The importance and directions of electromagnetic compatibility test methodologies development in the aspect of vehicle safety

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Abstract. In this paper the definition of electromagnetic compatibility in the context of testing vehicle components and complete vehicles was presented. Potential threats resulting from particular EMC phenomena in vehicles were presented. Analysis of the areas identified in obligatory and non-obligatory normative documents was made. The areas which, in the opinion of the authors, should be incorporated into the obligatory normative documents were indicated. The substantive justification for the need to conduct EMC tests and analysis at the design, prototyping stage, before implementation, and periodically during operation (for justified cases) was presented. Good engineering practices in the field of eliminating the negative effects of EMC phenomena were indicated. Authors described how the change in the approach to EMC issues increases the vehicles safety.

Keywords: safety, vehicle, automotive safety

1. Introduction
The fundamental problems related to electromagnetic compatibility (EMC) of automotive devices and vehicles have remained valid for many years. The general technological development and the encroachment of electronics into new and new application areas often require that these problems be dealt with in a new and modified way. This applies to both sides of the EMC. Namely the emission of electromagnetic disturbances by the tested devices and their immunity to such disturbances. Electromagnetic compatibility is the sum of elementary electromagnetic phenomena that defines the ability to operate undisturbed and not to interfere with the operation of other devices by a given electrical/electronic device.
Electromagnetic compatibility is of great importance in the context of vehicles safe road use. Imagine a situation in which a vehicle passing near a high power radio transmitter no longer functions properly. Malfunction of key components, such as driver assistance systems, can confuse the driver and make it difficult to steer, potentially putting other road users at risk. The source of the interference that may adversely affect the vehicle does not have to be the aforementioned radio transmitter by the road, but it can be any smallest device installed inside the vehicle. The effects of installing non-EMC components can be very similar as described above.
The assessment of such effects is performed mainly by accredited laboratories in semi-anechoic chambers, an example of an object in such chamber is presented in Fig. 1. The test object was an emergency vehicle extended with a large number of electronic components. The tests were carried out in the Electronics and Acoustics Laboratory, which is part of the Łukasiewicz Research Network - Automotive Industry Institute.

![Figure 1. Type-approval radiated emission test of vehicle (test object blurred for confidentiality reasons)](image)

2. Analysis of the problem status
Electromagnetic compatibility can be divide into four main areas [1]:
- radiated emissions,
- radiated immunity,
- conducted emissions,
- conducted immunity.
 Depending on the case, the phenomena may be continuous or transient. Many test methodologies have been developed to precisely define them due to the wide spectrum of their occurrence. The currently used equipment allows to assess the phenomena, which impacts the vehicle safety. List of these phenomena and possible influence on safety is given in tab. 1.

| Phenomenon                              | Potential influence on safety                                         |
|-----------------------------------------|-----------------------------------------------------------------------|
| Emission of radiated electromagnetic disturbances | Interference with the functioning of other vehicles in close proximity |
| Immunity to radiated electromagnetic field         | Malfunction of the vehicle sub-assemblies in the operating electromagnetic environment |
| Phenomenon                                                                 | Description                                                                 |
|---------------------------------------------------------------------------|-----------------------------------------------------------------------------|
| Emission of conducted electromagnetic disturbances                         | Interference with the operation of other devices physically connected by electricity or using the same power source |
| Emission of conducted transients                                           | Damage to other devices in the installation due to overvoltage               |
| Emission of harmonics generated in AC power lines                         | Interference with the operation of other devices drawing power from the same electric grid |
| Emission of changes, fluctuations and flicker                              | Interference with the operation of other devices drawing power from the same electric grid, especially danger for lighting devices |
| Immunity to transients                                                    | Incorrect operation as a result of impulses appearing in the vehicle's electrical system (e.g. engine starting, switching on relays, turning on/off devices) |
| Immunity to BURST                                                         | Incorrect functioning or damage to the device as a result of e.g. arcing in the electromechanical connections in the installation |
| Immunity to SURGE                                                         | Incorrect functioning or damage to the device as a result of e.g. lightning |
| Immunity to voltage dips, short interruptions and voltage variations      | Incorrect functioning of the device as a result of decays, dips and voltage changes in the power grid |
| Immunity to voltage fluctuations                                           | Incorrect functioning of the device due to voltage fluctuations in the power grid |
| Immunity to electrostatic discharge                                       | Incorrect functioning or damage to the device as a result of electrostatic discharge during transport, handling and service works |

