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Threats associated with electromagnetic field immunity tests of electronic devices according to selected standards

***Abstract**. Electromagnetic disturbances may interfere in operation of electronic devices. For protection against this phenomenon, each device should be subjected to EMC tests. Such tests are provided to check whether the device does not introduce too high level disturbances into the environment and whether it is sufficiently resistant to the electromagnetic field that may occur in this environment. The article describes test methods for electromagnetic interference immunity in relation to selected standards and an attempt of evaluation the reliability of the results has been undertaken.*

***Streszczenie.** Zaburzenia elektromagnetyczne mogą zakłócać działanie urządzeń elektronicznych. W celu ochrony przed tym zjawiskiem każde urządzenie powinno być poddawane testom EMC. Takie testy mają na celu sprawdzenie, czy urządzenie nie wprowadza do środowiska zakłóceń na zbyt wysokim poziomie i czy jest wystarczająco odporne na pole elektromagnetyczne, które może wystąpić w tym środowisku. W artykule opisano metody badań odporności na zakłócenia elektromagnetyczne w odniesieniu do wybranych norm oraz podjęto próbę oceny wiarygodności wyników. **(Zagrożenia związane z badaniami odporności urządzeń elektronicznych na oddziaływanie pola elektromagnetycznego w świetle wybranych norm**).*

Keywords: electromagnetic compatibility, electromagnetic disturbances, devices immunity, measurement techniques.
Słowa kluczowe: kompatybilność elektromagnetyczna, zaburzenia elektromagnetyczne, odporność urządzeń, techniki pomiarowe.

Introduction

The human beings live surrounded by various electronic and electric devices - cars, computers, mobile phones, medical apparatus, household appliances every day, IT devices, communication systems are just some of them. Huge technological development in the area of electronics has positively influenced the miniaturization of devices, their greater efficiency, functionality and energy saving. Unfortunately, simultaneously devices have become more sensitive to external factors, such as electromagnetic fields [1-2] or electrostatic discharge (ESD) [3].

Even slight disturbances radiated by one device may disrupt the operation of other devices nearby [4]. On the other hand, such action may also be considered. The low cost of electronic components fosters criminal activities. Developing a device radiating an electromagnetic field capable of disrupting the work or destroying the device has become possible even for inexperienced electronics engineer.

The effects of the disturbed functioning of devices and systems are imaginable – flight control system, traffic control or alarm systems, medical equipment – what has a direct impact on our safety. In such situations, TV, mixers or washing machines interference caused by a mobile phone or WI-FI router nearby, seems to be of little importance (although nuisance).

The external electromagnetic field has a particularly large impact on wireless radio communication devices such as transceiver, WI-FI routers, computer cards and even drone control devices. An increase of the electromagnetic field in the band of frequencies used, reduces the operating range of these devices and in some cases leads to block of the receiver. As a result occurs interference of the control or transmission analog and digital data.

To minimize the risk of interference into the operation of the device [5] (increasing the safety of use) has to meet the specific requirements of electromagnetic compatibility. These requirements relate to two basic aspects of electromagnetic compatibility:

- The device should not radiate electromagnetic disturbances that could cause other devices to malfunction.
- The device should be sufficiently resistant to electromagnetic disturbances occurring in its environment.

Various standards of electromagnetic compatibility contain the requirements and test methods concerning to the aspects, regarding both emission and immunity tests (for example [6-10]). The test methods for emission measurement presented in these standards are similar and the main differences are related to the frequency ranges, limit levels and distance between equipment under test and measurement antenna [6-8, 10]. However, significant differences are related with EMC immunity tests. In this case, there are additional differences concern the type of test signal (modulation) and above all, in the way of determining the value of the electromagnetic field intensity that affects the device [7-10].

And just it is the method of measuring the electromagnetic field affecting the devices that seems to be critical during these tests. Inaccuracies in the measurement of the electromagnetic field intensity, caused by the close presence of conductive structures and the EUT itself, will cause the wrong interpretation of the final result. For example, the device could be classified as meet the EMC immunity criterion because the real influencing field was much smaller than that measured with the field probe.

The tolerance of the electromagnetic field strength measurement established by the MIL-STD 461G standard is equal 3 dB. It means, that for the required level of electromagnetic field intensity equal 50 V/m, the measured real electromagnetic field should be in the range from 35 to

70 V/m, and for the required level equal 5 V/m the measured field should be in the range of 3.5 to 7 V/m. It seems, that in the case of the tested objects with large dimensions, the obtained results may exceed the permissible tolerance. Interferences of directed and reflected (from the object) waves can cause almost complete disappearance of the field at the measurement point and to double its value for some frequencies (this phenomena is connected with form a standing waves. It results in arrows and valleys, after removing the object, the electromagnetic field intensity measured at the measurement point would have a nominal value).

There are discuss the selected EMC immunity test methods and differences between them in the next parts of this article.

Methods – EMC Immunity tests

The EMC immunity test of IT devices depends of interacting with an equipment under test by a modulated electromagnetic field about specified intensity in the specified frequency range. Signal generators, amplifiers and antennas are most commonly used for this purpose.

Generators are used for preparation signal with specified modulation (e.g. amplitude modulation or pulse modulation). Then the signal is amplified to required level by an amplifier. The signal stimulates the antenna which is used to radiate an electromagnetic field in direction of tested device. Tested device is being observed for deterioration of operating parameters.

The EMC immunity tests are taken into a shielding rooms (an anechoic chamber) to prevent the energy radiating outside, because the radiated signals could interfere with devices other than tested. A set of generators, amplifiers and antennas was used for these tests (Table 1).

