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Using a Simulation of ALSE Long Wire Method to Lower Measurement Uncertainty in EMC Measurements

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***Abstract* – Electronic devices have become an essential part of our modern world, and manufacturers are obliged to ensure their safe coexistence and the reliable performance of their tasks. Operating safety means that nearby devices interfere with each other as little as possible. These interferences and immunity to interference signals are addressed in the field of Electromagnetic Compatibility (EMC). EMC has been in the focus of researchers since the mid-20th century, but serious regulations were not introduced until the late 1980s.**

The article describes the basics of EMC and the challenges and uncertainties of this relatively new field of science, despite of the strict standard regulations of numerous measurement procedures. Also a simulated environment is presented to demonstrate examination possibilities and variations of the standard interpretations.

I. INTRODUCTION

Electromagnetic compatibility measurements are based on standards determining test procedures of different types of products. The research was motivated by the fact that in many cases the standards are not clear and gives the laboratories and the test engineers freedom in making decisions. This situation causes differences between the results of two different laboratories performing a theoretically same, completely regular test, but using two different methods. Because of this, a product may fail in one laboratory and pass in the other. The aim of the research is to develop a simulation in which different test conditions can be analyzed under validated conditions, and how the different test definitions can be interpreted and how they affect the measurement uncertainty.

II. FUNDAMENTALS OF EMC

The concept of electromagnetic compatibility is defined in IEC 1000-1-1:1992 standard, which summarizes the fundamental definitions and terms. According to this, EMC is: “The ability of an equipment or system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment.” [1] There are two additional definitions in the standard describing essentials of EMC: Electromagnetic environment is “the totality of electromagnetic phenomena existing at a given location” [1] and electromagnetic interference can be “any electromagnetic phenomena which may degrade the performance of a device, equipment or system, or adversely affect living or inert matter” [1].

According to the EMC concept, electrical devices can cause disturbances, which can interfere with other devices or even themselves. These disturbances can occur in several ways. There may be noise from electromagnetic radiation source, noise from the power cord or a communication line, or interference from some other source, such as an electrostatic discharge from a person's hand. These disturbances can have harmful effects, such as if a mobile phone transmits signals to an HDMI cable that distort communication so much that the projector can no longer process it, but it can also have life-threatening consequences if the same phone interferes with the vehicle's electronics. The spread of electronic devices began at the first half of the previous century. More and more commercially available devices have entered the market. Telephones and radios, followed by televisions and computers. This extremely fast increase of equipment number has forced manufacturers to use cheaper and smaller parts which can be manufactured more easily. An important step for EMC was when robustly designed high-immunity electron tubes were continuously replaced by semiconductor-based circuit elements. Their immunity is significantly lower than their predecessor. [2] Furthermore, their size has allowed developers to implement more complex circuits in smaller devices. Over time, researchers have recognized that there is a steady narrowing gap between the decline in immunity caused by new technologies and the increase in emissions caused by the continued spread of electronic devices. This is called the EMC Gap, which is illustrated in the following figure. [3]

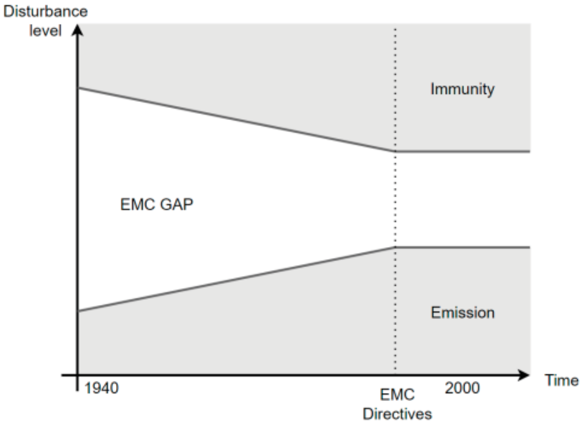

Fig 1. Illustration of EMC Gap

The illustration shows that over time, the general immunity and emission limits of electronic devices have become closer and closer to each other. If these two bands overlap, the devices cannot be operated without disturbance in each other's electromagnetic environment. To avoid this, the IEEE (The Institute of Electrical Engineers) introduced strict regulations in 1982, which came into force in Europe in 1996. [2]

III. EMC STANDARDS

Standards describing electromagnetic compatibility testing are regulated by the CISPR (Comité International Spécial des Perturbations Radioélectriques - International Special Committee on Radio Interference) within the IEC (International Electrotechnical Commission). There are a number of standards for EMC that are product-specific.