Many normative documents have been developed that differ mainly in the scopes of assessment of these phenomena, in order to describe the test methodologies allowing to determinate the above parameters. These documents are used in all industries (e.g. military, medical, railway, home and slightly industrialized environment, etc.)

The main obligatory area for every manufacturer of electrical/electronic components in the automotive industry and complete vehicles is the so-called type-approval. As part of the Geneva Agreement of 1958, the UNECE prepared a series of documents called UNECE Regulations, which included a list of test methodologies and criteria for assessing the parameters of all components and complete vehicles. The requirements for electromagnetic compatibility were laid down by the UNECE in Regulation No. 10 (R10) [2]. The test ranges described in R10 constitute the necessary minimum that devices and vehicles must meet in order to be allowed for sale on the European market and for use in public road traffic. Most of the test methodologies from R10 are derived from other normative documents, which cover much wider scopes, however, their requirements are not obligatory. They are used for testing electric devices dedicated to other areas of industry. There are also specific requirements of large automotive companies, which extend beyond the scope of the type-approval.

2.1. Type-approval field (required)

Type-approval area includes assessment of conducted and radiated disturbances. Tests for the emission of radiated disturbances (broadband/narrowband) are performed in accordance with the standards of the CISPR [3] series in frequency range of 30 MHz – 1 GHz. The most common reasons for their occurrence are: noise induced in the cables, ineffective decoupling of PCB, faulty cable termination, peripheral devices that do not meet the requirements, the wrong class of power supply, arrangement of components (including decoupling capacitors and their paths), large current loops.
Immunity to radiated electromagnetic field is tested according to the series of standards ISO 11451 (vehicle resistance) [4] and ISO 11452 (component resistance) [5] in frequency range of 20 MHz – 2 GHz. The tested object is subjected to an electromagnetic field with a specified modulation and intensity standards, which is to simulate the operation of the device in a characteristic electromagnetic environment. This serves to verify the correctness of its operation under the influence of disturbances. As in the case of emission, it is important here that the cables and the PCB are properly shielded, as well as the appropriate filtering of signals is used. Conducted disturbance tests are mainly performed in accordance with the ISO 7637 series of standards as well as the EN 61000 series. These tests include:
- measurements of transient emissions during devices switching on and off - some devices generate voltage spikes during switching on/off, which, if they exceed the permissible limits, can damage the elements of the installation or other devices [5];
- testing the immunity to transients - this test simulates the electrical impulses appearing in the vehicle installation during, e.g. starting the vehicle, switching on relays [5];
- emissions of radio disturbances conducted along the power line - radio disturbances with relatively low frequencies are conducted to the power grid and may cause its malfunction and disrupt the operation of other devices connected to the installation at a short distance from the device generating disturbances [3];
- emissions of harmonics generated from the device to the power grid - too high values of harmonic currents may cause overheating and decrease in the efficiency of the power source and have an impact on the quality of energy supplied to other devices in the power grid [6];
- emissions of voltage changes, voltage fluctuations and flickers in AC power lines - the impact on light sources connected to the same power grid is determined [7];
- immunity to fast electrical transients conducted along the AC power line (so-called BURST) - low-energy, but high-voltage pulses generated, e.g. by: switching electrical switches nearby, capacitive couplings of interference in the wiring from switched loads, electric motors and electromechanical relays, fluorescent lamps ballasts [8];
- immunity to surges conducted along the AC power line - high-current, relatively long-lasting pulses generated, among others, by: switching power supply, insulation damage in the power network, switching passive loads (e.g. motors) nearby, blown fuses, nearby (indirect) lightning.
Testing in the field of type-approval do not exhausts the subject of electromagnetic compatibility by any means.

