Simulation of conducted emissions in low voltage switching converters

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Abstract. The article analyzes the computational method used to assess the electromagnetic compatibility of electronic devices in the automotive industry. The analysis is carried out using the example of a pulsed synchronous DC-DC boost converter. Calculations of the conducted interference of the converter, as well as methods of their reduction are presented. This calculation method is performed in the PSpice electrical circuit simulator.

1. Introduction
Nowadays, the problem of electromagnetic compatibility is becoming more and more important with the development of computer technology and electronics. The impulsive nature of the operation of automotive converters leads to significant emissions of electromagnetic energy in a wide frequency range. In this regard, the task arises to ensure reliable and uninterrupted operation of electronic systems.

Using this method allows you to find and correct errors at the design stage, the detection and correction of which on the finished product will bring significant costs. For the same reason, the application of this method in the design of devices can be accelerated, and the quality of the result achieved can be increased. The use of technologies for numerical analysis of the design of electronic devices allows with a high probability of passing certification and validation tests the first time, and also opens the way to optimizing the design, reducing cost and technically sound use of various types of components.

The importance of the problem of electromagnetic compatibility is growing not only with the increase in the number and complexity of electronic devices in production, but also with its underestimation, which is responsible for the normal functioning of automated equipment. This method, and its emergence, is associated with the large-scale deployment of electronic devices and their use in various types of environments.

2. Sources of EMF
To solve the EMC problem in electronic devices, it is necessary to understand the cause of their occurrence. As you know, EMF covers a wide range of frequencies, but now we are only interested in conducted interference, which ranges from 150 kHz to 108 MHz in accordance with the state automobile standard GOST R 51318.25-2012 (CISPR 25) [1]. Conducted noise, in turn, is divided into two components: differential and common-mode.
Differential interference generates differential currents that occur when signals pass through the communication lines of a two-wire transmission line, shown in Figure 1a.

Common-mode current flows in one direction from the switching power supply through the power input and returns back to the source at ground, as shown in Figure 1b [2].

**Figure 1.** Diagram of voltage application of differential (a) common-mode (b) noise

3. **Measurement of conducted emissions**

To carry out measurements, a network equivalent is required, which serves both to supply the electronic device with mains voltage and to isolate the high-frequency components that need to be measured. In fact, the network equivalent consists of a high-pass filter and a low-pass filter (Figure 2). The measurement requires a dual delta network equivalent that can measure both common-mode and differential conducted emissions. The line impedance stabilization network connection diagram is shown in Figure 3.

**Figure 2.** Schematic diagram of a line impedance stabilization network

**Figure 3.** Connection diagram of the equivalent network for measurements of conductive mode

4. **Object of research**

The object of research is a synchronous pulse boost DC / DC converter with the following characteristics presented in Table 1. You can see the general view of the board in Figure 4.

**Table 1.** Characteristics of the step-up DC / DC converter.

| Characteristic         | Value | Units   |
|------------------------|-------|---------|
| Input voltage          | 12    | V       |
| Output voltage         | 24    | V       |
| Input current          | 18    | A       |
| Output current         | nine  | A       |
| Working frequency      | 500   | kHz     |
| Power                  | 216   | W       |
| Ripple current         | 20    | %       |
The noise paths of a pulsed DC / DC converter are shown in Figure 5. Differential noise current occurs at the moment of switching the power switches of the converter. This current flows simultaneously in opposite directions on the power bus and on the power ground, as shown in the figure. The current flow of the differential component is closed and has a relatively small area [4].

Common mode currents occur in parasitic capacitances between the power bus lines, the power ground and the ground plane as shown in Figure 6. Their current is directly proportional to the rate of voltage change. Common-mode interference currents are much less than differential currents, but the area of the loop through which common-mode interference currents flow is larger. This circuit is an antenna, and therefore it is much more difficult to cope with these currents.

