specific electromagnetic compatibility (EMC) standards. For the automotive industry, this is Comite International Special des Perturbations Radioelectriques 25 (CISPR25) standard [2]. For measuring the conducted emissions, this standard defines the necessary test setup and limits for the frequency range from 150 kHz to 108 MHz in specific frequency bands [3]. In this paper, class 5 limits (the most stringent in CISPR25) are used.

Chapter II of this paper describes the designed printed circuit board and the used device. Chapter III presents the results of time-domain measurements, while chapter IV shows conducted emissions measurement results. Chapter V presents the conclusion.

II. PRINTED CIRCUIT BOARD

A. ISOW774x

The main component of the developed printed circuit board is the ISOW774x quad-channel digital isolator with integrated DC-DC converter. It has two possible configurations for the output voltage (3.3V or 5V) depending on whether the VSEL pin is shorted to GND2 or to V_{ISOOUT} pin. In this paper, the 5V output configuration is used. The maximum output power of the device is 550 mW, with up to 46% efficiency at maximum load. The integrated isolated converter operates at 25 MHz switching frequency. Information about the output voltage is sent to the primary side through an isolated feedback channel and the switching duty cycle is modified accordingly. Beside the feedback channel, there are four isolated digital channels. Fig. 1 shows simplified functional diagram of ISOW774x [4].

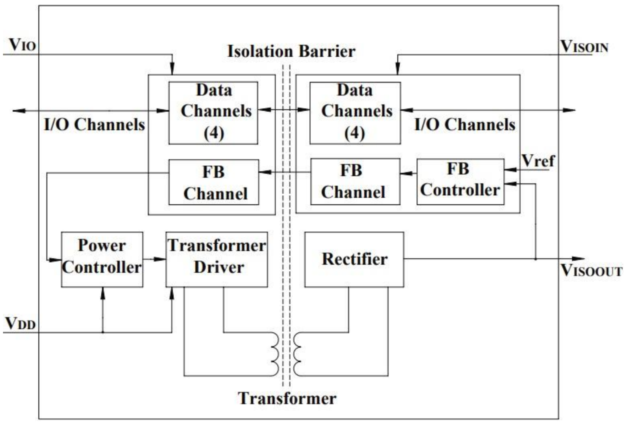


Figure 1. ISOW774x functional block diagram [4].

