Electromagnetic compatibility of the on-board electrical complex as a key factor in ensuring the operational safety of vehicles

V. N. Kozlovsky¹, P. A. Nikolaev², A. S. Podgorny¹, A. V. Kritsky¹ and M.A. Zhmaylo³

¹ Samara State Technical University, Samara, Russia, kozlovskiy-76@mail.ru
² JSC "AVTOVAZ", Togliatty, Russia
³ National Technology Initiative Center for Advanced Manufacturing Technologies based on the Institute of Advanced Manufacturing Technologies of Peter the Great St. Petersburg Polytechnic University Polytechnicheskaya, 29, St.Petersburg, 195251, Russia

Abstract. The issues of functional safety of the on-board electrical complex of vehicles under exposure of electromagnetic interference are considered in this paper. Besides, the modern practice of organizing the process of assessing the immunity of electrical systems of cars is shown.

Introduction

The vehicle is a source of increased danger because of their mass operation. Despite the measures taken, a large number of people constantly die and receive injuries of varying severity in car accidents. Because of accidents, technical damage is significant. Undoubtedly, a malfunction of the on-board electrical complex of the vehicle due to electromagnetic impacts is introduced into these statistics [1, 2].

In the context of the problem of immunity of road transport to electromagnetic interference (EMI), one proceeds from the concept of its functional safety, based on the standards [3-9].

The functional safety of electrical systems, as receptors, is associated with their response to the acting EMI. Failures occur when interfering signals are induced in electrical circuits that exceed the sensitivity thresholds. Summarizing practical experience, the following classification can be made. Disturbance of functions related to driving vehicles; with the protection of the driver, passengers and/or other road users; disorienting the driver and/or road users; with the functioning of data buses, which, in the event of a malfunction, can adversely impact the readings of devices displaying information.

For the first point, this can be obtained, for example, by deteriorating or changing the performance of the engine control system, brakes, active control, transmission, suspension, etc. For the second point, examples are the malfunctioning of the airbag system, as well as child restraints. For the third one, cases of creating optical and acoustic interference are evident, such as the incorrect operation of direction indicators, sidelights, brake lights, light signaling devices of the emergency system, incorrect operation of the anti-theft device and sound signal. For the fourth point, this may be a malfunction of the odometer, speedometer or navigation device.

The most critical consequences occur due to failures and failures of electrical systems that determine the safety of the vehicle. Functional safety is important not only for a single device, but for the entire
on-board complex as a whole, because within modern architecture, almost all electrical equipment is interconnected. EMI failure in the operation of one unit may lead to a malfunction of the other. The functional safety of the vehicle is indirectly related to the human factor. The behavior of vehicles on the road, especially those in private use, in case of malfunctioning of electrical systems due to EMI depends on the proper operation of the vehicle and the behavioral characteristics of the driver. A broad contingent of different people drives a vehicle, because of its massive availability. Therefore, there is a possibility that the driver's response to a failure of electrical systems due to its specific features would be inadequate. The degree of behavior during movement is determined by the psychophysical state, professional qualities: medical indications, age factor and temperament. The statistics have several examples: drivers who are used to being guided by the sound signal of safe parking allow hitting an obstacle when driving in reverse when the system fails under EMI or the driver loses control of the road due to his distraction from control to the radio that is disconnected under EMI exposure.

Main part
A certain category of drivers does not pay the necessary attention to the maintenance of vehicles, operating them in disrepair. Such treatment leads to a decrease in the immunity of electrical systems (Figures 1, 2) [10]. To ensure functional safety, electrical systems must have a certain margin of immunity that has to be guaranteed to be confirmed taking into account a given probability during testing.

![Figure 1](image.png)

**Figure 1.** The characteristics of the immunity of the instrument cluster of cars: 1 - Russian brand; 2 - foreign brand.
There exist test methods prescribed in national and international standards for the civil automotive industry. They make it possible to directly or indirectly assess the immunity of the vehicle’s electrical systems to external electromagnetic influences.

The indirect method is the volume current injection. It is based on a non-contact indication of electromagnetic interference in electrical circuits using a current transformer [11, 12, 13, 14]. This method is mainly used when testing individual units and systems. The frequency range of its applicability is limited to 400 MHz.