![Figure 4. General view of the board without filters](image-url)

![Figure 5. Differential noise paths for a DC / DC boost converter](image-url)

![Figure 6. Common-mode noise paths of a DC / DC boost converter.](image-url)
5. Simulation of conducted noise in the PSpice circuit simulator

To separate the common-mode and differential components of conducted disturbances, it is necessary to see the contribution of the common-mode and differential components in the network equivalent. When we measure the voltage between the two terminals V1 and V2, we get twice the differential noise voltage, which is shown in Figure 7. In common mode, the voltage flows in opposite directions, as shown in Figure 8, between the power supply and ground of the converter, in fact, it becomes almost zero. Figure 9 illustrates that the sum of the voltages V1 and the ground reference plane and V2 and the ground reference plane add up to almost zero for the differential component. If we measure the voltage between V1 and the ground reference plane and V2 and the ground reference plane, as shown in Figure 10, we get negative twice the common-mode voltage (Figure 11).

![Figure 7. Voltage between V1 and V2 of the differential mode](image1)

![Figure 8. Voltage between pins V1 and V2 of the common-mode](image2)

![Figure 9. The sum of the voltages between V1 and the ground plane and V2 and the differential ground plane](image3)

![Figure 10. Sum of voltages between V1 and ground plane and V2 and common mode ground plane](image4)

![Figure 11. Getting twice the voltage for the differential mode](image5)

The result is the conducted noise spectrum of the DC / DC boost converter for the differential mode (Figure 12) and common-mode (Figure 13) noise components in PSpice.

As you can see from the interference pattern, the interference level exceeds the established limits, which means that the EMC certification tests will not be passed. It is necessary to reduce the conducted noise level.
Figure 12. Differential noise spectrum of the converter

Figure 13. Common-mode noise spectrum of the converter

6 Ways to Reduce Conducted Noise

To successfully reduce the measured interference, both in the area of the fundamental operating frequency and its harmonics, it is most effective to use LC filters. They are able to reduce the level of interference due to their amplitude-frequency characteristic (AFC), which has a slope of up to 20 dB / Dec at a cutoff frequency of up to several kilohertz. It is necessary to take the following important rule: you need to set the filter cutoff frequency in the amount of about one tenth of the operating frequency of the inverter. The cutoff frequency can be calculated using formula 1. This approach will provide suppression of the EMC spectrum by about 40 dB µV [3].

$$f_c = \frac{1}{2\pi\sqrt{LC}} \tag{1}$$

In the case of an LC filter, we select an inductor with a rating of 0.625 µH, as well as a 33 µF electrolytic capacitor. We also convert the LC filter to a T filter for successful suppression of high frequency EMI. Let’s choose a ferrite SMD element WE-MPSB. WE-MPSB is a multilayer ferrite SMD component, which is a special inductance [5].

Since the T filter is a resonant circuit, a damper is required. The snubber is a series RC circuit, which is shown in Figure 14. The snubber resistor value can be calculated using formula 2. The snubber capacitor depends on the input capacitance and should be about four times the nominal value of the standard input capacitor.

$$R_d = \frac{L_{filter}}{C_{filter}} \tag{2}$$

where $L_{filter}$ and $C_{filter}$ is the inductance of the LC filter and is the capacitance of the LC filter.
After installing the filter, we get the following picture for the common mode and differential components of the interference, shown in Figures 15 and 16, respectively.

As you can see from the obtained EMI spectrum, after installing the T filter, we do not exceed the peak and quasi-peak values of the standard, which means we are more likely to pass the certification tests. A general view of the board with filters is shown in Figure 17.

**Figure 14.** Damper

**Figure 15.** Differential noise spectrum of the converter

**Figure 16.** Common-mode noise spectrum of the converter

**Figure 17.** General view of the board with a filter.

7. **Conclusion**

This method made it possible to determine the level of conducted noise of the step-up converter already at the design stage of the electrical device, and also to correct its operation.

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