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METHODS OF ANALYSIS AND EVALUATION OF ELECTROMAGNETIC RADIATION DURING TESTS OF ELECTROMAGNETIC COMPATIBILITY (EMC) OF MOTOR VEHICLES, IN PARTICULAR ELECTRICALLY DRIVEN

METODY ANALIZY I OCENY PROMIENIOWANIA ELEKTROMAGNETYCZNEGO W BADANIACH KOMPATYBILNOŚCI ELEKTROMAGNETYCZNEJ (EMC) POJAZDÓW SAMOCHODOWYCH ZWŁASZCZA ELEKTRYCZNYCH

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Part I

Requirements and methods of EMC testing of motor vehicles

Część I

Wymagania i metody badań EMC pojazdów samochodowych

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Summary

The article discusses electromagnetic compatibility (EMC) requirements for motor vehicles and their equipment and electromagnetic radiation (EMR) testing methods based on the normative documents that provide grounds for approving specific vehicle types for production and operation (type approval). The normative documents are UN ECE Regulation No 10 and Directive 72/245/EEC. Three groups of methods (line methods, area methods, and parameter estimation methods) have been proposed and described for the EMR assessment of vehicles. Based on the EMR tests carried out at PIMOT on a few electric vehicles (EV), the EMR of the vehicles was analysed and assessed with using some of the said methods. The following vehicles were used for the analyses and calculations: OPEL Ampera, RENAULT Fluence, Citroen C-Zero, and Mega e-City. The analysis and calculations carried out have revealed a close similarity between the proposed methods of EMR assessment of motor vehicles. The qualitative optimization of the parameters that can influence the assessment, primarily a reduction in the electromagnetic radiation (EMR) of the vehicle under consideration, will not only result in correct functioning of the vehicle, especially if it is electrically driven, but also will help to avoid possible harmful impact of EMR on vehicle occupants' health. The work outputs may be utilized and disseminated, especially by the designers and researchers who are involved in work on motor vehicles, in particular EVs, where lots of electronic systems and modules are present. In consideration of the size of this publication, it had to be divided into two parts. In the first one, the EMC requirements and the relevant motor vehicle test methods have been described. The second one presents an analysis of the electromagnetic radiation of selected electric vehicles.

Keywords: electric vehicle (EV) testing, electromagnetic compatibility (EMC) of motor vehicles, analysis of EMC tests, electromagnetic radiation (EMR) of vehicles

Streszczenie

W artykule zostały omówione wymagania kompatybilności elektromagnetycznej (EMC) dla pojazdów i urządzeń samochodowych oraz metody badań promieniowania elektromagnetycznego (PEM) w oparciu o dokumenty normatywne stanowiące podstawę dopuszczenia do produkcji i ruchu (homologacja) danego pojazdu. Dokumentami tymi są Regulamin nr 10 EKG ONZ oraz Dyrektywa 72/245/EWG. Dla oceny PEM pojazdów zostały zaproponowane i opisane trzy grupy metod: liniowe, polowe i estymacji parametrów. Na podstawie przeprowadzonych w PIMOT badań kilku samochodów elektrycznych w zakresie PEM przeprowadzono analizę i ocenę PEM wg wybranych metod. Do analizy i obliczeń wykorzystano następujące pojazdy: OPEL Ampera, RENAULT Fluence, CITROEN C-Zero i MEGA e-Cityco. Przeprowadzona analiza i obliczenia wykazały dużą zbieżność przydatności zaproponowanych metod oceny PEM pojazdów samochodowych. Zapewnienie wysokich jakościowo parametrów wpływających na ocenę, w tym przede wszystkim promieniowania elektromagnetycznego (PEM) ma wpływ nie tylko na poprawne działanie pojazdu, szczególnie EV, ale też na zdrowie przebywających wewnątrz: kierowcy i pasażerów. Wyniki pracy mogą być wykorzystane i rozpowszechniane szczególnie przez konstruktorów i badaczy pojazdów samochodowych, zwłaszcza EV, w których występują duże liczby systemów i modułów elektronicznych.

Ze względu na objętość materiału praca została podzielona na dwie części. W pierwszej części opisano wymagania i metody badań EMC pojazdów samochodowych. W drugiej dokonano analiza promieniowania elektromagnetycznego wybranych pojazdów elektrycznych – EV.