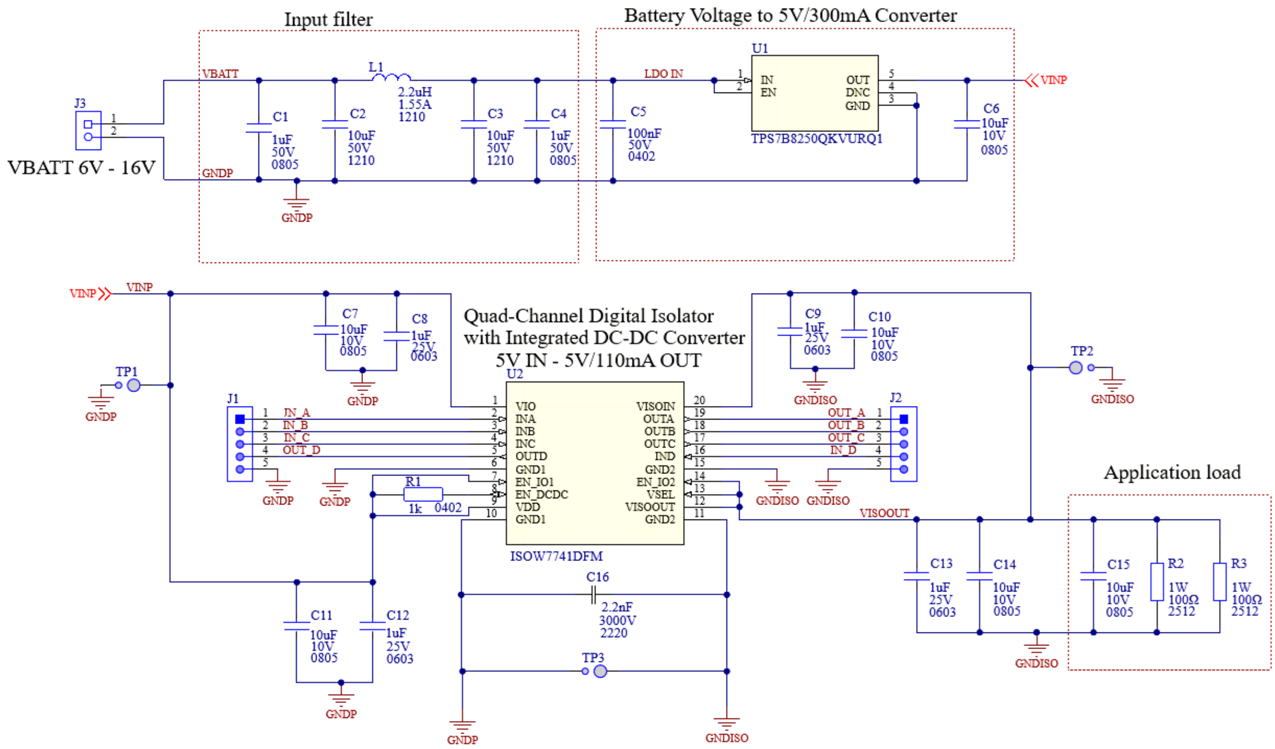


Figure 2. Printed circuit board schematic.

B. Schematic and layout

The printed circuit board (PCB) is designed in software tool Altium Designer [5]. Fig. 2 shows the schematic with important sections of the design marked, such as the passive input filter and LDO used for converting battery voltage to 5 V necessary for ISOW774x. The layout in 3D view is presented in Fig. 3. The board contains four metal layers, with copper thickness of 35 µm, and dielectric thickness between layers 1-2 and 3-4 of 100 µm. The dimensions of the board are 100 mm x 50 mm x 1 mm. Two ground planes GNDP and GNDISO are separated by 8 mm at the top and bottom layer, but overlap in two inner layers under the device creating a stitching capacitance. This technique is used to improve the EMC performance of the device [6].

III. Time-domain Measurements

A. Setup

Fig. 4 shows the measurement setup and the used instruments are marked as follows:

1. DC voltage supply
2. Oscilloscope with floating ground
3. Function generator
4. Programmable DC electronic load

The DC voltage supply is set to 7 V and it is connected to the VBATT connector on the board. The oscilloscope channels are connected to the three test points on the board and to the channel A output. The function generator is connected to the channel A input, and it is used as a source of the square wave signal with 1 MHz frequency and 5-V peak-to-peak amplitude. Instead of the application load marked in Fig. 2, a programmable DC electronic load is used to adjust the output load.

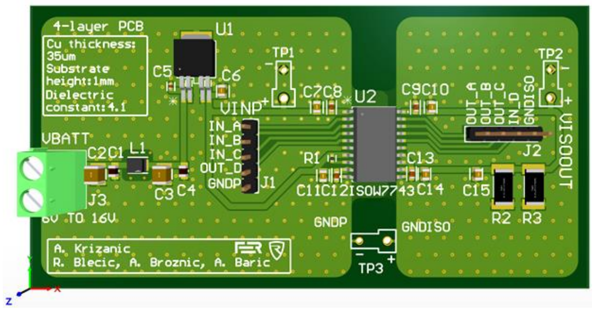


Figure 3. Printed circuit board 3D layout.

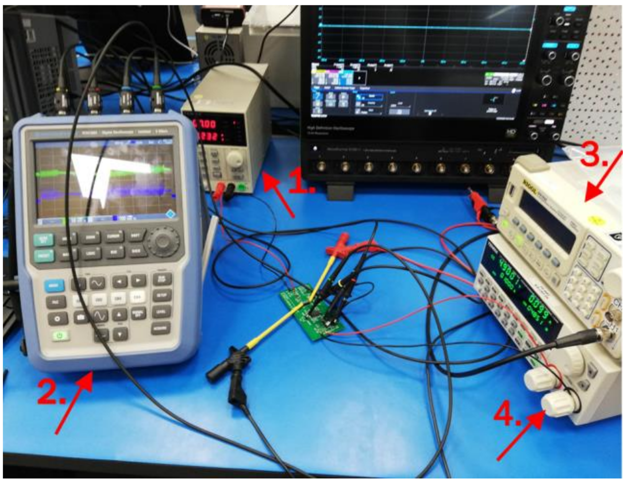


Figure 4. Time-domain measurement setup.

B. Results

The first step of measurement is checking the converter output voltage to confirm that the device is working properly. Table I shows the measured output voltage, along with the values of load resistance, input current, and voltage. These values are used to calculate the efficiency at a given load. The result is approximately 42% efficiency, which is a little lower than 46% given in the datasheet [4].

Fig. 5 and 6 show the AC output of the device without load and with 100 mA load. The change of the duty cycle depending on the voltage V_{ISOOUT} is visible from the on- and off-part of the cycle marked in the figures. With a higher current, the output capacitors are discharging much faster, so the off-time of the device is shorter and the duty cycle rises to approximately 0.5 when the load is applied. During the on-time, switching noise is visible as higher amplitude oscillations.

