Different constructions of step down voltage converters in terms of EMC

Martin Pospisilik, Milan Adamek, and Rui Miguel Soares Silva

Abstract**—** At present, the designers of voltage converters can choose from a wide variety of custom integrated drivers operating at different principles. The authors of this paper aim to show that although the two different designs of a step-down voltage converters can achieve comparable nominal values, at least from the view of the user, due to the differences in the basic principles applied in their drivers they may exhibit different behaviour in the area of the electromagnetic compatibility. This can lead to considerable problems in design of more complex circuits these voltage converters are a part of. For the purposes of the hereby presented results, two different constructions of step-down converters have been chosen. The first one is based on a low-cost and randomly operating solution based on the driver MC 34063 while the second one employs more advanced driver marketed under the label AP 1501. Both converters were constructed and tested for the purposes of application in a power backup device for Power over the Ethernet. The nominal input voltage of both converters is 24 V while their nominal output voltage is 12 V, as used in common applications. Both converters were tested in the EMC laboratory of Tomas Bata University Zlin in order to obtain not only the static parameters, but also the information on how they can interfere with other electronic devices. Within this paper, the most interesting findings are published.

Keywords**—** Electromagnetic interference, Fixed frequency controller, Step-down converter, Self-oscillating converter

I. Introduction

ACCORDING to the width of the current offer of the market of electronic components, it can be confusing to choose the proper driver for a construction of a low-cost step-down voltage converter. There are various chips with different internal organization that were designed on the basis of different approaches. This paper brings a comparison of real results obtained with two different constructions of low-cost and low-power step-down converters. The main difference between the two constructions lies in the fact that one of the converters is operated at a constant frequency, that is given by its internal oscillator, and its regulation is provided right by means of a pulse-width modulation, while the second converter oscillates at random frequency that is given by its output load and input voltage and its regulation is provided by interrupting of its operation when the output voltage is exceeded. Surprisingly, from the view of the user, the performance of both circuits is similar in terms of their voltage stability, output power, power efficiency etc. and even more surprisingly, from the point of view of the standard EN 61000-6-3 the converter driven by the internal oscillator provides higher interference than the randomly oscillating one, despite the fact, that the power density of his interference is much lower. All these phenomena are described within the framework of this paper.

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II. Description of the Tested Converters

Both converters, the performance of whose is compared within this paper, were constructed according to the following requirements:

- input voltage: 20 to 28 V,
- output voltage: 12 V,
- power efficiency: higher than 80 %,
- output power: at least 20 W.

The description of their philosophy, construction and operation is described in the text below.

A. Randomly Oscillating Converter with MC 34063

This converter is based on the well-known low-cost driver MC 34063 [4], the internal construction of which is based on a modified traditional 555 timer. The circuit diagram of this converter is depicted in Fig. 1. The input voltage is connected to the clamps X1 while the output voltage is connected to the clamps X2.

Because the peak switching current of the internal switch of the driver is limited to 1.5 A, external switching transistor Q2 is employed, being driven by an inverter based on the transistor Q1. The circuit operates as follows:

1. When the power is delivered to the circuit, the switching transistor Q2 is opened and the current through the inductor L1 rises in time. The rate of the rise is given by the inductance of the inductor.
2. Once the current flowing through the inductor L1 reaches the limit set by the value of the resistor R1 (the voltage

drop at the resistor exceeded 0.3 V), the switching transistor is closed. Now the current flowing through L1 continues to flow through the load and the diode D1. However, as the energy delivery is stopped, the current decreases in time.

3. The circuit waits for a period given by the capacitor C2. Once the off time expires, the transistor Q2 is opened again and new cycle of the circuit begins.
4. Provided the output voltage exceeded the limit given by the internal reference V_SEN (connected via a voltage divider based on the resistors R6 and R7 to the output of the converter), the transistor Q2 is switched off before the input current reaches the limit set by R1.

From the above described principle of operation of the circuit the following conclusions can be made:

1. The operating frequency of the circuit varies in time according to the output current and input voltage of the circuit.
2. The regulation is provided by means of the pulse width modulation. The time of the “off” state is fixed, being given by the capacitor C2, while the time of the “on” state is variable.
3. The spectrum of the interferences generated by this circuit should theoretically be continuous, whilst the distribution of energy within this spectrum is unpredictable.

The price of the circuit can be very low, because no specialized components are used. Therefore it is expected to provide rather poor performance.

More detailed description of this circuit can be found in [6].

B. Advanced Converter with Fixed Operating Frequency Based on AP1501A

This converter was built on the basis of a custom integrated circuit AP1501A with respect to the manufacturer’s notes provided within the datasheet of the circuit [5]. The circuit diagram of this converter is depicted in Fig. 2.