Słowa kluczowe: badania pojazdów elektrycznych (EV), EMC pojazdów samochodowych, analiza badań EMC, promieniowanie elektromagnetyczne pojazdów

1. Introduction

The technological progress that took place during the recent decade or so in electronics and electrical engineering has resulted in a significant growth in the share of such devices in automotive applications, especially in passenger cars. The demand for electrical and electronic solutions has been forced by vehicle manufacturers' drive to improve ride comfort and road traffic safety and to simplify vehicle maintenance and servicing. In this situation, it is important to ensure a high level of reliability and durability of electrical and electronic vehicle equipment based on the latest technologies. Therefore, vehicle equipment must be very thoroughly tested for the equipment to be brought to conformity with such requirements. The range of the subject matters to be addressed during tests of motor vehicles and their equipment is very wide, especially as regards electrical and electronic vehicle equipment. The scope of such tests is being continuously extended due to ongoing technology development and increasingly stringent requirements, especially in the field of safety, reliability, and ride comfort. In consequence, increasing importance is attached to electromagnetic compatibility (EMC) tests, although they have already been performed for a very long time (since 1950s).

In consideration of the characteristic features of electrical equipment of motor vehicles and the phenomena that take place in vehicles' electrical systems, in particular the possibility of occurrence of strong current and voltage surges, long wiring bundles, and a large number of wire connections, a statement may be made that there are real possibilities of reciprocal disturbances in the operation of individual electronic subassemblies and modules, caused to each other by electrical conduction (galvanic connections) or the existence of capacitive or inductive couplings or radiated emissions.

Electromagnetic disturbances may be classified in the large group of unwanted (undesired or unusable) signals, always accompanying the usable signals purposefully generated in systems in result of normal system functioning.

The electromagnetic disturbances are chiefly caused by the following:

- periodic and accidental (random) changes in supply voltages;
- rapid current and voltage changes in electric circuits in the presence of:
 - inductances (dispersed inductances inclusive);
 - capacitances (dispersed capacitances inclusive);
- signal penetration from one circuit to another, which takes place in particular between the lines that connect the circuits, i.e. signal transmission lines;
- occurrence of couplings in electric circuits (possibility of generation);
- appearance of short circuits and damage to elements or systems;
- noise generated by active and passive elements;
- instabilities of connections and contacts; temperature instabilities;
- non-linear characteristics of elements of systems, including non-linear loads.

The vehicle equipment and wiring system are also exposed to extraneous disturbing signals, i.e. signals coming from other vehicles, road and industrial infrastructure, radio

communication, etc. The disturbing signals differ from each other in their levels and occur in a wide frequency band. Therefore, it is very important that complete vehicles should be subjected to reliable EMC tests. Such tests must be carried out to assess vehicles' conformity with applicable safety and quality requirements.

2. EMC requirements for motor vehicles and their equipment

The drive to reduce the sensitivity of electronic components of motor vehicle equipment to electromagnetic disturbances and, on the other hand, the saturation of the environment with devices that produce such disturbances and are simultaneously affected by them have resulted in a necessity of undertaking normative and legislative steps to coordinate national regulations in the field of electromagnetic compatibility. In consequence, UN ECE Regulations and Directives of the Council of Europe concerning the type approval of vehicles and their equipment have been prepared and put into effect.

The basic legal and normative documents concerning the electromagnetic compatibility of motor vehicles and their equipment include UN ECE Regulation No 10 [1] and Directive 72/245/EEC [2] with later amendments.

The most important requirements laid down in these documents have been specified below.

2.1. UN ECE Regulation No 10, Revision 4, 2011 [1]

Scope of applicability - vehicles and their equipment

The Regulation applies to electromagnetic compatibility of vehicles of categories L, M, and O as well as components or separate electrical or electronic technical units intended to be fitted in vehicles.

The Regulation covers the requirements as specified below.

- a) Requirements regarding the immunity to radiated and conducted disturbances for functions related to:
 - direct control of the vehicle;
 - driver, passenger and other road users' protection;
 - vehicle data bus functionality;and to the immunity to the disturbances that would:
 - cause confusion to the driver or other road users;
 - affect the vehicle statutory data.
- b) Requirements regarding the control of unwanted radiated and conducted emissions to protect the intended use of electrical or electronic equipment at own or adjacent vehicles or nearby, and the control of disturbances from accessories that may be retrofitted to the vehicle.

- c) Additional requirements for vehicles provided with coupling systems for charging the traction battery ("REESS" = **RE**chargeable **E**nergy **S**torage **S**ystem) regarding the control of, and immunity to, emissions from this connection between vehicle and power grid.

Range of the values measured – broadband and narrowband disturbances

The Regulation applies to measurements of broadband and narrowband disturbances determined by means of measuring instruments with either quasi-peak or peak detectors. It upholds previous immunity requirements (for vehicles, electromagnetic field (EMF) strength of 30 V/m; for equipment, EMF strength of 30 V/m or equivalent exposure; for equipment, apart from the above, emissions and immunity to test pulses according to ISO 7637-2 [7]).

Frequency range and measurements

Frequency range:

Emission: 30-1 000 MHz, for both the vehicles and their equipment (subassemblies).

Immunity: 20-2 000 MHz, for both the vehicles and their equipment (subassemblies).