When a square wave signal is connected to the channel A it interferes with the converter output at every rising and falling edge, as it is shown in Fig. 7.

Fig. 8 shows the voltage between GNDP and GNDISO which is different from zero and confirms that these ground planes are isolated. During the on-phase of the converter the ground bounce is visible. This oscillation of the ground voltage is one of the main causes of electromagnetic emissions.

TABLE I.
MEASURED VALUES FOR CALCULATING EFFICIENCY

Parameter	I_{IN}	V_{DD}	V_{ISOOUT}	R_{LOAD}
Value	223 mA	4.97 V	4.86 V	50.9 Ω

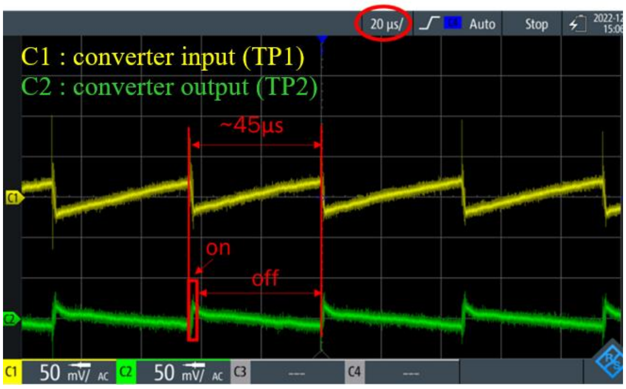


Figure 5. AC input and output without load.

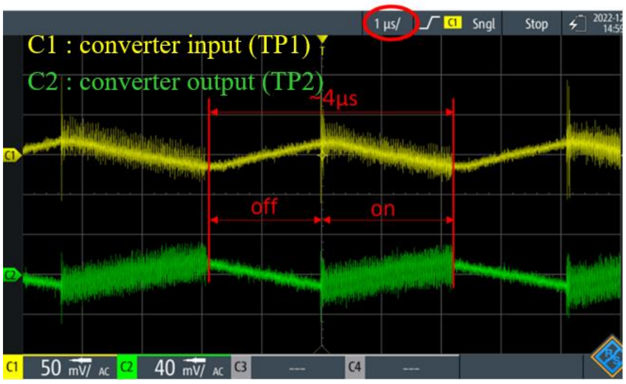


Figure 6. AC input and output with 100 mA load.

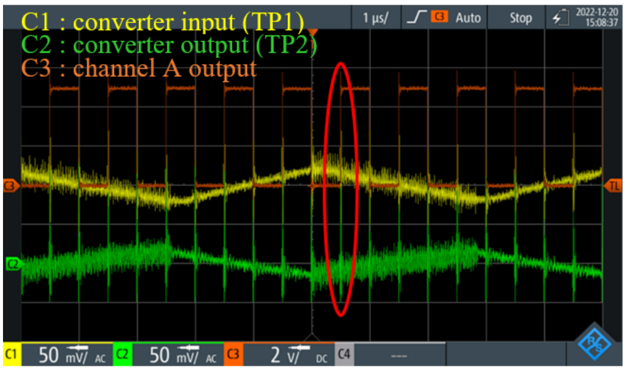


Figure 7. AC output with 100 mA load and channel A on.

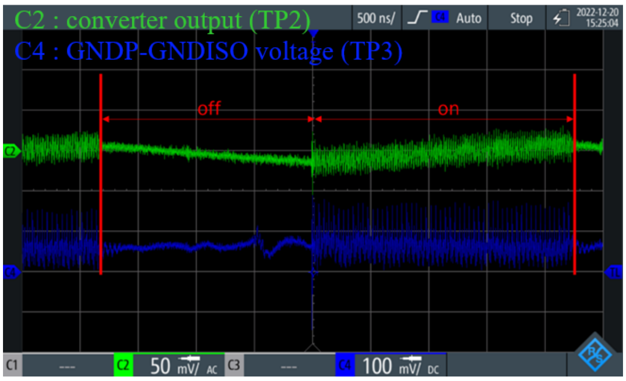


Figure 8. AC output and voltage between isolated ground planes with 100 mA load.

IV. CONDUCTED EMISSIONS MEASUREMENTS

A. Setup

To measure the conducted emissions an EMI-shielded box is used for testing in the lab. Inside the box, there is the device under test (DUT) placed on insulating material and connected to two Line Impedance Stabilization Networks (LISNs), as shown in Fig. 9. For these measurements a 5-µH LISN is specified by CISPR25 standard to "correspond with the approximate inductance of an automotive wiring harness" [3]. The power supply and EMI receiver are outside the shielded box and connected to LISNs through specific ports on the box. The frequency range for measurements is set from 150 kHz to 120 MHz, with a 9 kHz resolution bandwidth.