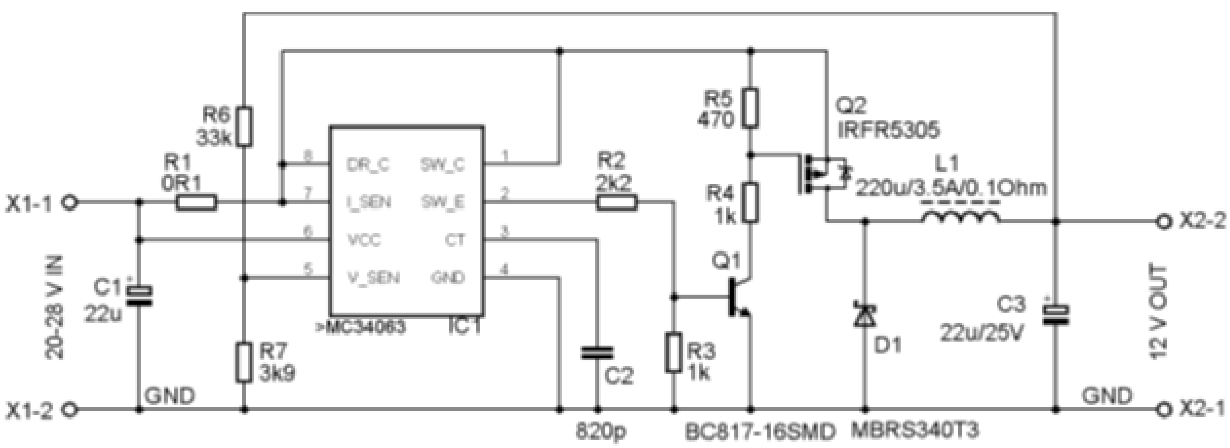

Fig. 1 circuit diagram of a voltage converter based on MC 34063

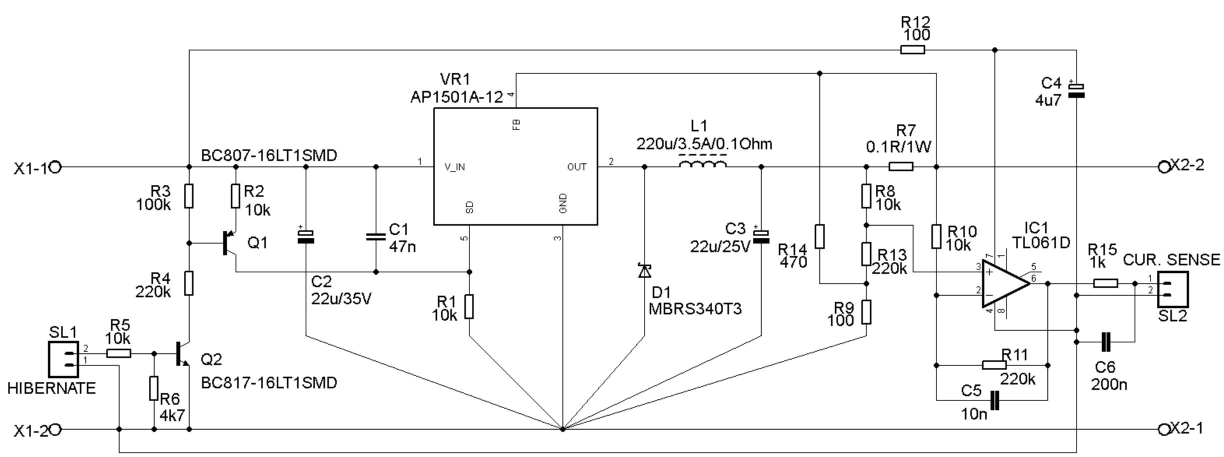

Fig. 2 circuit diagram of a voltage converter based on MC 34063

The circuit is supplied from the output of the backup unit by means of X1 clamps. Its operation can be externally hibernated by LVTTL voltage connected to SL1 connector.

The detailed description of AP1501A-12 can be found in [6]. The switching transistor is integrated on the chip. The manufacturer claims that the operating frequency of this integrated circuit is 150 ±25 kHz and the minimum achievable output current is 2 A. The inductance of L1 inductor is calculated in that way so the circuit operated in a continuous mode with a minimum output current of 0.1 A and maximum input voltage of 28 V. With a series resistance of 0.1 Ω maximum, the expected power dissipation is lower than 0.4 W. The saturation voltage of the switching transistor is approximately 1.7 V, so a power dissipation of approximately 3.5 W can be expected at the output current of 2 A. The expected total efficiency is 80 % at the output current of 2 A.

The circuit is equipped with the output current monitor based on the operating amplifier IC1. The values of the devices are calculated so the conversion ratio was approximately 2.2 V/A and the cut-off frequency was as low as 100 Hz (only DC component is measured). For the purposes of measurements described in this paper, the current sensing circuit is unnecessary as well as the possibility to hibernate the converter by means of connecting TTL voltage to the input HIBERNATE.

As described in the text above, this circuit runs at a fixed frequency, using a pulse width modulation to regulate its output power according to the output load and the input voltage. In comparison with the randomly oscillating converter it was supposed to achieve better performance.

For the purposes of testing the current sensing resistor R7 was replaced by a wire in order to discard the current sensing circuit and to make the circuit comparable to that one based on MC 34063A.

III. Measurements and Results

Both circuits were constructed as functional samples and tested for achieving of the required parameters. Consequently a set of tests was made in order to gain data on the basis of which the two different converters could have been compared one with the other. For the purposes of testing of the electromagnetic compatibility of the created samples, the standard EN 61000-6-3 has been chosen, since the target use of the circuits was not specified. The tests were as follows:

- output voltage stability versus input voltage,
- output voltage stability versus output load,
- power efficiency at different output loads and input voltages,
- maximum output power according to the cooling capability of the components,
- electromagnetic interference without a cover according to EN 61000-6-3,
- interference currents on the input cables measured by a current clamp according to EN 61000-6-3.

Whereas the DC parameters were measured as “static” ones without any transients, the measurements related to the electromagnetic compatibility were made in the frequency ranges covering the requirement of EN 61 000-6-3.

A. *Measurement Configurations*

Three different configurations of measurement instruments have been applied in order to obtain the above described results:

a) Measurement of DC parameters,
b) Measurement of radiated electromagnetic field,
c) Measurement of interferences on input cables .

1) *Measurement of the DC parameters*

The DC parameters were measured with the aid of linear stabilized laboratory power source Velleman PS3010 and the programmable electronic load Array 3721A that was operated in a constant current mode. The output voltage and current was measured directly by the electronic load while the input current was measured by a laboratory multimeter GW Instek GDM-8245.

The configuration of the experiment is described by the figure below.

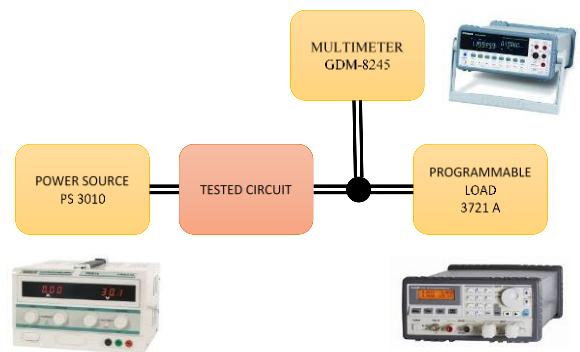

Fig. 3 configuration of the experiment consisting in measurement of DC parameters of the tested voltage converters

The DC parameters were measured with the aid of linear stabilized laboratory power source and the programmable electronic load Array 3721A that was operated in a constant current mode. The output voltage and current was measured directly by the electronic load while the input current was measured by a laboratory multimeter GW Instek GDM-8245.

2) *Radiated electromagnetic field*

The intensity of electromagnetic interference was measured by means of a bilogarithmical antenna Teseq Bilog CBL 6112 inside a semi anechoic chamber Frankonina SAC 3 plus according to the requirements of the standard EN 61 000-6-3. As the receiver Rohde&Schwarz ESU 8 receiver and spectral analyser was used. During the measurement, both converters were loaded by the electronic load Array 3721A that sunk a current of 1 A. The potential interferences caused by the electronic load were excluded by additional measurement during which the converters were bypassed. The data obtained by the receiver were processed by means of EMC 32 software.

The configuration of the experiment is described by the figure below.