The Regulation allows for measurements carried out with either frequency scanning or selection of individual frequencies in the spectrum (by means of a scanning receiver or a spectrum analyser).

Acceptable levels

Emission level: in a frequency range of 30-1 000 MHz, for vehicles and other devices;

Immunity level: EMF strength of 30 V/m (or equivalent exposure for equipment).

Test site

Test site in the form of a circular area with a radius of at least 30 m (for vehicles), according to UN ECE Regulation No 10.02. In the 10.04 revision of this regulation, the required test site was reduced and enclosed by an ellipse (for vehicles) and the minimum radius of the circle was shortened to 15 m (for equipment).

1. The open area test site for electromagnetic emission measurements, enclosed by an ellipse (for vehicles), has been presented in Fig. 1.
2. The antenna position in relation to the vehicle during measurements of the vertical radiation component has been shown in Fig. 2.
3. The antenna position in relation to the vehicle during measurements of the horizontal radiation component has been shown in Fig. 3.
4. Enclosed test facilities may be used if correlation can be shown between the results obtained in the enclosed test facility (semi-anechoic chamber) and those obtained at an outdoor site.

2.2. Directive 72/245/EEC [2]

Scope of applicability of the requirements – vehicles and their equipment

The Directive applies to electromagnetic compatibility of vehicles or their components or separate technical units (STU).

Range of the values measured – broadband and narrowband disturbances

The Directive applies to measurements of broadband and narrowband disturbances, carried out by means of measuring instruments with either quasi-peak or peak detectors. It upholds previous immunity requirements (EMF strength of 30 V/m); for equipment, it additionally introduces requirements for emissions of, and immunity to, impulse disturbances according to ISO 7637-2 [7].

Frequency range; measurements for specific frequencies and with frequency scanning

Frequency range:

Emission: 30-1 000 MHz, for both the vehicles and their equipment (subassemblies).

Immunity: 20-2 000 MHz, for both the vehicles and their equipment (subassemblies).

The Directive allows for measurements carried out with either frequency scanning or selection of individual frequencies in the spectrum (by means of a scanning receiver or a spectrum analyser).

Acceptable levels

Emission level: in a frequency range of 30-1 000 MHz, for vehicles and other devices;

Immunity level: EMF strength of 30 V/m for vehicles and 30 V/m or equivalent exposure for equipment.

Apart from the above, the equipment must meet the requirements concerning:

- emission levels of impulse disturbances;
- immunity levels to impulse disturbances, according to the ISO standard specified above.

Test site

The requirements are identical to those specified in the UN ECE Regulation, see section 2.1.

2.3. Conditions of operation of the object under test

The internal combustion (IC) engine speed should be 2 500 rpm for a single-cylinder engine and 1 500 rpm for an engine having more than one cylinder. All the devices that produce broadband emissions and can be permanently on, whether operated by the driver or a passenger, e.g. windscreen wiper motors or blowers, should be running with maximum

load. In immunity tests, the vehicle engine should drive road wheels, having been put on a roller test stand, with a speed of 50 km/h.

Both the UN ECE Regulation and the Directive referred to above define the most important safety-related functions that should be checked when the immunity to the impact of electromagnetic field is examined. The functions related to the immunity to the impact of electromagnetic field include:

- a) functions directly connected with controlling the vehicle, i.e.
 - impairing or changing the operation of e.g. engine, gearbox, braking system, suspension system, active steering system, speed-limiting devices;
 - affecting driver's position, e.g. by changing the position of driver's seat or steering wheel;
 - affecting driver's field of vision, e.g. by changing the vertical inclination of the passing beam or the operation of windscreen wipers;
- b) functions directly related to the protection of vehicle occupants or other road users, e.g.
 - affecting the operation of airbags or seat belt tightening systems;
- c) functions, the disturbance of which would disorientate the driver or other road users, i.e.
 - would cause optical disturbances, e.g. incorrect functioning of direction indicators, stop lights, clearance (marker) lamps, tail lights, hazard warning lights, as well as incorrect readings of warning tell-tale lamps, lamps or displays visible to the driver in his/her normal position and related to the functions that have been mentioned in items a) and b) above, etc.;
 - would cause acoustic disturbances, e.g. incorrect functioning of car alarm or horn;
- d) functions related to the operation of the data transfer bus in the vehicle, i.e.
 - stopping the data transfer in the vehicle bus systems used for the transmission of data necessary for the correct operation of other functions related to safety;
- e) functions, the disturbance of which would affect the collection of statutory data, e.g. from a tachograph or odometer.

3. EMC testing of motor vehicles with regard to electromagnetic radiation (EMR)

The electromagnetic disturbances emitted by vehicles are measured in an open area test site (OATS) or an absorber-lined shielded enclosure (ALSE).