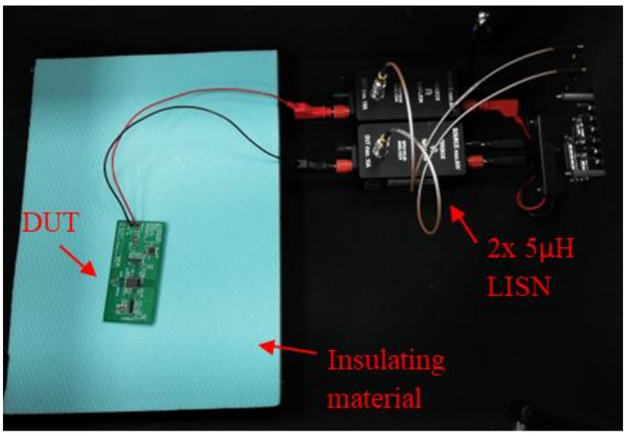
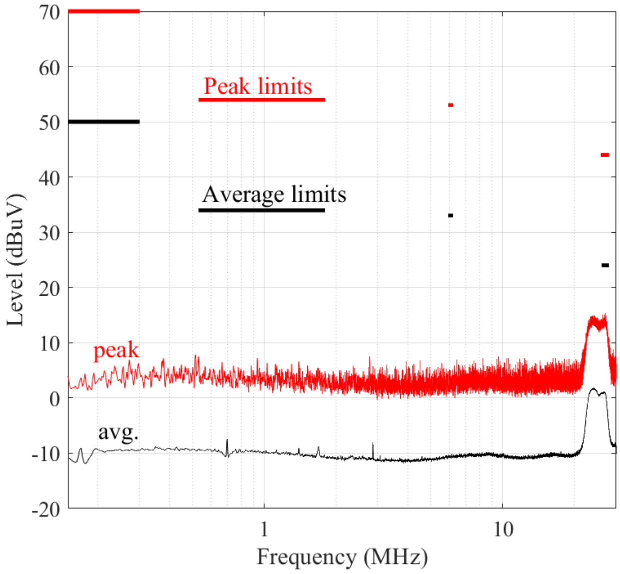


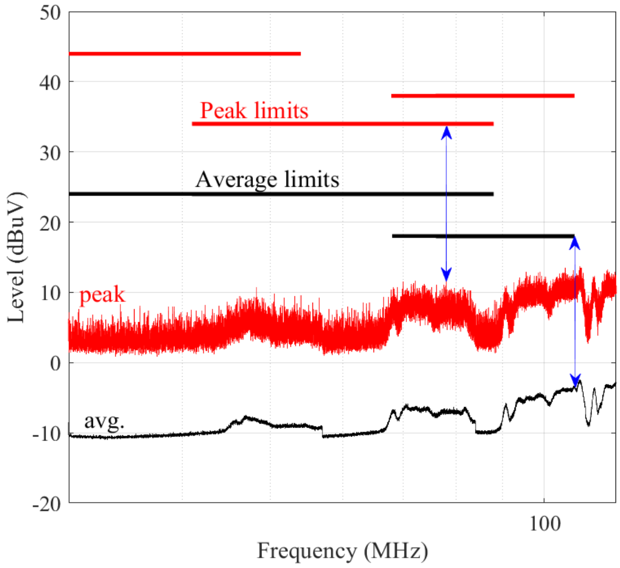
Figure 9. Conducted emissions measurement setup.

B. Results

The results are plotted in Matlab along with the limit lines of CISPR25 standard. Fig. 10 shows conducted emission measurements for a PCB without load and with an input filter. In Fig. 11 the values measured with a 51-Ω load are presented in two different configurations, with and without *C1*, *C2*, *C4* and *L1* components of the input filter. It is visible that both peak and average values are lower than the limits in both figures. There is also a clear difference in the amplitude of emissions with and without the load mounted on the board. Higher emissions with the load appear because of higher current and shorter off-time of the device. This is also shown in Table II where minimum margins for tests with load are much lower than without the load. The values of minimum margins are also marked on Fig. 10 and 11 with blue arrows.