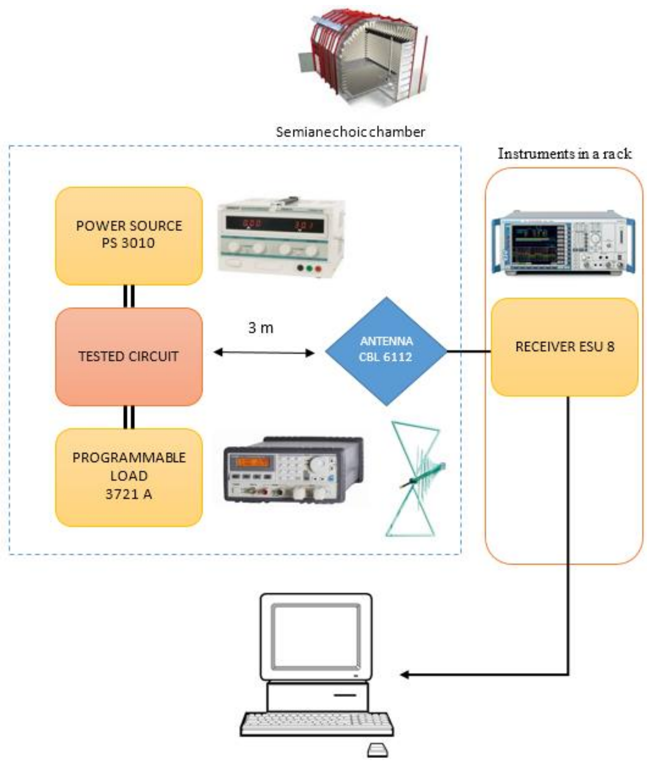

Fig. 4 configuration of the experiment consisting in measurement of electromagnetic field radiated by the tested voltage converters

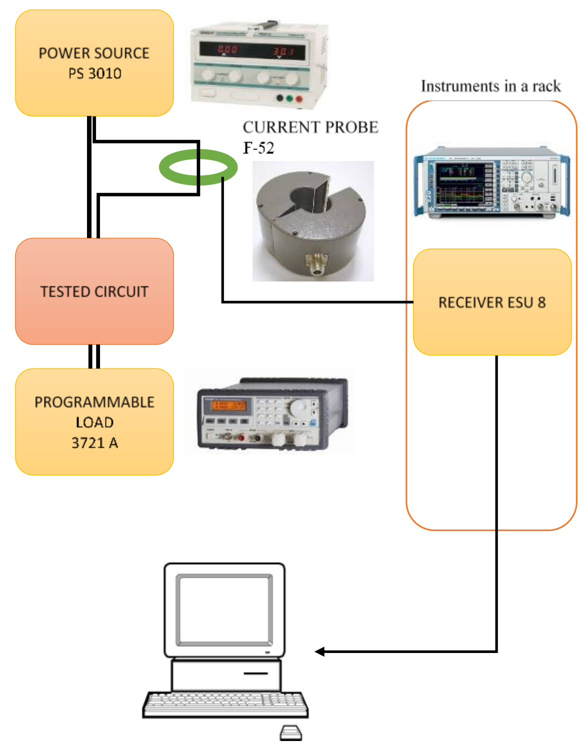

Fig. 5 configuration of the experiment consisting in measurement of interferences on input cables caused by the tested voltage converters

3) Interferences on input cables

The interfering currents on the cables between the linear power source and the converters were measured separately on both wires by means of a current clamp FCC F-52 connected to the receiver Rohde & Schwarz ESU 8. The data obtained by the receiver were processed by means of EMC 32 software and afterwards in MS Excel. During the measurement the converters were also loaded with the electronic load Array 3721A in order to achieve the required load current.

The configuration of the experiment is described by the figure below.

A. Obtained Results

Under the conditions described in the subchapter above, a large set of results was obtained. Because the space of this paper is limited, only the most interesting results are displayed in the text below.

1) Maximum achievable output power

The maximum achievable output power was in both cases limited by the heat produced by the components on the printed circuit boards after a continuous current load lasting approximately 5 minutes. This also corresponds with the efficiency of the converters that became poor at high loads. Generally, it can be said that the converters were operated in safe area until their power efficiency dropped below 70 %. The maximum achievable output power and the total power dissipation of the components mounted on the printed circuit boards of the functional samples of the converters are enlisted in the table below.

Table I Maximum achievable output power and total power dissipation of the converters

Converter	Input voltage [V]	Output power [W]	Power dissipation [W]
AP 1501	22	27.8	11.65
	26	33.3	12.21
MC 34063	22	20.14	8.46
	26	20.53	6.25

Based on the results enlisted in Table I, the load current was limited to 2 A in case of MC 34063 (randomly oscillating) and to 3 A in case of AP 1501 (fixed frequency). It is obvious, that the converter with MC 34063 achieved lower maximum output power. Partially this was caused by the fact, that the most dissipating component is the transistor Q2 (see Fig. 2) the case of which is less efficient in cooling as the case of AP1501A that was the most dissipating device of the other converter. More information on this topic is provided in discussion further in the text.

2) Power Efficiency

The power efficiency was calculated from the measured input power and the measured output power achieved by the converters. A comparison of power efficiency achieved by both converters at the nominal input voltage of 24 V is depicted in Fig. 6.

Dependences of the power efficiencies of the converters on the output loads and input voltages are depicted in Fig. 7 for MC 34063 and Fig. 5 for AP 1501A.

As can be seen in Fig. 6 to Fig. 8, the converter based on MC 34063A reaches a slightly worse efficiency and operates without excessive power dissipation with the output power up to 15 W. With higher output load its efficiency drops steeply.