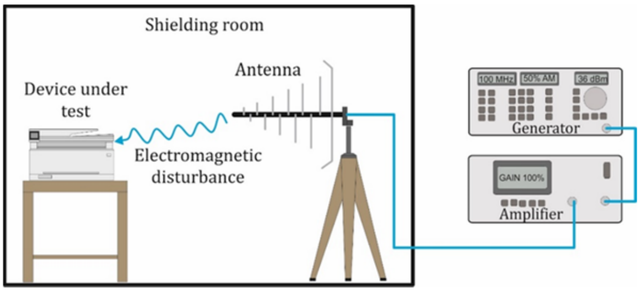


Fig. 1. The general test setup to EMC immunity test

Table 1. A set of devices used during the EMC immunity tests

Device	Parameter	Producer / Type
Signal generator	9 kHz – 1 GHz	Rohde&Schwarz / SMGL
Signal generator	100 kHz – 20 GHz	Agilent / N5183A
Function generator	--------	Rigol / DG1062
Amplifier	10 kHz - 220 MHz; 1 kW	IFI / M406
Amplifier	80 MHz - 1 GHz; 250 W	Rohde&Schwarz / BBA150
Amplifier	800 MHz – 3 GHz; 110 W	Rohde&Schwarz / BBA150
Amplifier	2 GHz – 8 GHz; 250 W	BONN / TWAL 0208-250
Biconical antenna	20 MHz – 200 MHz; 2.5 kW	Schwarzbeck / WHBD 9134
Log-periodic antenna	80 MHz - 1000 MHz; 2 kW	IFI / LP2000
Double ridged antenna	1 GHz – 18 GHz; 300 W	EMCO / 3115
Field power meter	10 kHz – 4 GHz	DARE / CTR 1002A
Field power meter	30 MHz - 18 GHz	DARE / CTR 1001S

The general principles of immunity tests are presented on the Figure 1. A very important issue during measurement of intensity of electromagnetic field is - locations of electromagnetic field probe (on the back, front or side of the test device). Also existing other metal elements have a great influence on measured intensity of electromagnetic field. More details about EMC immunity tests according to applicable standards are described in the following subsections.

Methods - IEC 61000-4-3 standard

IEC 61000-4-3 standard [9] deals with EMC immunity tests related to the protection against RF electromagnetic fields from any source. In this standard particular considerations are devoted to the protection against radio-frequency emissions from electronic devices (e.g. mobile phone or other RF devices, household goods).

The method described in this standard relies on placing the device under test in a reference electromagnetic field with the required intensity and frequency. Standard test levels are 1, 3, 10, 30 V/m. Additionally there is a special level X of indefinite value too. Tests are carried out in the frequency range from 80 MHz to 1 GHz for the device of general purpose or to 6 GHz for mobile phones or other RF devices). A distance between measurement antenna and device under test is 3 m. The test setup for electromagnetic field calibration is presented on the Figure 2.

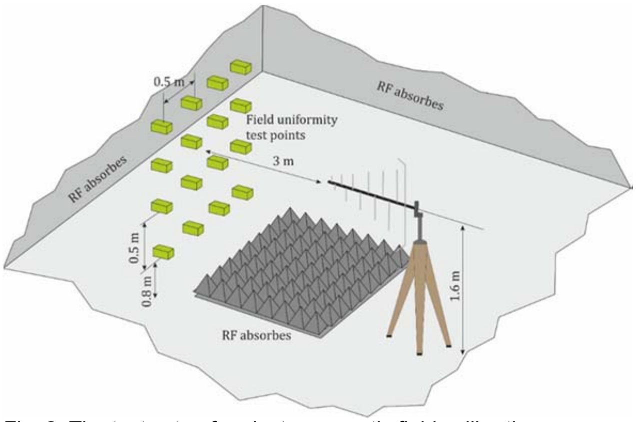


Fig. 2. The test setup for electromagnetic field calibration

During the calibration process a field intensity probe is placed in green color marked points. Field intensity is measured in all points. Absorbers minimalize reflection from metal wall, floor and ceiling. It makes measurements more reliable and repeatable. The same placement of absorbers must be during the tests. A calibrated field is uniform if at least 12 measurement points out of 16 measured values are within a range of tolerance -0 … +6 dB.

When the uniform field area is appointed it is possible to start EMC immunity tests.

The test setup for EMC immunity test is presented on the Figure 3.

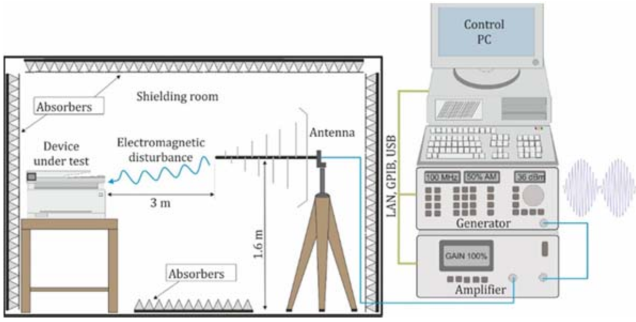


Fig. 3. The test setup to EMC immunity test

The device under test is set in appointed uniform field on unconducted table. The PC control amplitude, modulation and frequency of the generator and gain of amplifier. The signal from the amplifier is transmit to the antenna and is radiated as electromagnetic field

During the test, the device is monitored for satisfactory operation.

Methods - MIL-STD-461G standard

The essence of the tests according to the MIL-STD-461G [7-8, 10] is very similar to that presented in the IEC 61000-4-3 standard, but some differences could be seen. The antenna is placed 1 m away from tested device and 1.2 m above the floor. There are no absorbers on the floor and the non-conducted table is covered by metal ground plane which joint with metal floor. An uniform field area is determined by antenna characteristic (3 dB beam width of the antenna). Additionally, in frequency range from 10 kHz to 1 GHz, value of required field is determined by the field intensity probe during the test.

At the range of frequencies from 1 GHz to 40 GHz the field intensity may be determined by probe during the test or before the test, during the calibration. The second method (two antennas method) is similar to the method described in IEC 61000-4-3.