There are several product fields defined by different EMC standards, like commercial, automotive, medical, military equipment and others. The basic standard for commercial measurements is CISPR 16. Several other standards that apply to different subtypes of commercial equipment often refer to the specifications set out in CISPR 16. These include for example CISPR 14 for household appliances and hand tools, CISPR 11 for industrial, scientific and medical equipment or CISPR 32 for electromagnetic compatibility testing of multimedia equipment. Similarly, CISPR 25 is the basic standard for automotive measurements, but in many cases, it also refers back to CISPR 16. So we can see that standards also overlap between the different device types, thus creating a very complex system of regulations for the EMC specifications of the devices.

In addition to the tested equipment, the EMC can be further classified according to the measurement of emissions, the electromagnetic interference emitted by a particular device, and the immunity, the ability of a device to perform without degradation in the presence of an electromagnetic disturbance. [1]

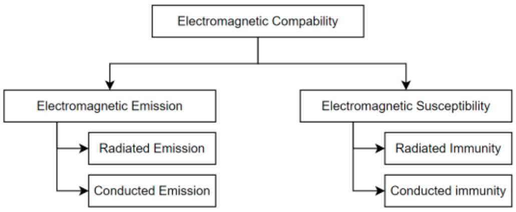

Fig 2. EMC classes

In the simulation created in the framework of the research the aim is to measure emission, so this article will cover that topic. The emission measurements include wide range of measurement methods. The two common test methods that are in the focus of our research are, the radiated emission tests using antenna and the conducted emission test using artificial network. An artificial network according to the CISPR 25 standard is a "network inserted in the supply lead or signal/load lead of an apparatus to be tested which provides, in a given frequency range, a specified load impedance for the measurement of disturbance voltages and which may isolate the apparatus from the supply or signal sources/loads in that frequency range" [4] In these tests, the radiated electromagnetic interference emitted by the product is measured with an antenna from a defined distance and in case of conducted emission measurement, an artificial network is connected between the device and the power supply or on the signal lead, and the interference signals are measured through it.

The test description usually specifies the level of emission limits to be applied for a given frequency range. This is because different electronic devices have higher electromagnetic susceptibility in certain frequency ranges or may have some form of wireless communication, such as Wi-Fi, Bluetooth, GSM and so on. If the product emits more than this limit, the device may not be placed on the market.

In addition, the standards specify the level of measurement uncertainty accepted for each measurement. This is ± 6dB for antenna measurements and ± 3dB for conducted emission measurements. These values are high compared to the limit values for the frequency ranges. For example, according to CISPR 25, the highest value of the radiated emission limits used in automotive applications is 26dB(μV). [4] In theory, it is possible that the measuring instrument results 26dB(μV) radiated emission, but the real value is close to 32dB(μV). Since decibel denotes the ratio of two values as a logarithmic unit, it is worth converting the result to a linear unit for which equation (1) can be used to make the problem easier to understand.[5]

$$[\mathrm{dB}\,\mu\mathrm{V}] = 20\log_{10}\left(\frac{[\mu\mathrm{V}]}{1\,\mu\mathrm{V}}\right) \tag{1}$$

Rearranging to voltage, keeping in mind, that 1μV equals to 0dBμV:

$$[\mu\mathrm{V}] = 10^{\frac{([\mathrm{dB}\,\mu\mathrm{V}])}{20}} \qquad (2)$$

Using formula (2), 26dB(μV) corresponds to 19.95μV and 32dB(μV) to 39.81μV, which is twice the specified emission limit.

Commercial and automotive standards have developed a different solution to deal with this degree of uncertainty. For automotive measurements, the measured interference signal must not reach the level of uncertainty. So, the measured signal must always be 6 dB below the limit set for the frequency range. In case of the interference still reaches this value, the measurement must be repeated with a lower resolution bandwidth at that frequency. If the value measured by this way is still higher than 6 dB below the limit, the product has failed. [4] Similarly, in commercial devices, the difference between the limit and acceptable level of the interference signal can be determined, but here it is determined on a statistical basis which limit value belongs to a given sample number. Table 1 shows these limits. [6]

Table 1. Commercial measurement limits

Sample size (n)	3	4	5	6
General Margin to the limit (dB)	3.8	2.5	1.5	0.7

As the Table 1. shows, in case of higher number of samples the EMC conformity can be determined using a lower margin.