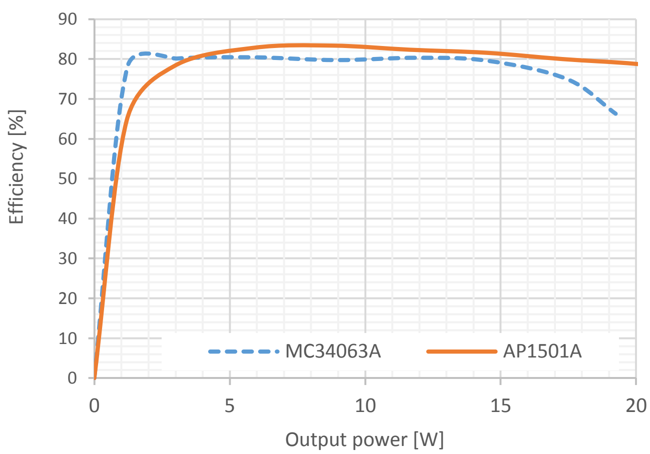

Fig. 6 comparison of power efficiency of the converters depending on their output power

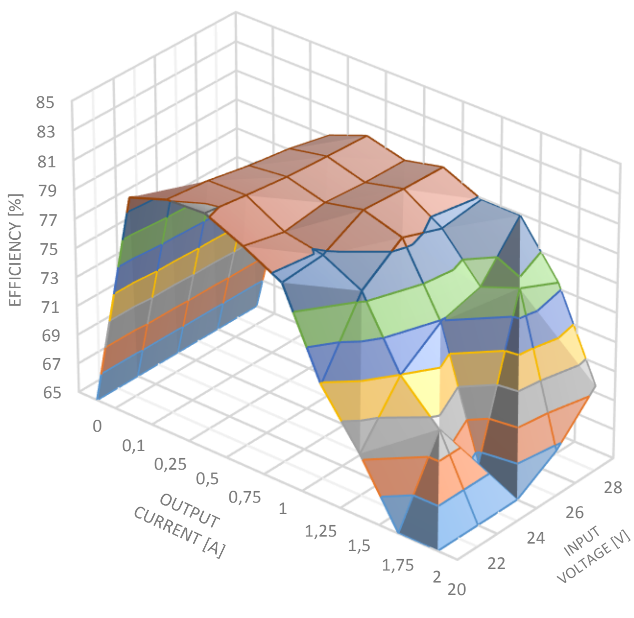

Fig. 7 dependence of power efficiency of the converter based on MC 34063 on the input voltage and the output current

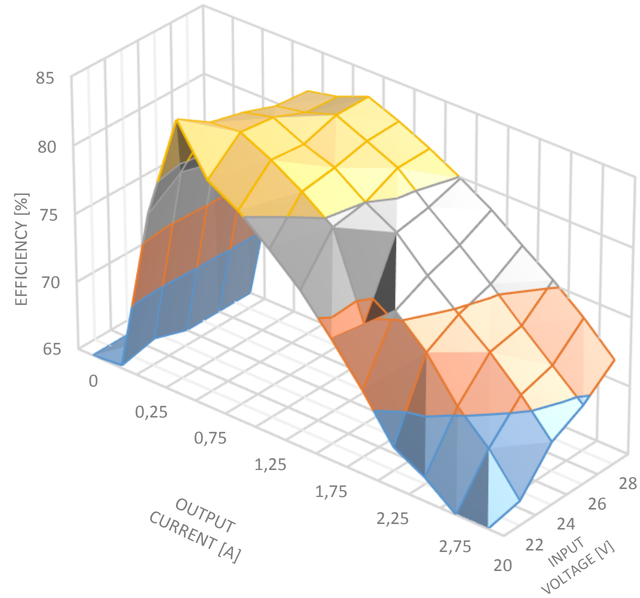

Fig. 8 dependence of power efficiency of the converter based on AP 1501A on the input voltage and the output current

On the other hand, the voltage converter based on AP 1501A reaches worse efficiency at low output powers. Its decreasing efficiency with the increasing output power is partly caused by the power sensing circuit that is connected at the output of the converter.

3) Output voltage stability

The output power stability of the converters depends on many factors as input voltage, output current, temperature, aging of devices etc. For the purposes of this test only the dependence on the input voltage and on the output current was observed.

A direct comparison of the two converters is provided in Fig. 9 and Fig. 10. Fig. 9 shows the dependence of the output voltage of both converters on their input voltage when a constant current load of 1 A is ensured. Fig. 10 shows the dependence of the output voltages of both converters when the output current is changed while the put voltage is stabilized at the nominal value of 24 V. Complex view of this parameter is provided in Fig. 11 and Fig. 12. Whereas the Fig. 11 shows the dependence of the output voltage of the converter based on MC 3406A on both, the input voltage and the output current, the Fig. 12 shows the same dependence for the converter based on AP 1501A. It is worth recommending that the output current sensing circuit that has been integrated on the converter (see Fig. 2) was bypassed by replacing the resistor R7 by a wire so no voltage drop caused by this circuit should be observed at the output of the converter.

The results show that the voltage stability of the converter based on AP 1501A is better, but both converters provide a similar performance with the load up to approximately 1.6 A (this corresponds to the output power of approximately 19 W).

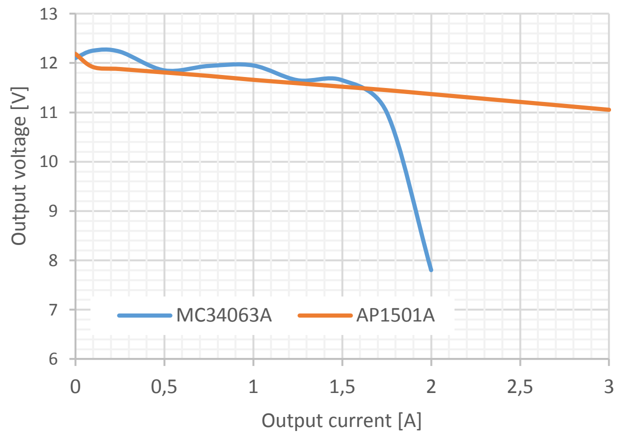

Fig. 9 output voltage dependence of both converters on the input voltage at the constant load current of 1 A

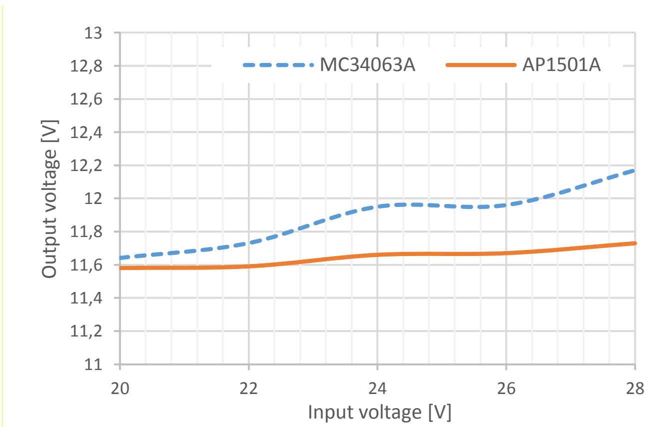

Fig. 10 output voltage dependence of both converters on the output current at the constant input voltage of 24 V