The test setup for EMC immunity test according MIL-STD-461G is presented on the Figure 4.

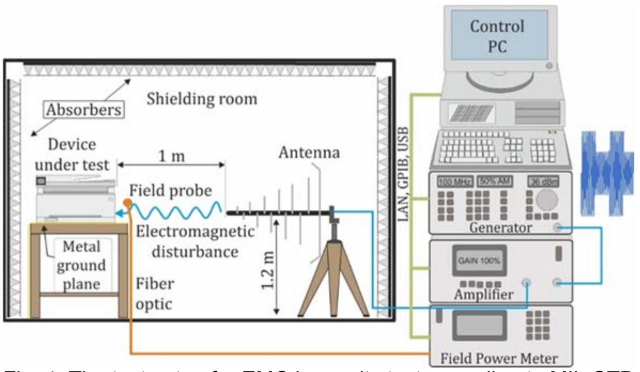


Fig. 4. The test setup for EMC immunity test according to MIL-STD-461G

Methods - Differences between MIL-STD-461G and IEC 61000-4-3 methods

The basic differences between test methods described in MIL-STD-461G and IEC 61000-4-3 standards are presented in Table 2.

Table 2. The basic differences between test methods

Feature	MIL-STD-461G	IEC 61000-4-3
distance between EUT and antenna	1 m	3 m
antenna height	1.2 m	1.6 m
frequency range	80 MHz..6 GHz	10 kHz..40 GHz
absorbers	walls, ceiling	walls, ceiling and floor
signal modulation	80% AM	50% PM
measurement of field intensity	during the test/during the calibration[1]	during the calibration
[1] From 1 GHz to 40 GHz both methods are possible		

The most important of these differences is the method of measuring of the electromagnetic field intensity when the equipment under test is set inside of the electromagnetic field. Then measurements of the field during the tests, especially for large metal objects, may be subject to significant errors [11-13]. It is explain in next sections.

Influence of metal constructions on electromagnetic field propagation

All metal structures significantly affect the distribution of the electromagnetic field [12,14]. There are phenomena of reflection, diffraction or absorption dependent of the frequency of the electromagnetic field. Additionally, each metal element (conductor) may became the new source of radiation.

A comprehensive analysis of electromagnetic field propagation in a wide range of frequencies becomes very complicated. In the most of the analyzed cases, the reflection method (or ray tracking method) [11,12] seems sufficient to determine the electromagnetic field distribution. It consists with compose waves reflected from metal elements (e.g. from the floor, test object, etc.) as shown on Figure 5.

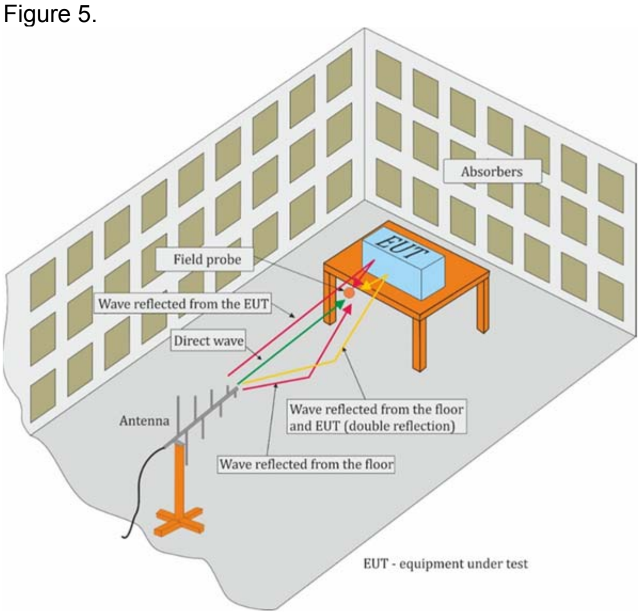


Fig. 5. Visualization of the reflections method (ray tracing) to determine the distribution of electromagnetic field intensity

Electromagnetic field distribution – theoretical simulations

Field intensity at the analyzed point for each of the waves (reflected and directed) can be determined using the equation (1). It is especially important during calculations to take into account the change of the phase of the signal after each reflection [6].

(1) $$\vec{E} = \frac{Il}{j4\pi\omega\varepsilon_0} e^{-j\beta R}\left(\frac{1}{R^3} + \frac{j\beta}{R^2} + \frac{\beta^2}{R}\right),$$

(2) $$\omega = 2\pi f,$$

(3) $$\beta = \omega\sqrt{\varepsilon_0\mu_0},$$

where: R – distance between analyzed point and antenna (other for the reflected and direct wave), I – antenna current, l – length of radiated element of antenna, f – frequency, β – phase constant for propagation in free space conditions, ε_0 – electric permeability, μ_0 – magnetic permeability.

Then it is possible to determine the value of amplitude of field intensity in the analyzed point from direct and reflected waves (4):

(4)
$$|\vec{E}| = \left|\sum_{i=1}^{n} \vec{E}_i\right|,$$

where: $|\vec{E}|$ – amplitude of total electromagnetic field, n – number of analyzed propagation paths, $\vec{E}_i$ – value of electromagnetic field for *i*-th path.

It is rather simple but effective method allows to determine the distribution of the electromagnetic field disturbed by presence of metal elements (floor, EUT) in the appointed area (yellow square on Figure 6).