Other methods are based on direct exposure to electromagnetic radiation. Generalizing them, it can be distinguished tests using radiating antennas and in stripline systems. Tests in stripline systems [14, 15] are based on the electromagnetic effect of a plane-transverse wave distributed between two parallel metal plates. Unshielded stripline systems and shielded TEM-cameras have become widespread [16, 17, 18] (Figure 3). The frequency range of field forming systems depends on their size. The upper range is limited by the frequency at which higher types of electromagnetic waves appear. The lower limit starts at 0 Hz. A typical dependence is the larger the system, the lower the upper operating frequency. In general, field-forming systems intended for the vehicle operate in the range up to 20 MHz, and up to 300 MHz - for products. The main disadvantage is the impossibility of testing at higher frequencies.

Tests using radiating antennas are carried out in the frequency range above 20 MHz in anechoic shielded chambers (ASC) [19, 20]. Open areas are an alternative to ASC, but their use is minimized due to the dependence of the results because of weather conditions. The versatility of the ASC allows it to be used both for testing products and for the vehicle.

Figure 2. The immunity characteristics of the Russian-made automobile anti-theft system: 1 - 10 km; 2 - 140 thousand km.
According to the requirements for civilian vehicles, the exposure is produced by antennas with vertical polarization. When testing products up to 1 GHz, the phase center of the antenna should be opposite the center of the wire harness, and an antenna operating above 1 GHz should be positioned opposite the product. During the vehicle's certification [11-13], tests are performed in the range from 20 MHz to 2 GHz. The frequency tuning step in terms of electromagnetic radiation is chosen linear or logarithmic steps (Table 1) [21]. The analysis shows that the larger the step, the wider the frequency range that is not captured during testing. As a result, during the tests, one can skip frequencies at which low noise immunity.

| Frequency range, MHz | 0.01–0.1 | 0.1–1 | 1–10 | 10–200 | 200–400 | 400–1000 | 1000–2000 |
|----------------------|-----------|-------|------|--------|---------|----------|-----------|
| Linear step, MHz     | 0.01      | 0.1   | 1    | 5      | 10      | 20       | 40        |
| Logarithmic step, %  | 10        | 10    | 10   | 5      | 5       | 2        | 2         |

For speeding up the test, it is recommended to act on the object only at a few resonant frequencies in [22].

The regulated impacts have the following parameters (Figure 4):
- amplitude modulation 1 kHz with modulation factor 0.8 in the frequency range 20-800 MHz;
- pulse modulation with a duration of 577 μs and a period of 4600 μs in the range from 0.8 to 2 GHz MHz

Figure 4. Standard test signals: a) unmodulated harmonic signal; b) amplitude-modulated signal; c) pulse-modulated signal.
The minimum exposure time at a given frequency is 2 s. In the testing process, the vehicle moves on the stand at a constant speed of 50 km/h, and if it is slow-moving, then the speed is set to 25 km/h. The distance from the car to the radiating antenna is chosen so that the entire front part of the vehicle falls into the main lobe of the radiation pattern of the radiating antenna [23].

Before testing, the vehicle is installed with its front part to the fixed antenna so that its center line is at the control point (line) [23]. If the electrical systems are mainly located in the back or on some side of the vehicle, then the vehicle is oriented with the corresponding part to the radiating antenna [11-13].

In tests (Figure 5), a passenger car was tested for resistance to microwave fields. It was irradiated from the front and obliquely from the rear towards the left side, because in the latter case, the electrical engine management systems were located in the passenger compartment in front of the metal shield separating the passenger compartment and the engine compartment [24].

![Figure 5. Microwave device for testing the vehicle: MGS - microwave generation system; PGS - power generation system; RCC - remote control cabin.](image)

Leading car manufacturers are additionally testing horizontal polarization at 1 MHz to improve the quality of their products, applying unmodulated harmonic effects as well. Special tests, taking into consideration the peculiarities of the operation of these systems, are developed to check the special functions of electrical systems. [25].