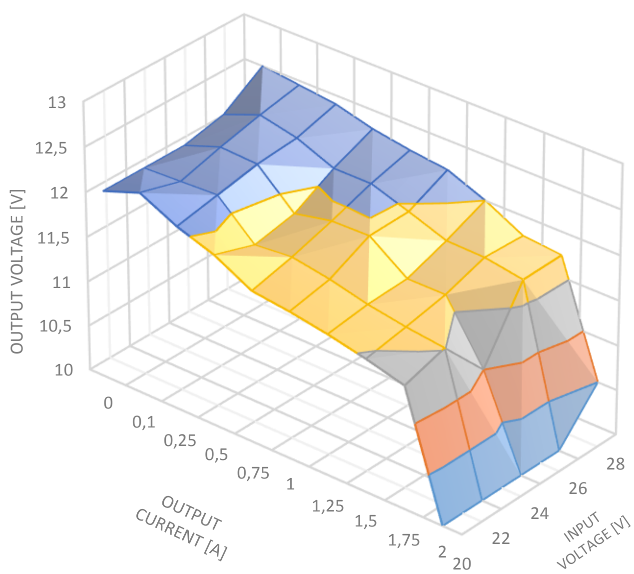

Fig. 11 output voltage dependence on the input voltage and load current – converter based on MC 34063

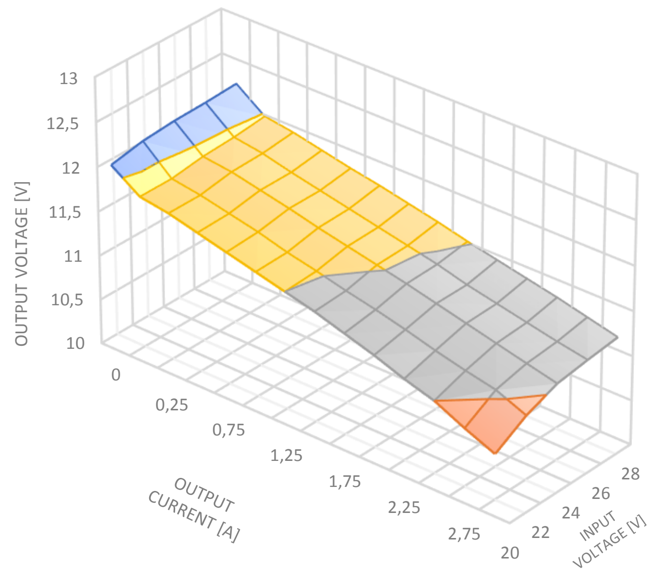

Fig. 12 output voltage dependence on the input voltage and load current – converter based on AP 1501A

4) *Electromagnetic Interferences*

The electromagnetic interferences were measured according to the requirements of the standard EN 61000-6-3. This standard requires measurement at frequencies exceeding 30 MHz. The measurement was processed in the base band from 30 MHz to 1 GHz and both converters, although not mounted in a shielding, passed the test without any problem. This is caused mainly by the fact that the converters are operated at low frequencies where radiation by means of electromagnetic field is not probable. More interesting are inductive and capacitive couplings to other circuits operating in the near field of the converters and the interference currents spread by means of the input and output cables of the converters.

However, the worst-case results obtained at the measurement of the electromagnetic interferences are depicted in the figures below. It is worth mentioning that the measurement was processed with the configuration depicted in Fig. 4 which means that the results include the interferences caused by the power source and the programmable load as well. For this reason, prior to the measurement of the converters, the programmable load and the power source were tested as well in order to prove that their contributions to the results are low enough. On the other hand, at all circumstances, the results of the measurement were below the limit line, which is decisive for the results assessment.

5) *Interferences on the Input Wires*

According to the principle of their operation, the voltage converters create interfering current ripples at their input and output cables. Because the gained data are too complex, only the measurements on the active power supply wires are described here. The measurement was processed according to the configuration depicted in Fig. 5.

On the figures below the dependences of the measured ripple current spectrums on the output currents (at a constant

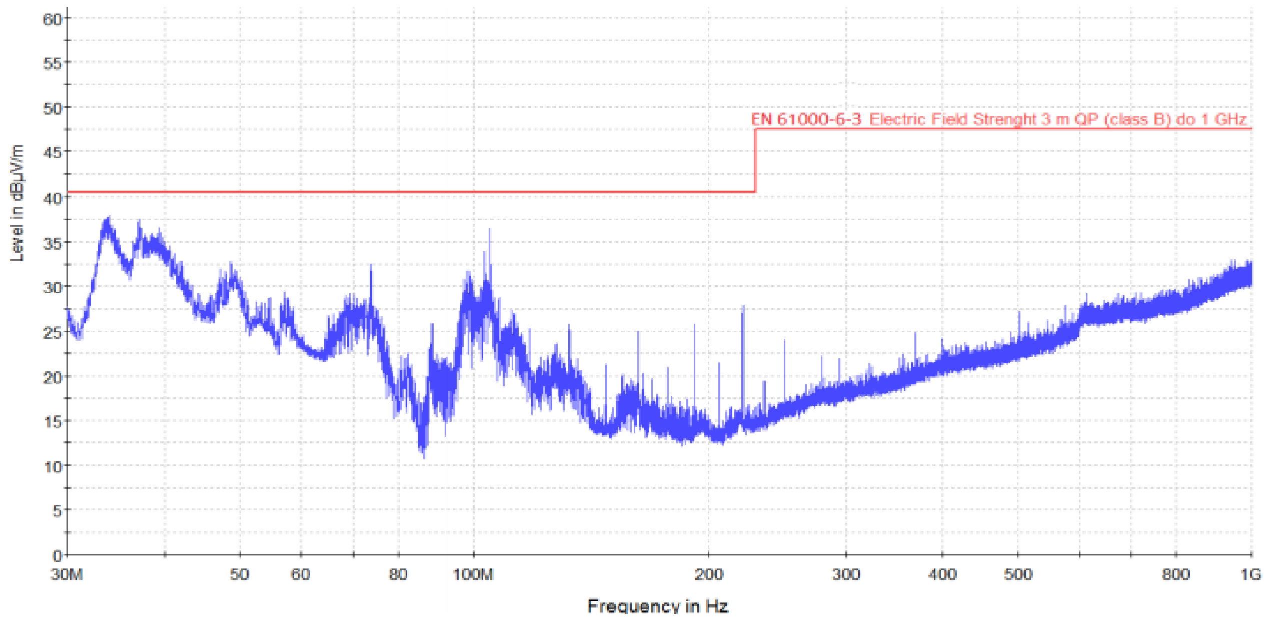

Fig. 13 Worst case results of electromagnetic interferences measurement for the converter with AP 1501 (vertical antenna polarization)