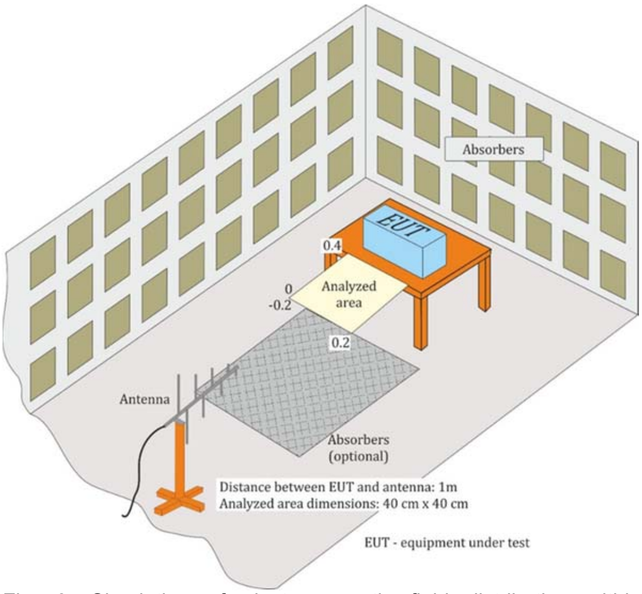


Fig. 6. Simulation of electromagnetic field distribution within analyzed area.

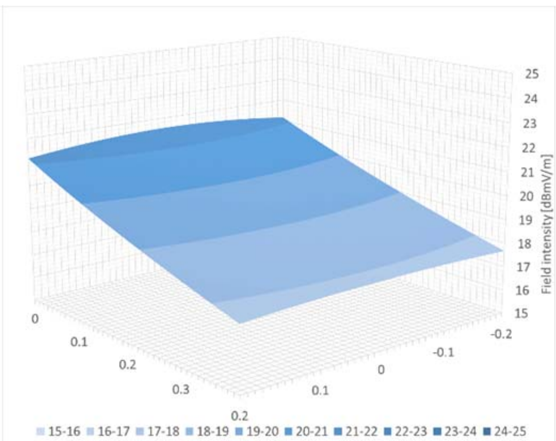
Conditions of simulations was similar as described in MIL-STD-461G standard [10] (without including the metal ground plane on the table). During simulating field distribution, the analyzed points were placed on a plane (yellow square in Figure 6), at a height of 1.1 m. The distance between the antenna and EUT was 1 m. The antenna was placed on non-conducted tripod at a height of 1.2 m. A distance between analyzed points was 1 cm.

Simulations were carried out for exemplary frequencies that were determined during preliminary tests. There were selected the frequencies, for which the greatest influence of conducted objects on the electromagnetic field distribution was observed.

There were simulations for 3 cases:

- With absorbers but without EUT (case closest to the conditions of free space);
- Without absorbers and EUT (determining the effect of a metal floor);
- With absorbers and EUT (determining the effect of a metal test equipment).

Results of the simulations is presented on Figure 7-9.



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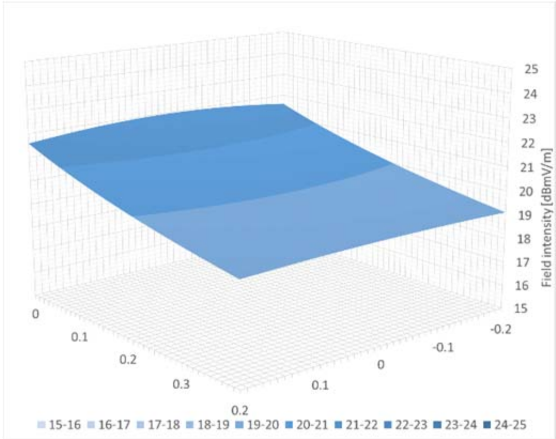

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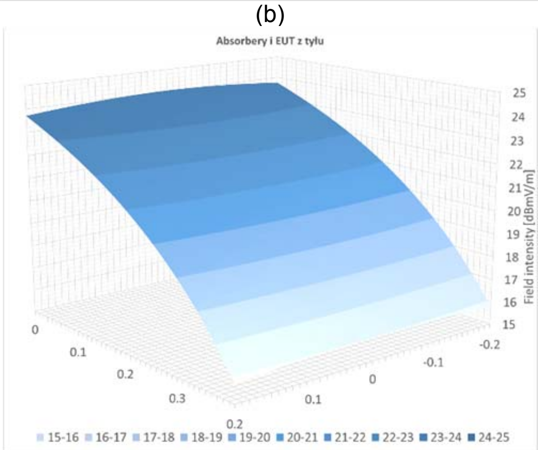
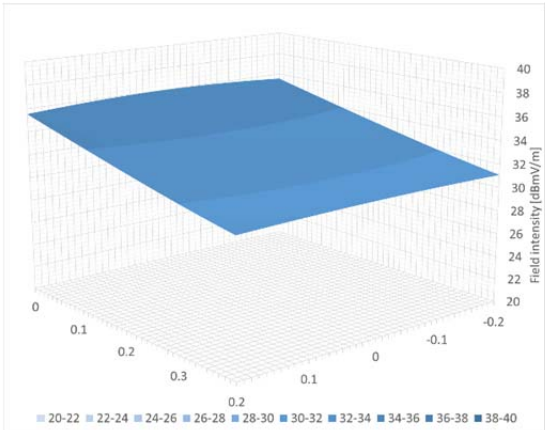


(c)

Fig. 7. Electromagnetic field distribution for frequency 130 MHz: (a) with absorbers and without EUT; (b) without absorbers and without EUT; (c) with absorbers and EUT



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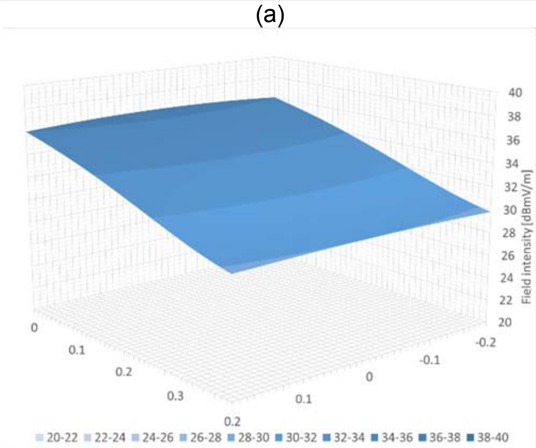