A very important question is to answer why do standards allow measurements with such high measurement uncertainties in EMC tests? To perform most of electromagnetic compatibility measurements an Absorber Lined Shielded Enclosure (ALSE) or EMC chamber is required. Figure 3 shows the Rejtő Ferenc EMC chamber of the University of Miskolc, Hungary.

Fig 3. EMC chamber

This chamber is a SAC-3 EMC chamber. The SAC is an abbreviation for Semi Anechoic Chamber and means that the inner wall of the enclosure has been partially coated with foam absorbers in addition to the ferrite tiles. The number 3 means that maximum distance of 3 meters can be set between the product and the antenna. Figure 4. shows the inside of the EMC chamber.

The purpose of ferrite tiles and absorbers is to prevent the reflection of electromagnetic interference from the product to ensure measurement of direct radiation only. The difference between the two covers is in the frequency range they are able to absorb. Ferrite tiles are efficient at lower frequencies, up to about 1 GHz, while foam is sized to work properly in the range above, up to 20 GHz. In a SAC chamber only, the internal wall and ceiling are covered with absorbers, on the floor it is not needed (nevertheless in some cases they can be used). [7]

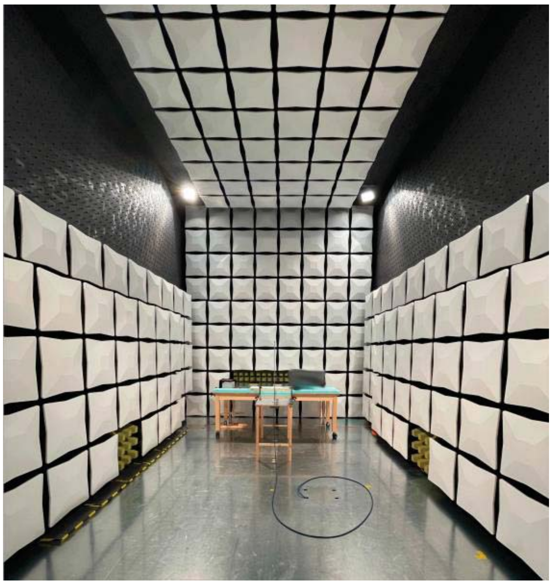

Fig 4 Inside of a SAC-3 EMC chamber.

Building an ALSE is a highly skilled task and even if the right specialists are available, environmental factors cannot be neglected. Proper grounding and power supply is one of the most important tasks. To ensure this, a suitable location should be defined, where the surrounding buildings do not cause disruption to the power grid. One of the other problems is the perfect fitting of the chambers shielding panels. Fitting inaccuracies can degrade the shielding causing noise from outside which can affect the measurement. The goal is to keep the background noise within the ALSE as low as possible.

Quality of such a building depends on many parameters, so there is no enclosure that can be used for comparative measurements to validate newly built chambers. There is no etalon. The CISPR 25 standard contains two validation procedures to determine if valid measurements can be conducted in an ALSE from 150kHz to 1GHz. These are the reference measurement method and the modelled long wire method.

The two methods are very similar. In the case of a reference measurement, comparative measurements shall be made at the ALSE being tested and at an alternative test site that meets the validation requirements of the standards. In case of the modeled long wire antenna, the measurements are performed only in the ALSE to be validated, the reference data are provided by a simulation described in the standard. The latter method is suitable for the implementation of the research project, as a validated simulation environment can be created based on the CISPR 25 standard. In this simulation different test procedure interpretations and the measurement uncertainties caused by them can be validated. This method is described in the next section of this paper.

IV. ALSE LONG WIRE METHOD

In the process, a long wire antenna is used with parameters specified in the standard. The antenna emits a known interference signal in the EMC chamber in the 150kHz-1GHz frequency range and the amplitude of the interference signal is measured. The advantage of this method is the comparison possibility of the values measured during the validation procedure and to the simulation results described in the standard. In this way, a comparative measurement with ideal parameters can be performed. Validation of a chamber is successful if 90% of the measured values are within ± 6dB of the specified data. [4]

The Long Wire antenna consists of two L-shaped sheet profiles to which a female N-connector is attached. Between them is a 500mm, 4mm diameter copper rod that serves as an antenna. The measurement also requires a 50Ω termination resistor, a 10dB attenuator and an RF cable on which the generated interference signal can be connected to the antenna. The standard highly recommends placing of ferrites with a minimum impedance of 50Ω at 25MHz and 100Ω at 100MHz in every 20cm along the entire length of the RF cable. In addition, recommended type of antenna for different frequency ranges is also determined, which is summarized in Table 2. [4]