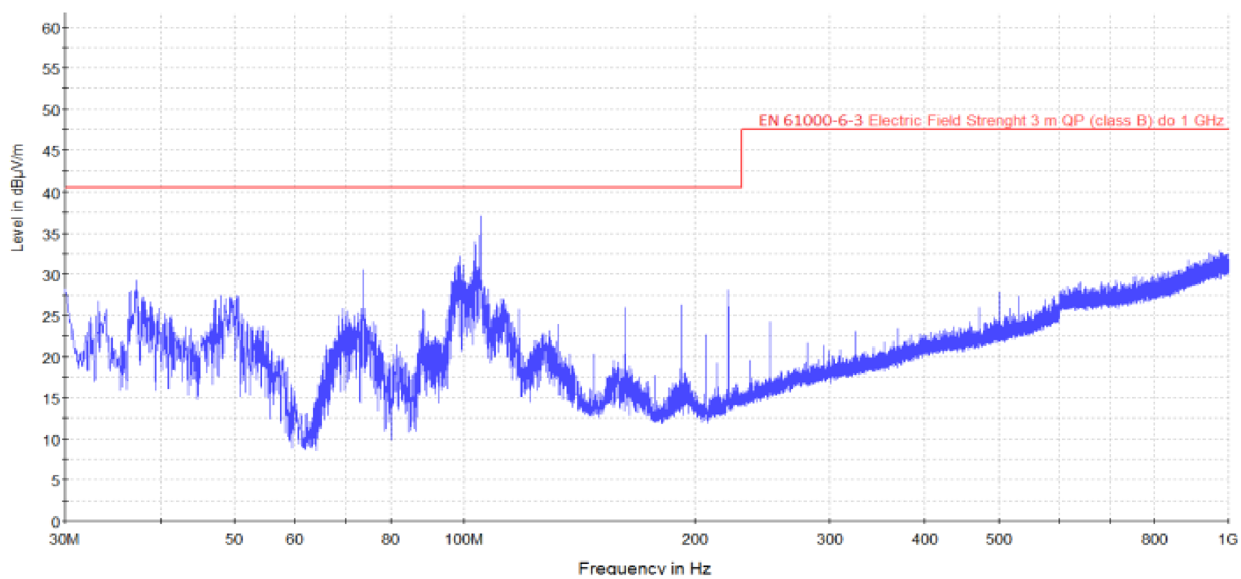

Fig. 14 worst case results of electromagnetic interferences measurement for the converter with MC 34063 (vertical antenna polarization)

input voltage) and on the input voltage (at a constant output current) of the converters are depicted. Both converters were supplied with a constant input voltage of the nominal value 24 V in order to obtain results depicted in Fig. 15 and Fig. 16 and afterwards, both converters were load by a constant current of 500 mA in order to obtain results depicted in Fig. 17 and Fig. 18. As described in the text above, the ripple currents were measured by a current clamp and are reported in dBµA. Maximum values (MaxPeak detector) were indicated.

Based on the results depicted in Fig. 15 to Fig. 18, although the driver based on MC 34063A generates “more rich” spectrum, the maximum measured values generated by both converters are comparable. On the other hand, differences in spectral amplitude densities can be observed, as depicted in Fig. 19 and Fig. 20.

IV. Results Discussion

According to the expectations, the voltage converter based on AP 1501A has shown better performance, but there is a question whether the improvement, compared to the converter based on MC 34063, is worth the increased costs of the design of the circuit.

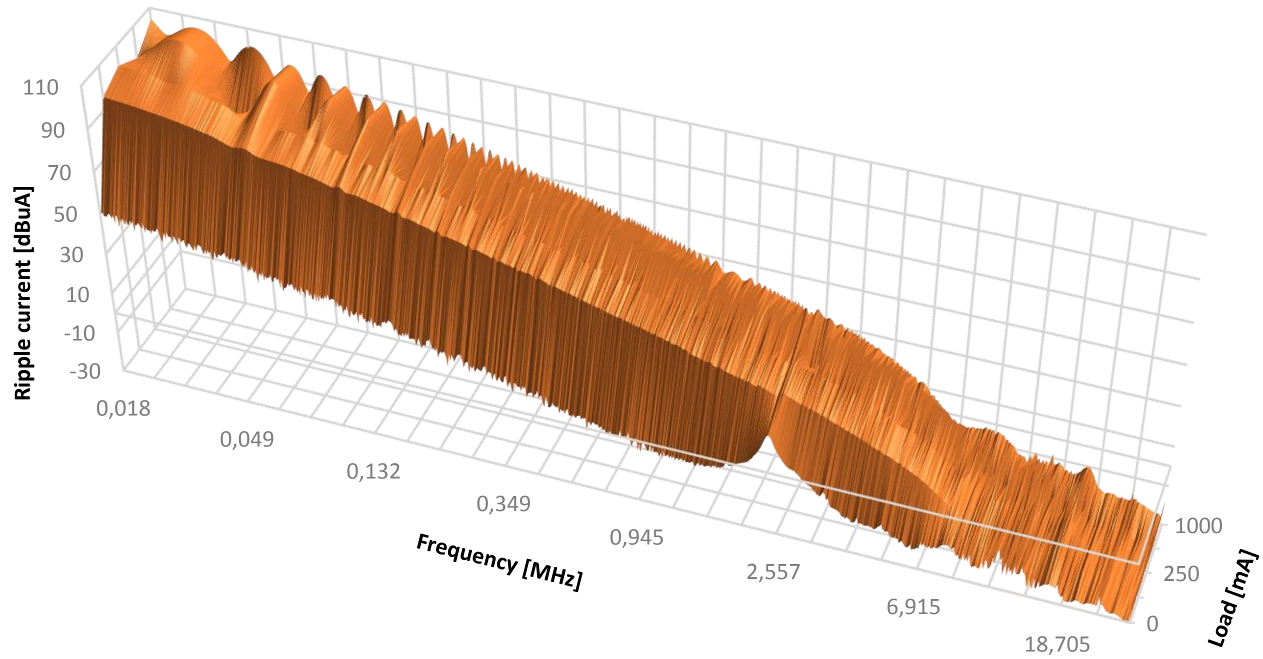

Fig. 15 ripple current spectrum on the input of the converter based on MC34063A (constant input voltage 24 V)