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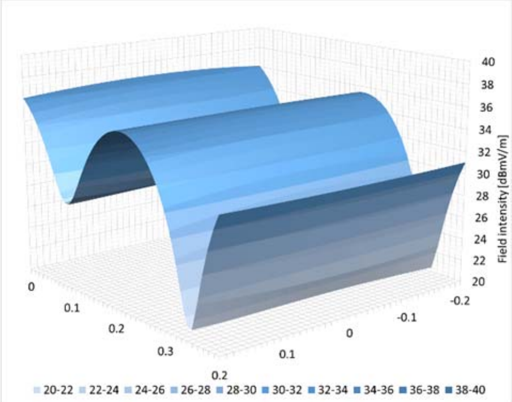
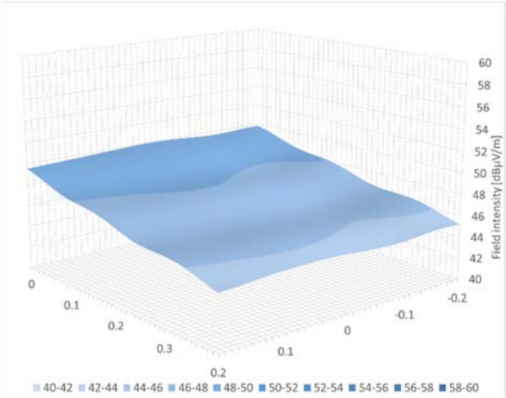


(c)

Fig. 8. Electromagnetic field distribution for frequency 600 MHz: (a) with absorbers and without EUT; (b) without absorbers and without EUT; (c) with absorbers and EUT



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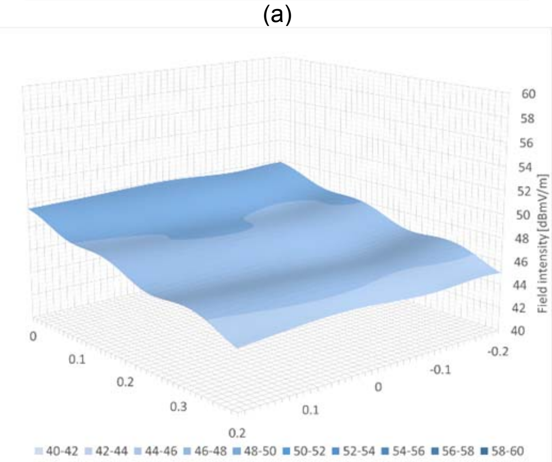

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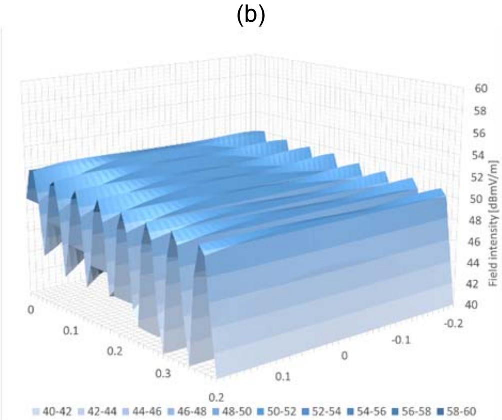
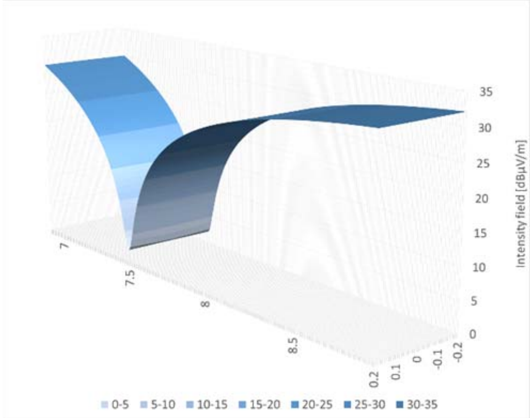


(c)

Fig. 9. Electromagnetic field distribution for frequency 3 GHz: (a) with absorbers and without EUT; (b) without absorbers and without EUT; (c) with absorbers and EUT



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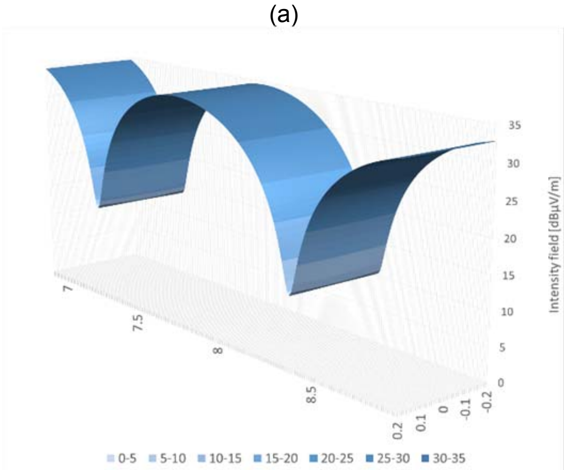

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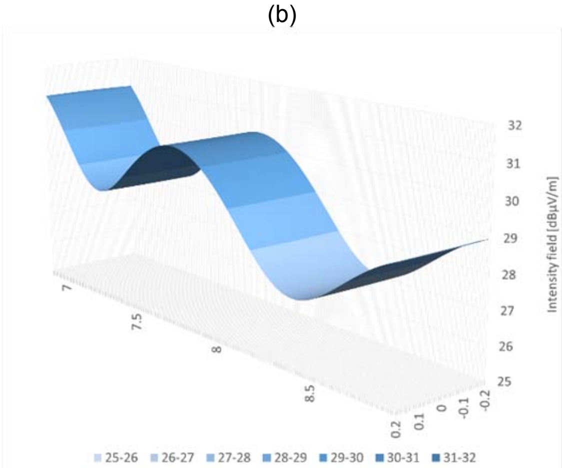


(c)

Fig. 10. Electromagnetic field distribution for frequency 3.6 GHz: (a) without absorbers, antenna height 0.8 m; (b) without absorbers, antenna height 1.6 m; (c) with absorbers, antenna height 1.6 m

Based on the analysis of the obtained results, the impact of the metal floor does not significantly affect the distribution of the field. This is due to the fact that the reflected wave path is even 3 times longer than for a direct wave (the amplitude of the reflected wave at the analysis point is about 10 dB lower than the direct wave amplitude).