2.2. Other fields (not obligatory, e.g. OEM)
Large automotive companies, military industry or industry in general use the same test methodologies. However, they use requirements that go far beyond the scope of type-approval. For example, the emission of radiated disturbances according to CISPR or MIL-STD 461 standards should be measured also in frequency ranges from 9 kHz to 30 MHz and from 1 to 40 GHz, depending on the type of test object. The immunity to electromagnetic field is tested even up to 40 GHz [3, 10]. The tests of immunity to ESD and various types of impulse anomalies along the power and signal lines also do not coincide with the requirements of the tests for type-approval. There are normative procedures and documents, e.g. LV 124, LV 148, which describe the characteristic exposure pulses, which are not provided by the UNECE Regulation No. 10 [11, 12]. Nowadays in the automotive industry it is not reasonable to carry out measurements in the entire above-mentioned range, but at the same time it should be emphasized that the existing obligation seems to be insufficient for the correct assessment of the vehicle safety.

3. Fields not mentioned in obligatory normatives for type-approval procedures
Taking into account the design of electronic components used in the automotive industry, the communication interfaces used and radio-wave transmitting and receiving devices, it is reasonable to indicate areas of radiated disturbances tests that are not covered by the testing procedure for type-approval, and it seems that these phenomena may have significant influence on the proper functioning and safety of the vehicle. Examples of technologies widely used in automotive components are GPS
(1580 - 1650 MHz), Wi-Fi (2400 - 2500 MHz) or DSRC (5900 - 6000 MHz) [13]. The scope in which these technologies operate exceeds the test ranges of radiated emission by R10 (30 - 1000 MHz) and electromagnetic field immunity according to R10 (20 - 2000 MHz). That is why it should be considered to expand frequency range of R10 radiated tests to 20 – 6000 MHz.

The literature indicates individual works on the measurements of electromagnetic disturbance emissions inside electric vehicles [14]. Although this study was carried out on a passenger car with a low power drive, a very important problem was highlighted, which should be addressed especially to large electric vehicles with a high power drive, e.g. city buses. There are no normative documents that would describe the test methodology and the requirements for assessment of the electromagnetic field value inside such vehicles, especially in the passengers compartment. The power supply elements for the propulsion of such a vehicle are usually placed under and above the passengers compartment, surrounded by cables and high current components. Thus, it is suspected that the electromagnetic field due to the flowing current may reach intensity values that are harmful to the health of travelers. A research project on such measurements is carried out at the Łukasiewicz Research Network - Automotive Industry Institute, and its result is to be an assessment of the problem scale, possible harmfulness and guidelines for vehicle manufacturers for design solutions limiting the intensity of the field inside.

Another area that is becoming more and more important, especially in the context of autonomous vehicles, is the immunity of sensitive electronic components in a vehicle to electromagnetic attack (in the sense of deliberately interfering with an electromagnetic field). The assessment of this parameter and the appropriate refinement of devices, e.g. a decision computer, ambient sensors in the context of their immunity to electromagnetic field, is of key importance for the safe use of these vehicles. [15] Looking towards electric or autonomous vehicles that use and will use more and more electronic devices for communication and the decision-making system, it is important to emphasize the importance of the safety problem of these vehicles related to the lack of information on the scale of the risk in the above-mentioned ranges.

4. Good practices in electronic components designing in the automotive industry

Currently, the topic of EMC tests is mainly touched upon at the stage of the finished product. Many manufacturers consider it to be just a problem of type-approval administrative procedure not considering the physical influence on vehicle safety. However, as described above, the topic is much more complicated and it should be taken much more seriously.

Due to the high impact on vehicle safety, the EMC assessment process should start much earlier. Literature [15] indicates list of activities which are related directly to functional safety of the electronic/electric systems. This list explains how to properly manage the levels of risks caused by electromagnetic disturbances at all stages of the product’s life. It is not addressed to automotive directly, but it should be considered because of that vehicle is the perfect example of characteristic electronic/electric system.