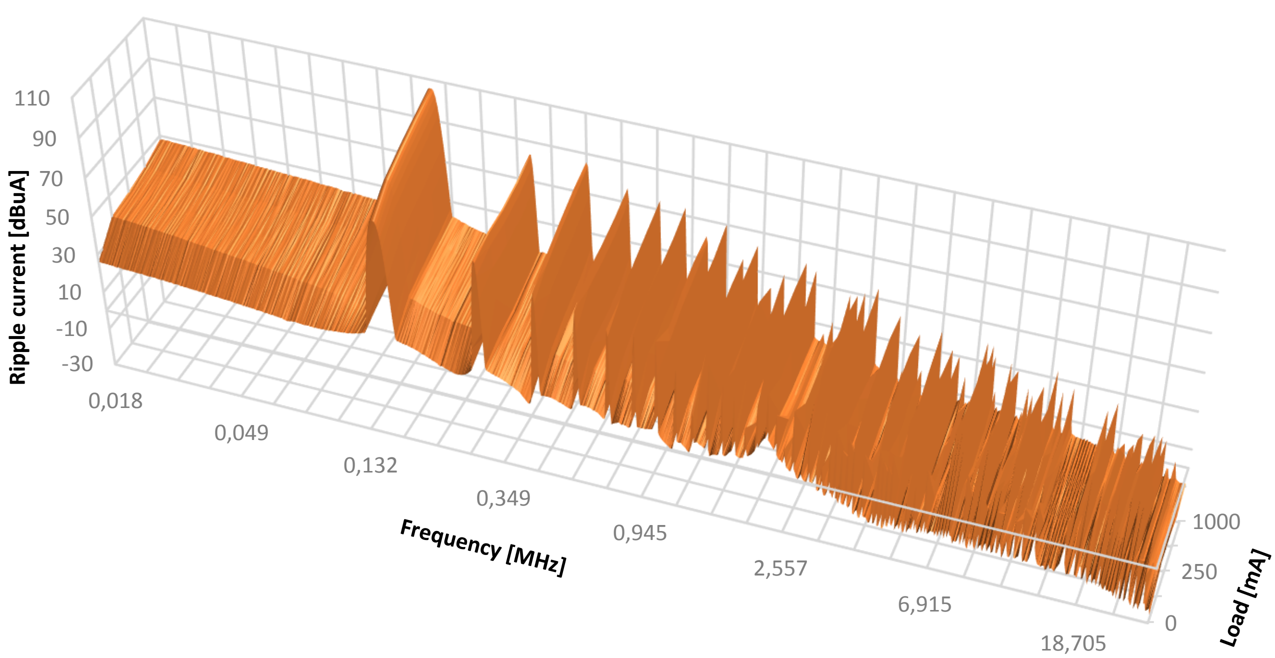

Fig. 16 ripple current spectrum on the input of the converter based on AP 1501A (constant input voltage 24 V)

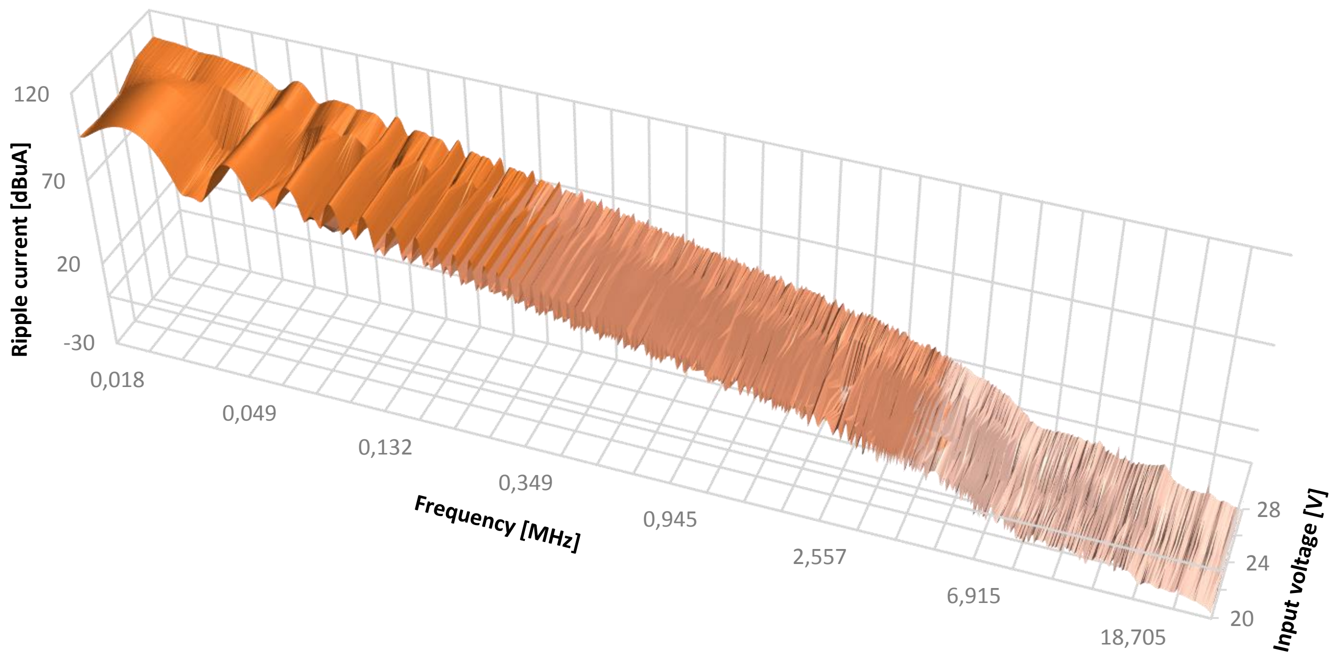

Fig. 17 ripple current spectrum on the input of the converter based on MC34063A (constant output current 500 mA)