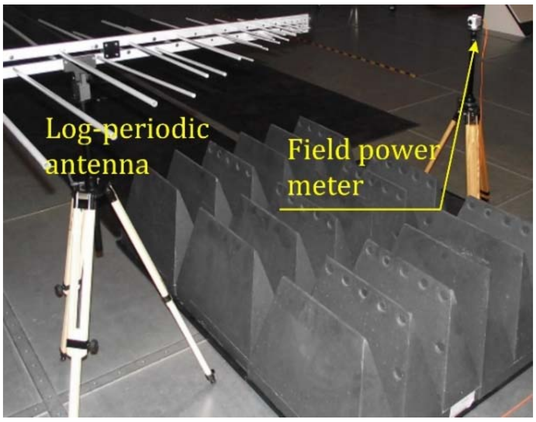
However, a large impact of EUT is observed. In this case, the direct wave path is comparable to the reflected wave path, therefore the amplitudes of these waves at the analyzed points are similar. The phase differences between the reflected and direct waves (resulting from different path lengths) cause a decrease or increase of amplitude at the point of analysis.

In addition, simulations of the electromagnetic field distribution were carried out for a bigger measuring distance of 9 m (similar reflected and direct wave path). In this case, as expected, a large impact of metal floor on field distribution was observed, as illustrated on Figure 10.

At the same time, the beneficial effect of absorbers is visible (reduction of electromagnetic wave amplitude changes from 20 dB to 3 dB). The area was analyzed at a distance of 7 to 9 m from the transmitting antenna and 40 cm of width.

Electromagnetic field distribution – measurements results

To confirm the correctness of theoretical considerations, series of measurements were provided in adequate measurement systems which shown on Figure 11.



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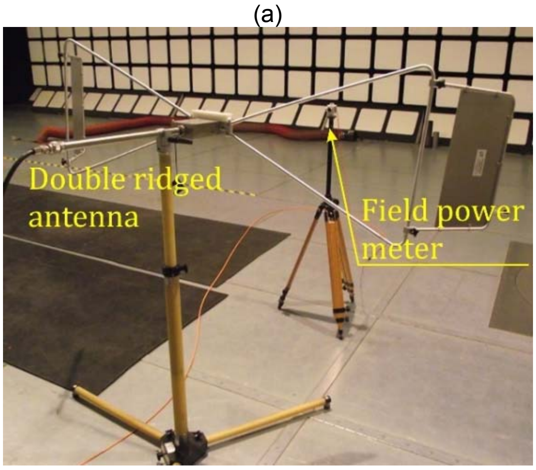

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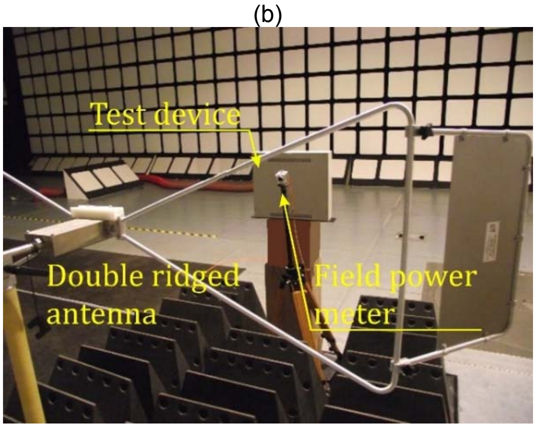
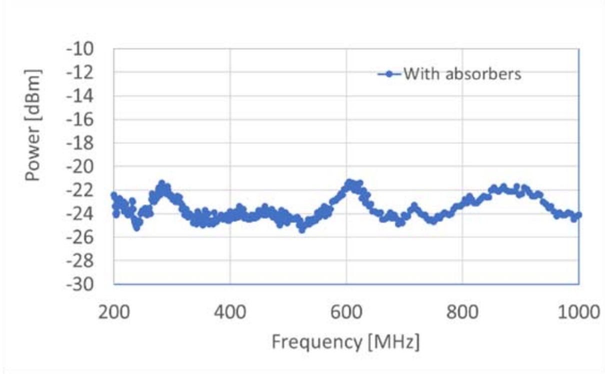


(c)

Fig. 11. Measurement setup to check the influence of metal objects on electromagnetic field distribution: (a) with absorbers; (b) without absorbers; (c) with absorbers and EUT

The type of the antenna used for measurements depends from the range of frequencies. Examples of measurement results are shown on Figures 12-14. The observed changes in the electromagnetic field amplitudes at the analyzed point correspond to the changes determined by the simulation method. On the chart was presented the demanded power of the generator to achieve 5 V/m intensity of the electromagnetic field. The power depends on the frequency and configuration of metal objects (metal case with dimension 43 x 38 x 9 cm).