An alternative test for susceptibility is testing the vehicle to the fields generated by on-board transmitters [26, 27]. There are two types of tests, characterized by the location of the antenna in relation to the body. In one test, an antenna is mounted externally to the body of a vehicle and power is supplied from an external source or an on-board radio. The tests are carried out at multiple antenna locations. In another test, a handheld transceiver with a built-in antenna is positioned in the interior of the vehicle. The program includes tests at several locations of the airborne transceiver when located in three mutually perpendicular planes. Recommended modulations: Telegraphy, AM, SSB, FM, TDMA / FDMA, Tetra: π/DQPSK and GMSK with modulation parameters AM 1 KHz with 80% depth; CW and PM 18 Hz with duty ratio 50%.

Tests for resistance to fields of power frequency are divided into two types: the exposure of the electric and magnetic components. In the first case, testing is carried out using a strip line. In the second one, Helmholtz coils are used [28, 31].

Most tests for external EMI, the spectrum of which does not exceed 20 MHz, such as remote lightning impact, by the fields of the contact network of railways and power lines, are carried out in strip systems. [29, 32].

Special purpose technical means are additionally tested for direct and close lightning strikes (Figure 6) [30, 33-34].

All considered tests involve one or several fixed positions relative to the field-generating system, which is insufficient in considering the vehicle as a complex antenna system. This approach does not assess the immunity of vehicles from those directions where slots and holes form an effective antenna at a
specific frequency. A comprehensive, uniform effect is achieved in a reverberation chamber. However, they are mainly used for product testing. There are size limitations for testing full-size vehicles. The larger the camera, the higher its lower frequency range. The typical test frequency is 200 MHz.

![Diagram of test impulses](image)

**Figure 6.** Test impulse of a direct lightning strike.

**Conclusion**

The analysis of the considered methods shows that the existing requirements for frequency tuning step, positioning relative to the field generating system, to the parameters of impulse influences, as well as for the operating modes during testing, are not sufficient for a full assessment of the noise immunity of the vehicle. This imposes certain risks in the process of their operation. Thus, the future development of the above methods is directly related to the solution of problems associated with the development of relevant techniques and tools. That solves the problem of determining the required frequency tuning step, taking into consideration the uncertainty factor in the positioning of the vehicle relative to the field-forming system, as well as providing a set of operating modes for the on-board electrical system of the vehicle during control testing.

**References**

[1] Kozlovsky V N 2010 Ensuring the quality and reliability of the electrical equipment system of cars *Dissertation abstract for the degree of Doctor of Technical Sciences* (Moscow automobile and road construction state technical university Tolyatti)

[2] Stroganov V I and Kozlovsky V N 2014 Modeling of systems of electric vehicles and vehicles with a combined power plant in the design and production processes: monograph (Moscow) p 264

[3] GOST R IEC 61508-1-2012 2013 Functional safety of electrical, electronic, programmable electronic systems related to safety. Part 1. General requirements. (Standartinform) p 53

[4] GOST R IEC 61508-2-2012 2013 Functional safety of electrical, electronic, programmable electronic systems related to safety. Part 2. Requirements for systems (Standartinform) p 87

[5] GOST R IEC 61508-3-2012 2013 Functional safety of electrical, electronic, programmable electronic systems related to safety. Part 3. Requirements for software (Standartinform) p 133