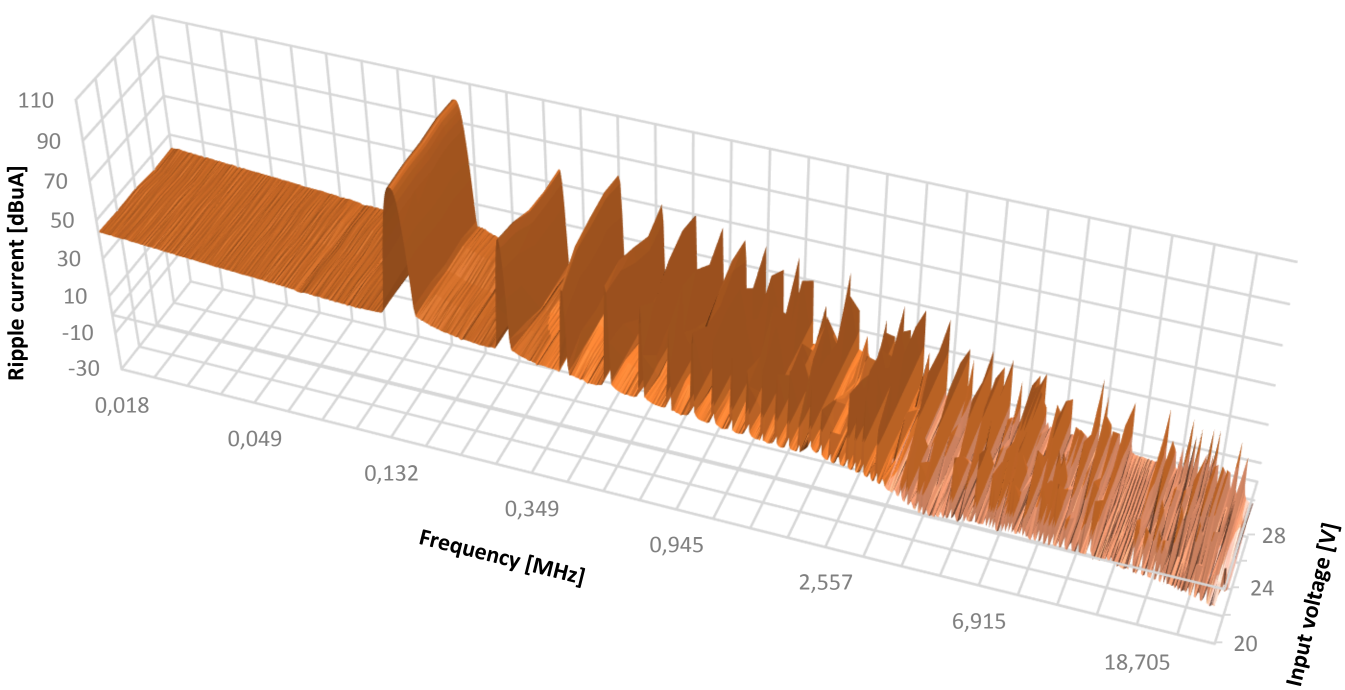

Fig. 18 ripple current spectrum on the input of the converter based on AP 1501A (constant output current 500 mA)

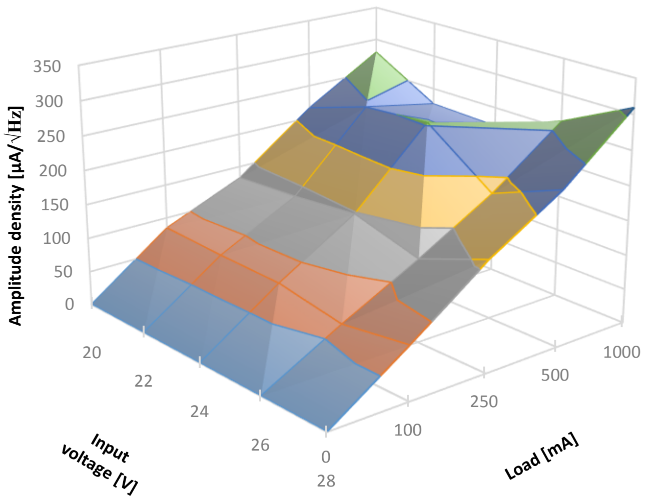

Fig. 19 spectral amplitude density of ripple currents generated by the converter based on MC 34063A

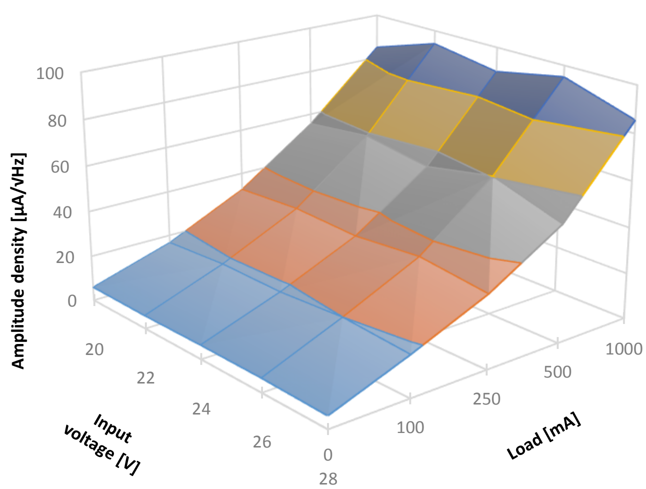

Fig. 20 spectral amplitude density of ripple currents generated by the converter based on AP 1501A

Concerning the electromagnetic compatibility, both converters require efficient input filters as their input interference currents greatly exceed the requirements given by the standard EN 61000-6-3. From this point of view there is no difference between them as the peak levels of the interfering currents were comparable.

Concerning the voltage stability, the output voltage of the converter based on MC 34063 was more dependent on the input voltage (scatters by 4.5 % within the range of the input voltages), but on the other hand, when the output load was changed, the performance of both circuits was comparable up to the output power of 20 W. Then, in case of MC 34063 the current limitation occurred, while the converter based on AP 1501A operated without current limiting, being secured only by the internal overheat and short-circuit protection. In this case, the performance of the circuit based on MC 34063 could be improved by improved construction of the switching transistor's driver.

V. Conclusion

This paper provides a comparison of two step-down voltage converters, both decreasing the voltage from 24 V to 12 V, but each built according to a different philosophy. One of them is a very cheap one, self-oscillating, with operating frequency dependent on its load and other factors, while the second one is based on a specialized driver that incorporates an internal oscillator as well as the switching transistor and other necessary circuits.

Unfortunately, the set of results obtained by the measurements greatly exceeds the framework of one paper, so only the most interesting results are described. Nevertheless, these results include interesting findings about voltage converters operating at low powers. The most interesting is probably the fact, that although the simple and cheap self-oscillating converter produces great interference currents on its power supply wires (the maximum spectral amplitude density was approximately 310 $\mu A/\sqrt{Hz}$ versus 85.55 $\mu A/\sqrt{Hz}$), from the point of view defined by the standard EN 61000-6-3 they both produce excessive peaks that must be eliminated by means of input filters. The measured peak values are comparable for both converters (approximately 105 dBµA for AP 1501A and 110 dBµA for MC 34063).

Further research will be focused on increasing the performance of the driver base on MC 34063 concerning the deficiencies in the power switching. Based on the results obtained by the tests described within the paper, there is a chance to tune the cheap self-oscillating converter in order to achieve performance comparable to the more complex drivers.

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