3.1. Tests in an open area test site (OATS)

The test area (measuring site) should meet the following requirements:

- The measuring site should be an open level area, free from electromagnetic reflecting surfaces, within a circle or ellipse having dimensions as specified in item 2.

- The background radiation level (extraneous noise and signals) should be at least 6 dB below the maximum acceptable disturbance emission level, except for intentional narrowband ambient transmissions.
- The measuring site should be provided with metal earthing to be used as a reference level.

The above requirements stem from CISPR recommendations.

In general, the requirement of low level of extraneous noise and signals is very difficult to be met, even in locations far from towns and industrial facilities. However, if the total measured level of the noise and signals existing in the environment and the disturbances emitted by the vehicle under test (VUT) does not exceed the acceptable disturbance level then the VUT may be considered as meeting the requirements regarding the disturbance limit. As a rule, the strength of the field of intentional extraneous signals within the range of measurement frequencies exceeds the acceptable levels of the disturbances emitted by the VUTs. Then, the following alternative test methods may be used.

- a) The disturbance emissions may be measured at a shorter distance between the antenna and the VUT. In both Directive 72/245/EEC and UN ECE Regulation No 10, the disturbance limit values are specified for two antenna-vehicle separation values, i.e. 10 m and 3 m (for the 3 m distance, the acceptable emission level is higher).
- b) The orientation of centrelines of the antenna and the VUT should be selected with taking into account the directions from which the extraneous signals are received, so that such signals are weakened by the orientation of the measuring antenna.
- c) If the frequencies of the narrowband disturbances generated by the VUT are close to the frequencies of the extraneous radio signals and if the signal and disturbance frequencies are within the standardized bandwidth of the measuring receiver, then the use of a narrower bandwidth may help.
- d) If the above steps do not bring about a satisfactory effect, the measurements at the frequencies of the radio stations whose signal level exceeds the limits of disturbances emitted by motor vehicles may be skipped but these frequencies should be specified in the test report.

The strength of the field of extraneous noise and intentional signals should be measured before and immediately after measurements of the disturbance emissions from the VUT and this strength should be specified in the test report. The tests should not be carried out during, and within 10 min. after the end of, a precipitation event.

The reference EMF strength is measured for the impact of the earth potential on the result of an EMF measurement to be eliminated, as the electrical parameters of earth vary depending on weather conditions. The reference level is usually provided by metal plates or metal gauze with a mesh not exceeding 0.1 of the wavelength corresponding to the maximum frequency of the measurement bandwidth. The earthing structure that provides the reference level is always made of non-ferromagnetic metals (aluminium, copper, non-ferromagnetic alloys), because this is the only case where the relative magnetic permeability has no impact on the reflection coefficient value.

3.2. Tests in an absorber-lined shielded enclosure (ALSE)

The shielded anechoic chamber (lined with a material that absorbs electromagnetic waves) should meet the following requirements:

- The energy reflected from chamber walls and ceiling should not cause a measurement error exceeding 6 dB.
- The background radiation level should be at least 6 dB below the maximum acceptable level of the disturbance emitted by vehicles.
- The VUT and components of the measuring antenna should not be situated closer than 2 m to the chamber walls and ceiling and closer than 1 m to the surface of the absorbing liner.
- The chamber dimensions should be sufficient for the measuring antenna and the VUT to be positioned in conformity with the requirements specified below in item 3.4.
- During disturbance emission tests, the chamber floor should not be lined with an absorbing material.

The above requirements stem from CISPR recommendations.

If the disturbance emission tests are carried out in an anechoic chamber, the background radiation level checks before the start and after completion of the tests are not required.

3.3. Test equipment

The test equipment should be in conformity with the CISPR 16-1-1 requirements. A quasi-peak detector should be used for the measurements and the measurement results should be expressed in decibels in relation to 1 $\mu\text{V}/\text{m}$ for the frequency bandwidth of 120 kHz. If spectrum analysers or scanning measuring receivers are used, then peak detectors may be used to shorten the scanning time because the measurement results will not be lower than they would be if quasi-peak detectors were used. In such a case, however, every measurement showing a value close to, or exceeding, the acceptable limit should be repeated with using a quasi-peak detector. The maximum scanning rate should be in conformity with the CISPR 16-2-3 requirements. For spectrum analysers and a bandwidth of 120 kHz, the recommended scanning time is 100 ms/MHz for a peak detector and an average detector and 20 s/MHz for a quasi-peak detector.

A receiving antenna of any kind, linearly polarized, may be used to measure the disturbance emission from vehicles, providing that it be normalized to the reference antenna. If measurements are carried out with the use of scanning instruments then a broadband antenna should be used, with making sure that its output is normalized to the output of the reference antenna in the specific measurement conditions.