[6] GOST R IEC 61508-4-2012 2013 Functional safety of electrical, electronic, programmable electronic systems related to safety. Part 4. Terms and definitions (Standartinform) p 45
[7] GOST R IEC 61508-5-2012 2013 Functional safety of electrical, electronic, programmable electronic systems related to safety. Part 5. Recommendations for the application of methods for determining safety integrity levels (Standartinform) p 62
[8] GOST R IEC 61508-6-2012 2013 Functional safety of electrical, electronic, programmable electronic systems related to safety. Part 6. Guidance on the application of GOST R IEC 61508-2 and GOST R IEC 61508-3 (Standartinform) p 60
[9] GOST R IEC 61508-7-2012 2013 Functional safety of electrical, electronic, programmable electronic systems related to safety. Part 7. Methods and tools (Standartinform) p 177
[10] Moroz S M, Nikolaev P A and Nikolaev A D 2012 The concept of increasing the electromagnetic safety of vehicles in service *Electronics and electrical equipment of transport* (№2-3) pp 51-55
[11] Regulation №10. Uniform provisions concerning the approval of vehicles with regard to electromagnetic compatibility (Appendix 9, Revision 3, UNECE) 2008
[12] Regulation №10. Uniform provisions concerning the approval of vehicles with regard to electromagnetic compatibility (Appendix 9, Revision 4, UNECE) 2012
[13] Regulation №10. Uniform provisions concerning the approval of vehicles with regard to electromagnetic compatibility. (Appendix 9, Revision 5, UNECE) 2014
[14] ISO 11451-2 2005 Road vehicles. Vehicle test methods for electrical disturbances from narrowband radiated electromagnetic energy. Part 2: Off-vehicle radiation sources
[15] ISO 11452 2005 Road vehicles - Component test methods for electrical disturbances from narrowband radiated electromagnetic energy
[16] Electromagnetic susceptibility measurements of vehicle components using TEM cells (14 kHz – 200 MHz), SAE, 1984, June) pp 130–136
[17] MIL-STD-464A 2002 US Department of Defense Interface Standard. Electromagnetic Environmental Effects for Systems (USA DoD 19.12.2002) p 121
[18] Open field whole-vehicle radiated susceptibility 10 KHz – 18 GHz, Electric field (SAE, 1981, June) pp 115-125
[19] Kovneristy Yu K, Lazarev I Yu and Ravaev A A 1982 Materials that absorb microwave radiation. (Moscow: Nauka) p165
[20] Mitsmaher M Yu and Torgovanov V A 1982 Microwave anechoic chamber (M.: Radio and communication) p 129
[21] ISO 11451-1 2005 Road vehicles. Vehicle test methods for electrical disturbances from narrowband radiated electromagnetic energy. Part 1: General principles and Terminology
[22] Komyagin S I 2015 Electromagnetic resistance of unmanned aerial vehicles. (M.: KRASANDR) p 432
[23] ISO 11451-2 2005 Road vehicles. Vehicle test methods for electrical disturbances from narrowband radiated electromagnetic energy. Part 2: Off-vehicle radiation sources
[24] Microwave test facility *Ericsson Saab Avionics, Electromagnetic Technology Division* (Linkoping, Sweden) pp 581-588
[25] Nikolaev P A and Kechiev L N 2015 Electromagnetic compatibility of vehicles (Ed. L.N. Kechiev, M.: Grifon) p 424
[26] ISO 11451-3 2007 Road vehicles. Vehicle test methods for electrical disturbances from narrowband radiated electromagnetic energy. Part 3: On-board transmitter simulation. Second edition
[27] SAE J 551/12:1996 Vehicle Electromagnetic Immunity-On-Board Transmitter Simulation
[28] Kniazev A D, Kechiev L N and Petrov B V 1989 Design of radio-electronic and electronic-computing equipment taking into account electromagnetic compatibility. (M.: Radio and communication) p 224
[29] Davydov A A, Plygach V A and Chibisov Yu F 2010 Electromagnetic factors of natural and man-made origin and methods of their reproduction during testing of weapons and military equipment *EMC technologies* (№1 (32)) pp 38-48
[30] MIL-STD-461F US Department of Defense Interface Standard. Requirements for the control of electromagnetic interference characteristics of subsystems and equipment (10.12.2007) p 255
[31] Alekseev, A., Maksimov, A., & Tarasov, A. (2020). CFD investigations of the effect of rotating wheels, ride height and wheelhouse geometry on the drag coefficient of electric vehicle. International Journal of Mechanics, 14, 130-134. doi:10.46300/9104.2020.14.17

[32] Aleshin, M., Gavrilova, L., Goryainov, I., & Melnikov, A. (2020). Dem generation based on commercial uav photogrammetry data. Paper presented at the Engineering for Rural Development, 19 1750-1756. doi:10.22616/ERDev2020.19.TF461

[33] Maksimov, A., Igoshina, D., Petrov, R., & Klyavin, O. (2020). Optimization of the electric vehicle hvac duct system based on gradient method. International Journal of Mechanics, 14, 135-140. doi:10.46300/9104.2020.14.18

[34] Panyukov, D., Kozlovsky, V., & Klochkov, Y. (2020). Development and research FMEA expert team model. International Journal of Reliability, Quality and Safety Engineering, doi:10.1142/S021853932040015X