To ensure the greatest functional safety of the vehicle, it is necessary to divide the EMC assessment into individual stages:

- development of the concept and initial specification:
  ✓ making the list of EMC standards related to object under development,
  ✓ specifying verification testing plan,
  ✓ gathering the characteristic parameters, interfaces and functions of the device which results from its intended use,
  ✓ defining which parameters impacts vehicle safety,
  ✓ considering unusual risks of degrading device functions in scope of EMC (e.g. high impact, malicious EMI),
  ✓ analyzing operational electromagnetic environment for the device,
- designing of the prototype:
  ✓ using appropriate filtering and shielding for used interfaces,
  ✓ using appropriate materials for housing,
  ✓ specifying critical components and its paths arrangement on PCB,
  ✓ specifying critical sub-assemblies and its wiring arrangement in vehicle,
analyzing what coupling phenomena can occur in the device,
- defining intentional electromagnetic emission in terms of frequency range and transmitting power level,
- conducting EMC simulation in dedicated software,

- integration of the system, installation method:
  ✓ specifying bill of materials with minimum quality level defined,
  ✓ verification test of peripherals and sub-assemblies of device/vehicle,
  ✓ integration of the most comprehensive variant of designed prototype (including all of peripherals and interfaces intended to use),
  ✓ analyzing the consequences of reducing amount of peripherals and interfaces,
  ✓ specifying detailed installation instruction in terms of EMC (including filters, components arrangements, materials, etc.),

- verification of integrated prototype:
  ✓ verification according to the plan prepared at the initial stage,
  ✓ conducting not standardized, simplified tests,
  ✓ verifying correct assembly, wiring termination, length and arrangement,
  ✓ conducting EMC tests before and after deliberate aging of key components,
  ✓ verification should be finished with conclusion that the device is not prototype anymore and the producer gaining confidence of passing obligatory testing,

- testing of final device:
  ✓ conducting tests according to obligatory normative,
  ✓ conducting tests according to EMC standards list made at the initial stage,
  ✓ specifying final technical documentation,
  ✓ conducting control of production (COP) - ensuring the repeatability of the finished product quality,

- post implementation activities
  ✓ conducting tests after: any modifications of PCB, any modifications in sub-assemblies arrangement in vehicle, any change in bill of materials (especially connected with degradation of components quality),
  ✓ periodic tests of random sample from production line,

All above-mentioned points are really important to achieve complex compliance with EMC requirements. Example of the tests results corrected by tests at various stages of production is shown in Fig. 2.
5. Conclusion
Electromagnetic compatibility is an area that is directly related to vehicle safety. This safety may be influenced by a direct impact on the basic functions of the vehicle (steering, drive operation, etc.) but also by indirectly influencing the functioning of the vehicle components, causing e.g. confusion for the driver or other road users (e.g. external lighting dysfunction). In modern vehicles, most of the functions are controlled by electronic/electrical devices that must meet the relevant requirements to ensure this safety. Unfortunately, it is impossible to ensure full safety by meeting the obligatory/type-approval requirements, because, as it has been shown, they do not cover the full range of EMC phenomena. Further development of vehicles (electric, autonomous) should confirm the belief that this scope should be extended in the near future.

The experience of EMC laboratories notified for testing in the automotive industry shows difficulties even in meeting the obligatory requirements, however, the activities indicated in the work and the procedures described for each stage of the device/vehicle life are to help meet the requirements even in the proposed-extended scope.

The current state of technology and easier access to advanced research equipment (e.g. in the Łukasiewicz Research Network - Automotive Industry Institute) allow manufacturers of equipment and vehicles to ensure vehicle safety in the comprehensive scope of electromagnetic compatibility.

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[7] IEC 61000-3-3 *Electromagnetic Compatibility (EMC) - Part 3-3 - Limits - Limitation of voltage changes, voltage fluctuations and flicker in public lowvoltage systems for equipment with rated current ≤ 16 A per phase and not subjected to conditional connection*

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