The antenna should be placed successively on the left- and right-hand sides of the vehicle, in parallel to the plane of symmetry of the vehicle and in line with the engine centre. Two options of the distance between the antenna and the side of the VUT, i.e. 10 m or 3 m, have been provided in Directive 72/245/EEC, with the 10 m distance being preferred. For these antenna-vehicle distance values, the antenna elevation should be 3 m and 1.8 m, respectively.

3.4. Test procedure

For each measurement frequency, measurement results are read for the horizontal and vertical polarization of the antenna. The readout considered characteristic for a specific measurement frequency should be defined as the maximum value of four readouts taken for both antenna polarization modes and on the left- and right-hand sides of the vehicle.

During broadband disturbance emission tests, the engine of the VUT should be running in accordance with CISPR 12. All the devices capable of producing broadband emissions, switched on and off by the driver or a passenger, e.g. windscreen wiper or blower motors, should be running with maximum load. This does not apply to horn and window lift motors because they are not intended for permanent operation.

During narrowband disturbance emission tests, the engine of the VUT should not be running but its ignition system should be on. The electronic systems of the vehicle should be set to their operation mode typical for the vehicle being at a standstill.

All the devices that can be permanently on, whether operated by the driver or a passenger, having internal oscillators of more than 9 kHz working frequency or generating repetitive signals, should be functioning normally.

4. Proposed methods of EMR testing and assessment of motor vehicles

The electromagnetic radiation (EMR) assessment criteria given in UN ECE Regulation No 10 and Directive 72/245/EEC, based on the limit values specified there, are the minimum acceptability requirements. The electromagnetic emission limit lines provide grounds for a statement whether the VUT is in conformity with the requirements of the said documents. No quality criteria exist that would make it possible to compare the EMR of the vehicles that meet the requirements. Neither the designers nor users of the vehicles can determine "to what extent" the vehicle subjected to EMC assessment is "free from EMR". Therefore, the introduction of EMR assessment methods for tightened requirements (lower emission) is proposed.

In automotive engineering, many analytical, graphical, and combined methods exist that are employed to analyse measurement signals with using computer techniques. For the analysis and assessment of the EMR of motor vehicles, the use of methods of at least one of the following groups is proposed:

- line methods (ML);
- area methods (MP);
- parameter estimation methods (MEP).

The terms "line" and "area" are shortcuts used to represent the methods of analysing and assessing the EMR curves; they will be explained in a subsequent part of this section and their application to the testing of e.g. specific electric vehicles (EV) will be discussed in the next sections of this publication.

The proposed methods of the group of line EMR assessment methods are founded on the concept presented in publication [13]. According to the assumptions adopted, the following line methods of EMR assessment of motor vehicles are considered:

1. one-line method (ML1);
2. two-line method (ML2);
3. two-line-plus method (ML2+);
4. three-line method (ML3);
5. three-line-plus method (ML3+).

The analysis was carried out on broadband EMR, with the antenna-VUT distance values being 3 m and 10 m.

The limit lines for the broadband emission from the VUT, for the 3 m antenna-VUT distance, have been presented in Fig. 4. As mentioned previously, the ML1 method is based on the requirements of UN ECE Regulation No 10 and Directive 72/245/EEC. The analysis and assessment carried out pursuant to this method have been described in detail in the said EMR normative documents.

In the ML2 method, the EMR curve is compared with the L_2 limit line, lowered by -10 dB in relation to the L_1 limit line required by UN ECE Regulation No 10.

The ML2+ method consists in comparing the EMR curve with the L_2 limit line defined for method ML2, with exceedances of this line being allowed in a frequency range of up to 10 % of the overall bandwidth of 30-1 000 MHz, as specified in UN ECE Regulation No 10.

In the ML3 method, the EMR curve is compared with the L_3 limit line, lowered by -20 dB in relation to the L_1 limit line required by UN ECE Regulation No 10.

The ML3+ method consists in comparing the EMR curve with the L_3 limit line defined for method ML3, with exceedances of this line being allowed in a frequency range of up to 10 % of the overall bandwidth of 30-1 000 MHz, as specified in UN ECE Regulation No 10.

In the case of the 10 m distance between the antenna and the VUT, the lowering of the limit lines L_2 and L_3 is -8 dB and -16 dB, respectively. The limit lines corresponding to L_1 , L_2 , and L_3 and denoted by L_{1A} , L_{2A} , and L_{3A} for this case, i.e. for measurements of the broadband emission at the 10 m antenna-VUT distance, have been presented in Fig. 5.

In the proposed EMR assessment methods of group MP (area methods), the area between the reference (limit) line and the curve representing the actual electromagnetic emission is calculated for the three limit lines L_1 , L_2 , and L_3 defined in the ML group of methods. According to the assumptions thus formulated, the following area methods of assessment of the EMR of motor vehicles are distinguished:

- one-line area method (MP1 (-));
- two-line area method (MP2 (+));
- three-line area method (MP3 (+)).