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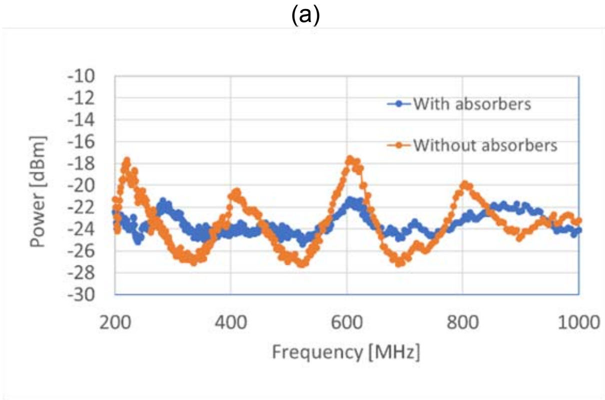

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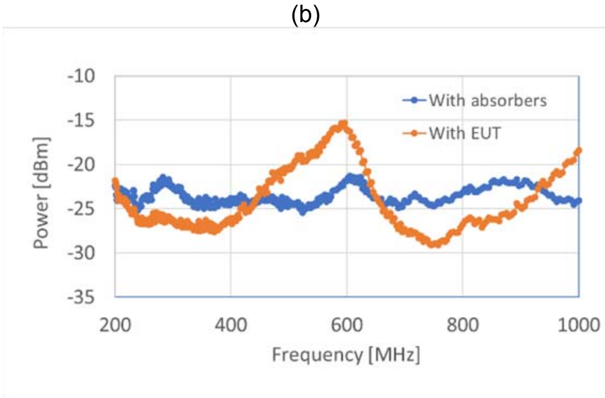
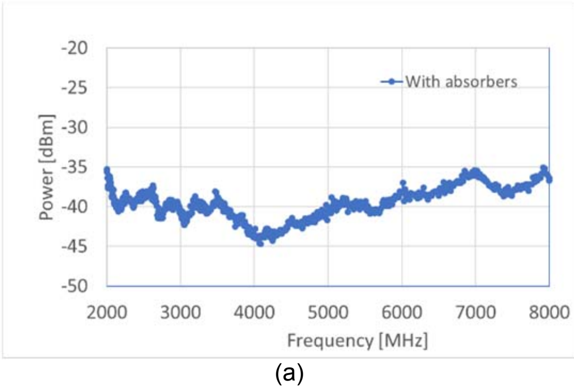


(c)

Fig.12. Required power of the generator to achieve 5 V/m intensity of the electromagnetic field in the range of frequencies from 200 MHz to 1000 MHz: (a) with absorbers; (b) without absorbers; (c) with absorbers and EUT



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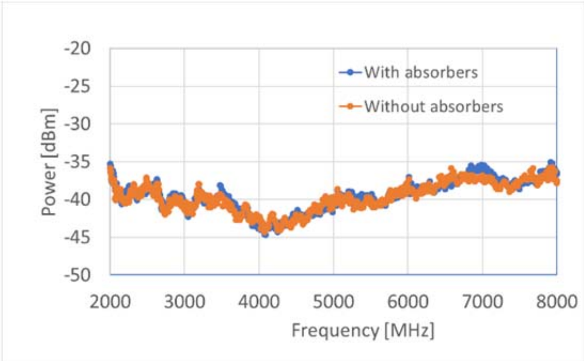

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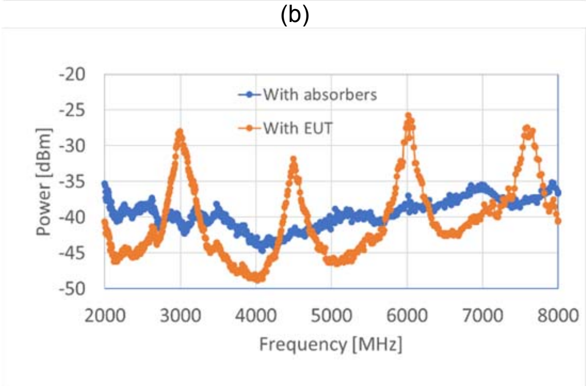

(c)

Fig. 13. Required power of the generator to achieve 5 V/m intensity of the electromagnetic field in the range of frequencies from 1000 MHz to 8000 MHz: (a) with absorbers; (b) without absorbers; (c) with absorbers and EUT

Lack of differences between propagation with and without absorbers for high frequencies (Figure 13b) is caused by the use of a highly directional antenna. As a result, a small part of the radiated power reaches the floor. Most of the radiated power reaches the device directly. Then it reflects from its metal case and interferes at the measuring point with a direct wave. Because of comparable path lengths of the reflected and direct wave large differences are observed in terms of “free space propagation” (Figure 13a).

Discussions

During testing real objects (especially those with large dimensions), the previously presented results should be taken into account.

Especially during tests according methods and requirements of MIL-STD-461G, where the field intensity is measured during the test, there is a high risk that the actual electromagnetic field intensity is much lower or greater (depending of the frequency) than indicated by the field probe.

An example of EMC immunity test of big object (vehicle) is presented on the Figure 14. During the test the power of signal was controlled to indicate by the probe 50 V/m field intensity. Then the same power of signal was used to generate the electromagnetic field but the object was removed. At this way, the values of the real electromagnetic field in which the tested object was set were determined.

As can be seen, for some frequency ranges the real field intensity is much greater (even more than twice) than the specified requirement.

However, there are ranges in which this field represents only 30% of the value of the required field strength. This phenomenon is particularly dangerous because the EUT could be under-tested. It is not known how the device will work in real conditions.