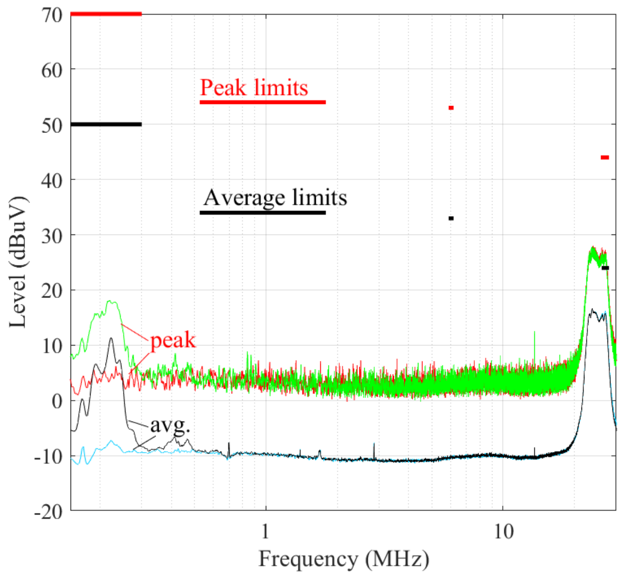


a) 150 kHz to 30 MHz range

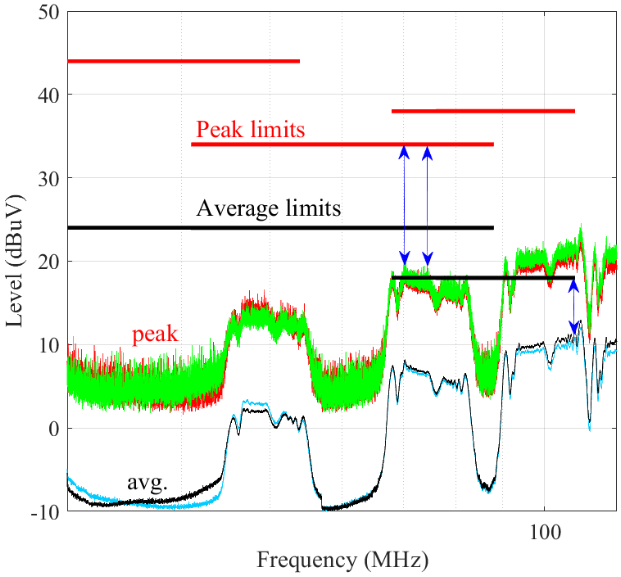


b) 30 MHz to 120 MHz range

Figure 10. CISPR25 conducted emmissions measurement without load (red line: peak values, black line: average values).



a) 150 kHz to 30 MHz range



b) 30 MHz to 120 MHz range

Figure 11. CISPR25 conducted emissions measurement with 51-Ω load (red line: peak values with filter, green line: peak values without filter, cyan line: average values with filter, black line: average values without filter).

To achieve the results under the limit lines, different techniques can be used. Mitigation of conducted EMI can be achieved at the source or along the propagation path [7]. The ISOW774x design includes advanced schemes to reduce the emissions at the system level, some of which are bigger on-chip decoupling capacitors and reduced common currents across the isolation barier [4]. From the presented results, it is visible that instead of high peak amplitude at the switching frequency of 25 MHz there is a wider spectrum of frequencies with lower amplitudes. This is called a spread spectrum technique and it is used for reducing EM emissions in many applications, including DC-DC converters [8].

For mitigating emissions along the propagation path external and internal filters can be used [7]. In this paper, an example of external filter is the passive input filter used for attenuating differential mode noise.

TABLE II.
MINIMUM MARGINGS FOR MEASURED RESULTS

Test	Minimum margin AV detector, dB	Frequency of minimum margin AV detector, MHz	Minimum margin PK detector, dB	Frequency of minimum margin PK detector, MHz
Without load, with filter	21.7	108	22.4	78
With load, with filter	7.2	108	14.5	74.4
With load, without filter	6.3	108	13.9	70.3

It dominantly works in a frequency range below 30 MHz, and its role is visible in Fig. 11 a) where there is a rise in amplitude without the filter. Another filter used is an interlayer stitching capacitance achieved with specific layout design. The overlaping ground planes under the device in the second and third layer create a common-mode capacitive filer [6].

V. CONCLUSION

A 5V-to-5V DC-DC converter based on ISOW774x developed on a printed circuit board is presented. Time-domain measurements confirm the functionality of the device and show the change of the duty cycle with varying load, interference from the digital channel and the ground bounce. The results of conducted emission measurements are below the CISPR25 class 5 limit lines. This is a result of the chip-level improvements in ISOW774x, input filter, and interlayer stitching capacitance on the PCB. The next step in the research is designing a 5V-to-5V isolated DC-DC converter in 4 different configurations on one PCB. It will include the one presented in this paper and also one designed with discrete components, both made with and without interlayer stitching capacitance. Those different configurations will then be tested and compared.

ACKNOWLEDGMENT

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