The "-" and "+" signs written in brackets have the meaning that in a specific method, the EMR radiation curve is situated under or above the limit line and the areas are subtracted from, or added to, each other.

In the parameter estimation methods (MEP), the essence lies in a statistical analysis of parameters of the EMR curve for the whole measurement bandwidth, according to UN ECE Regulation No 10.

In these methods, the following statistical estimators are determined:

- average value (X);
- quadratic average value (X²);
- variance (W);
- root-mean-square value (RMS);
- standard deviation (S);
- amplitude (A).

5. Recapitulation

The electromagnetic compatibility (EMC) of motor vehicles, in particular electrically driven, is an important element among those subject to assessment. The qualitative optimization of the parameters that can influence the assessment, primarily a reduction in the electromagnetic radiation (EMR) of the vehicle under consideration, will not only result in correct functioning of the vehicle but also will help to avoid possible harmful impact of EMR on vehicle occupants' health. The assessment criteria given in normative documents (UN ECE Regulation No 10 and Directive 72/245/EEC), based on the limit values specified there, are the minimum acceptability requirements. No quality criteria exist that would make it possible to analyse and assess the EMR of motor vehicles in EMC tests.

In this article, general EMC requirements for motor vehicles and their equipment have been presented. The EMR testing methods based on the normative documents mentioned above, which provide grounds for approving specific vehicle types for production and operation (type approval), have also been described. The description of the EMR tests covers tests carried out in an open area test site (OATS) and in an anechoic chamber, i.e. absorber-lined shielded enclosure (ALSE), test equipment, and test procedure based on CISPR requirements referred to both in the UN ECE Regulation and in the EU Directive.

Three groups of electromagnetic radiation testing methods have been proposed: line methods (ML), area methods (MP), and parameter estimation methods (MEP).

Results of an analysis of testing selected electric vehicles (EV) based on the criteria proposed will be presented in Part II of this publication.

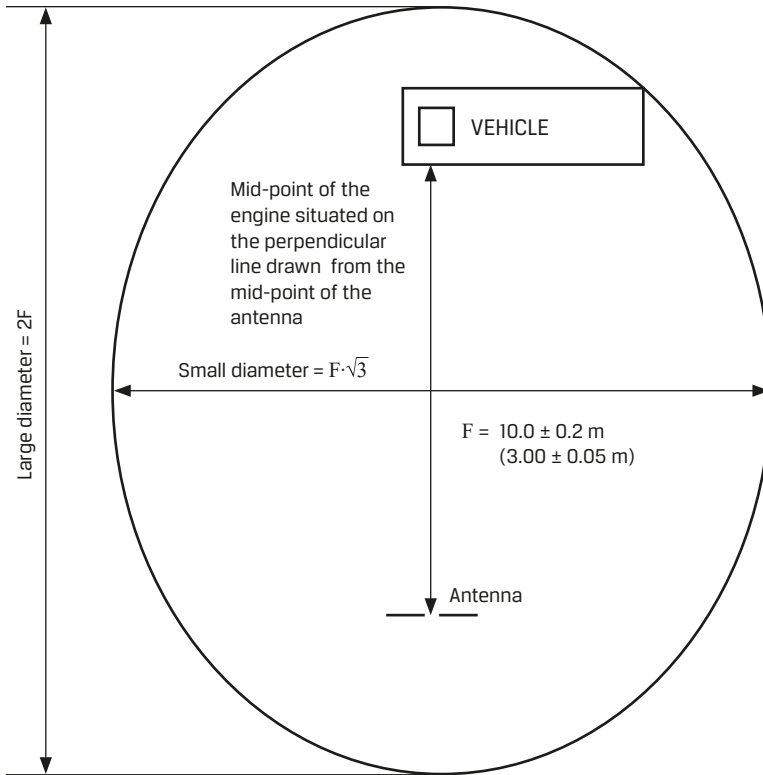


Fig. 1. Test site

Komentarz:

W powyższym rysunku wg R10.04 występuje mała średnica = $F \cdot \sqrt{3}$, natomiast powinno być $F \cdot \sqrt{3}$ tak jak było w poprzedniej wersji regulaminu R10.03, zgodnie z zaleceniami CISPR 16-1.