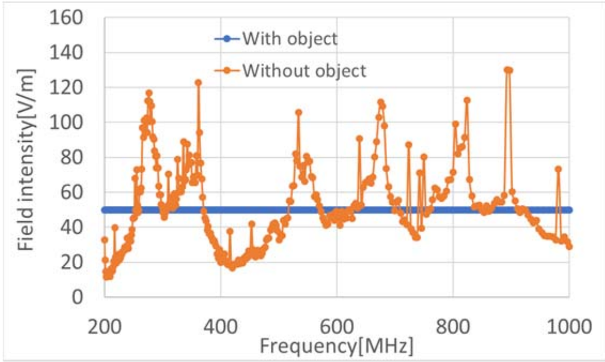

Figure 14. The electromagnetic field intensity indicated by probe both with and without tested object (EUT) by using the same signal power from generator

Conclusions

Electromagnetic immunity tests ensure the proper work of electronic devices, in conditions of saturation of EMC environment. Unfortunately, some standardized testing methods do not provide clear information about the resistance of the device under test (EUT). The most reliable method seems to be the one of placed the object in a calibrated field (IEC 61000-4-3) [20].

The greatest risk of not detecting lack of EMC immunity is associated with the method described in MIL-STD-461G (and other documents based on this standard [7,8]).

The main source of significant errors in determining the electromagnetic field intensity are the conductive structures present close to the transmitting antenna and measuring probe. These include, first of all, the metal floor and the tested object (especially large dimensions, comparable to the wavelength).

The effect of the conductive floor (reflections from metal floor) is dependent on the transmitting antenna, more specifically its directional radiation pattern. In the case of the log-periodic antenna (for frequency up to 1GHz), a significant influence of reflections on the resultant value of the electromagnetic field can be noticed. The differences in propagation with the use of absorbers are up to 4dB (Figs.12a-12b).

In the case of using antennas with a narrower beam (horn antennas, frequency range above 1 GHz), no significant influence of the floor on the electromagnetic field strength was observed (Figs.13a-13b).

A greater influence of the tested object on the measured value of the field intensity was observed than that of the metal floor during the tests. The differences in propagation with the use of absorbers reached the values of 10dB (Figs.12a, 12c, 13a and 13c) in this case.

The obtained results of measurement (Figs.12-13) are similar to the predicted results obtained by the simulation method (simulation of the electromagnetic field distribution by ray tracing method, Figs.7-9).

Such big errors in the measurements of the electromagnetic field intensity significantly exceed the permissible tolerance limits specified in the standardization documents.

It is even more disturbing that for some frequency ranges the tested object is exposed to too low an electromagnetic field (e.g. 10 V/m instead of 50 V/m as shown in Fig.14), which may result in incorrect assessment of the object's compliance.

One way to improve the reliability and repeatability of EMC immunity tests may be to use the floor absorbers between the antenna and the electromagnetic field probe. However, this solution is not completely compatible with MIL-STD-461G (Fig.4).

Additionally, the location of the electromagnetic field probe in relation to the antenna and the tested object may have a significant impact on improving the reliability of the research.

Work is currently underway to increase the reliability of EMC immunity tests by appropriate location of the electromagnetic field probe and multiple tests with changed positions of the field probe. Such a solution should significantly reduce the risk of exposing the object to an electromagnetic field with too low intensity.

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REFERENCES

[1] Suarez A., Victoria J., Torres J., Martinez P.A., Alcarria, A., Martos J., Garcia-Olcina, R., Soret J., Muetsch S., Gerfer A., Effectiveness Assessment of a Nanocrystalline Sleeve Ferrite Core Compared with Ceramic Cores for Reducing Conducted EMI, *Electronics 2019*, 8, 800; doi:10.3390/electronics8070800
[2] Kubiak I., LCD & CRT monitors radiated electromagnetic emission level, *International Conference on Electromagnetic Disturbances*, EMD Wilno 2004
[3] Białek K., Wetoszka P., Paś J., Wyniki badań podatności wybranych urządzeń na wyładowania elektryczne – wnioski, *Przegląd Elektrotechniczny*, 95 (2019), nr 11, 124-126
[4] Kałuski M., Michalak M., Spalt K., Szafrańska M., Praktyczne przykłady braku kompatybilności elektromagnetycznej dużych urządzeń, *Przegląd Elektrotechniczny*, 90 (2014), nr 7, 183-186
[5] Kubiak I. Level of electromagnetic safety of graphic digital interface, *EMC Europe 2018, Amsterdam, Netherlands, Special Session: Electromagnetic Eavesdropping*, 27-30 August 2018, DOI: 10.1109/EMCEurope.2018.8484981
[6] CISPR 22 Information technology equipment – Radio disturbance characteristics – Limits and methods of measurement
[7] Polish Military Standard NO-06-A200:2012 Electromagnetic Compatibility – limit levels of electromagnetic interferences and susceptibility
[8] Polish Military Standard NO-06-A500:2012 Electromagnetic Compatibility – test methods of electromagnetic interferences and susceptibility
[9] IEC 61000-4-3 Electromagnetic compatibility (EMC) – Part 4-3: Testing and measurement techniques – Radiated, radio-frequency, electromagnetic field immunity test
[10] MIL-STD-461G Requirements for the control of electromagnetic interference characteristics of subsystems and equipment
[11] Nowosielski L., Wnuk M., Siłaczuk M., Modelowanie propagacji fal elektromagnetycznych metodą ray-tracingu, *Przegląd Elektrotechniczny*, 90 (2014), nr 7, 218-221
[12] Musial S., Romanik J., Field disturbances inside non-anechoic chamber – EMC tests aspect. *Electromagnetic Disturbances 2003, XIII International Conference on Electromagnetic Disturbances 2003*, Bialystok, Poland, 2003, ISBN 83-88229-46-X
[13] Noga A., Wójcik D., Surma M., Pełnofalowa analiza odporności elektroencefalografu na zaburzenia promieniowane, *Przegląd Elektrotechniczny*, 94 (2018), nr 2, 70-73
[14] Katulski R.J., Namiotko R., Topological Model of an Electromagnetic Environment Inside a Ship for Electromagnetic Compatibility (EMC) Analysis, *Appl. Sci*. 2019, 9, 4293; doi:10.3390/app9204293