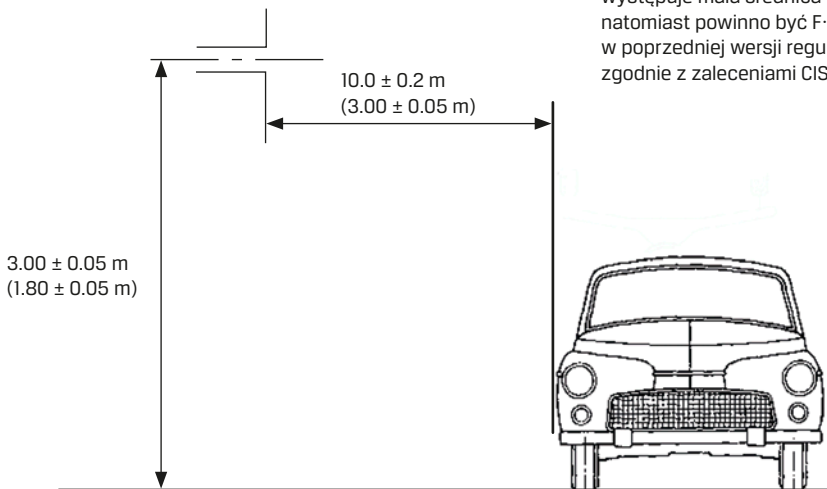


Fig. 2. Measurement for vertical polarization of the antenna

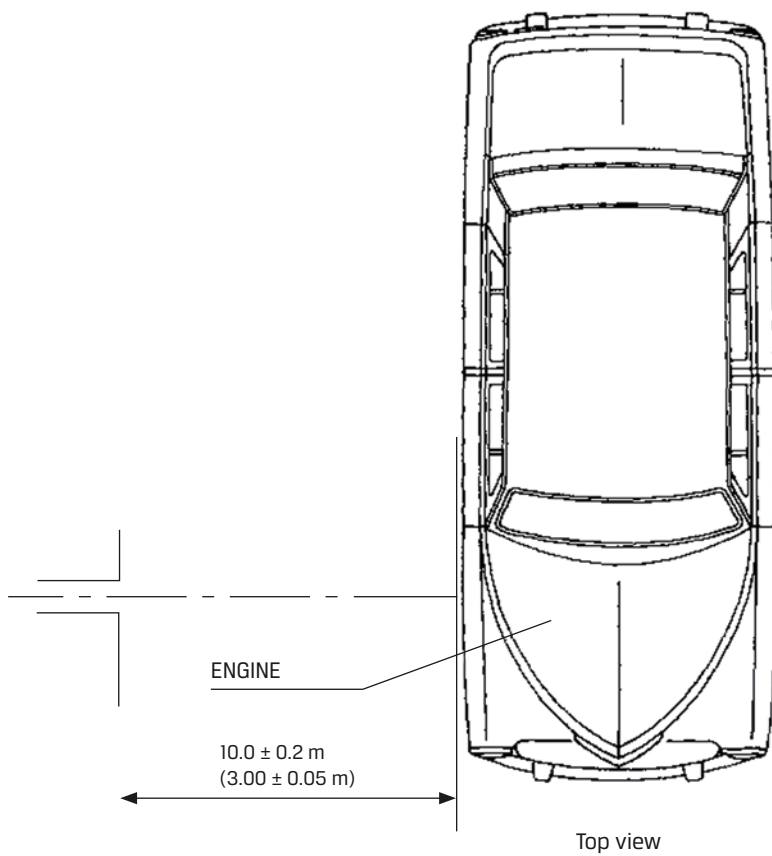


Fig. 3. Measurement for horizontal polarization of the antenna

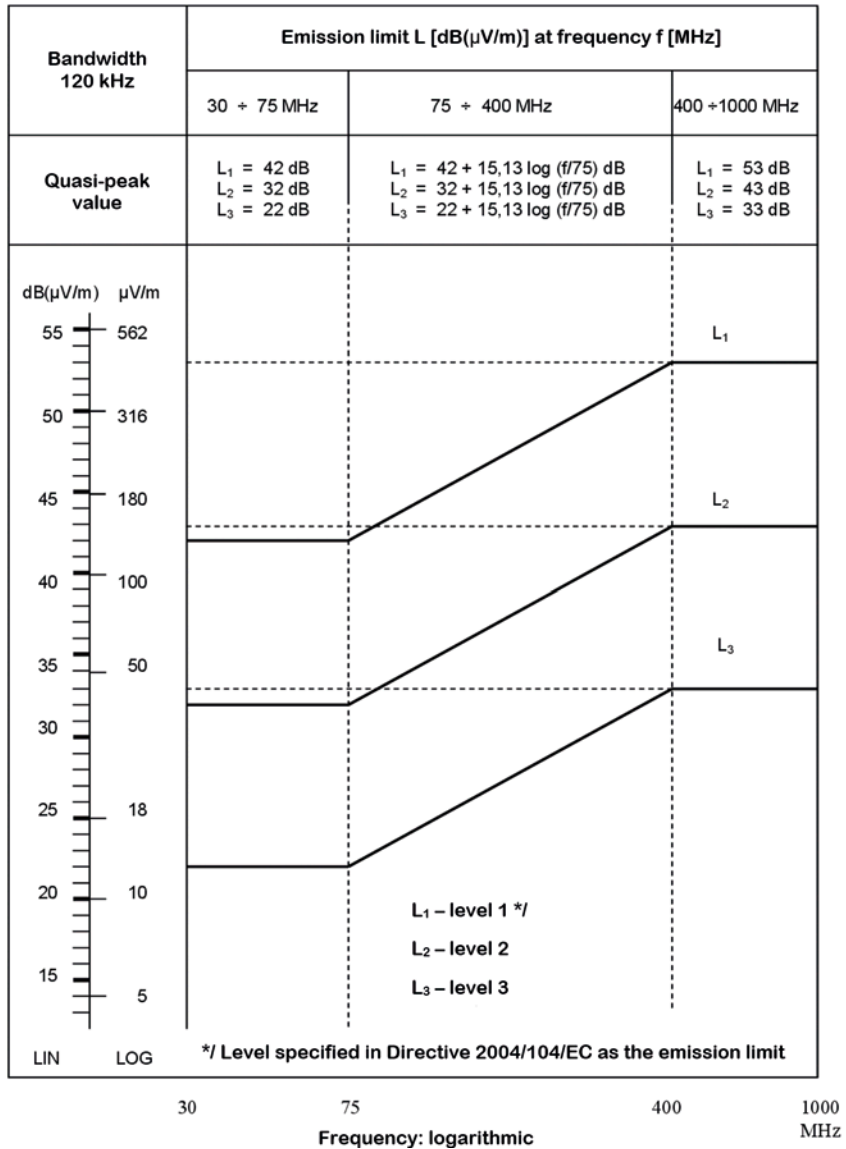


Fig. 4. Proposed broadband emission limits for vehicles (for the antenna-vehicle distance = 3 m)

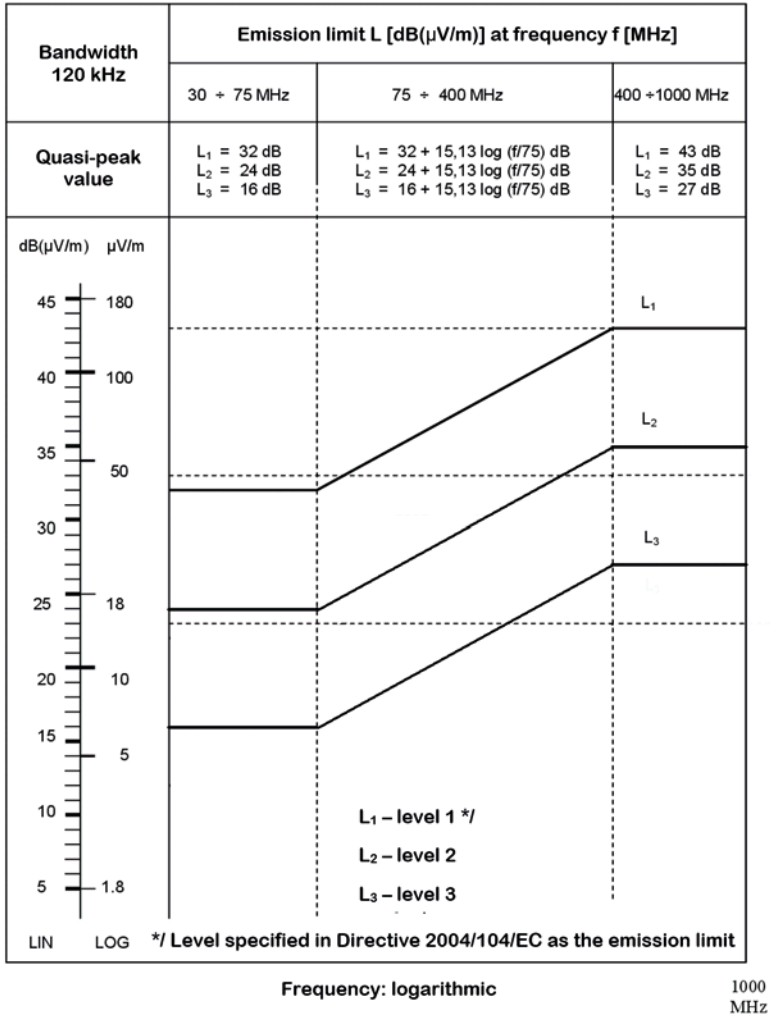


Fig. 5. Proposed broadband emission limits for vehicles (for the antenna-vehicle distance = 10 m)

The full text of the article is available in Polish online on the website
<http://archiwummotoryzacji.pl>.

Tekst artykułu w polskiej wersji językowej dostępny jest na stronie
<http://archiwummotoryzacji.pl>.

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