Table 2. Antenna types for different frequency ranges

Frequency	Antenna type
0.15MHz to 30MHz	1m vertical monopole antenna
30MHz to 300MHz	biconical antenna
200MHz to 1000MHz	log-periodic antenna

The first step in the validation process is to assemble the test setup by placing the long wire antenna in the center of the edge of the measurement table used in automotive chambers. The measuring antenna shall be positioned so that the reference point of the antenna is 1000mm ±10mm above the reference ground plane of the measuring table and 1000mm ±10mm from the vertical plane of the long wire antenna. The output of the signal generator is set to deliver 1Vrms (120dB(μV)) This can be seen on figure 5. [4]

The test included two measurements. First is a preliminary measurement, when the measurable signal output of the signal generator is determined. In this measurement the interference signal is connected directly to the input of the spectrum analyzer inside the chamber. The test layout must be unchanged during the test. [4]

In the second measurement, the signal generator is connected to the Long Wire antenna via the 10dB attenuator, the other end of which is terminated. Here the input of the spectrum analyzer is connected to the measuring antenna. [4]

Performing the two measurements, two data sets are created, on the basis of which the equivalent field strength at the given frequencies can be calculated using formula (3).

$$\mathrm{E_{eq}} = 120\mathrm{dB}(\mu\mathrm{V}) + (\mathrm{M_A} - \mathrm{M_0}) + \mathrm{k_{AF}} \qquad (3)$$

where M_0 is the directly measured value, M_A is the value measured at the antenna output, k_{AF} is the antenna factor and E_{eq} is the equivalent field strength. [4]

The formula shows that if we would have an ideal function generator, this calculation would be not necessary, as its output is a stable 120dB(μV) at all frequencies. But in the reality, the error should be compensated by this method.

Fig 5. Validation of Rejtő Ferenc EMC chamber

V. THE SIMULATION

The ANSYS Electronics desktop was used to perform a finite element simulation for the validation procedure. In this part of the research, the simulation focuses primarily on the frequency range of measurements between 30MHz and 200MHz further ranges will be developed later. The ground plane of the measuring table and the long wire antenna were drawn in the 3-dimensional area. The floor and a 10cm wide grounding strap were also drawn according to the CISPR25 standard. The excitation of 120dB (μV) was determined on one N-connector of the long wire antenna and the 50Ω termination on the other, thus the test setup was implemented. This is shown in Figure 6.

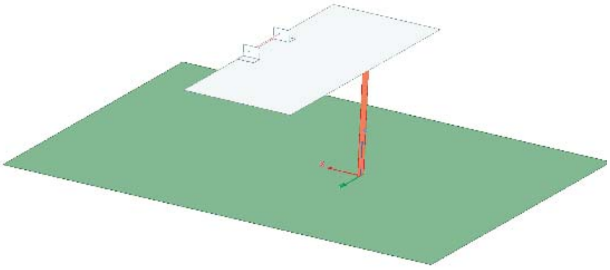

Fig 6. 3D model of the simulation

The excitation is determined at one end of the long wire antenna. The ANSYS software assigns power values to the wave ports, so 120dB (μV) must be converted to dBm (short form of dB (mW)). If the system has constant impedance, a conversion can be done between the two units of measurement. First, the voltage level represented in dB (μV) can be calculated by formula 2.

$$10^{\frac{(120\mathrm{dB}\,\mu\mathrm{V})}{20}} = 1\mathrm{V} \tag{4}$$

To calculate the power of the excitation, formula 5 is used.

$$\mathrm{P} = \frac{V^2}{R} = \frac{1V^2}{50\Omega} = 20mW \tag{5}$$

To understand the calculation, it has to be mentioned that 0dBm corresponds to 1mW. Calculating the dBm level means calculating dBm compared to 0dBm. The dBm of a 120dB (μV) excitation in a 50Ω system is calculated by formula 6. [5]

$$10\log_{10}\left(\frac{20\mathrm{mW}}{1\mathrm{mW}}\right) = 13.01dBm \tag{6}$$

The description of the validation procedure also includes a 10dB attenuator that connects directly to the long wire antenna. This is used to correct signal mismatch. This means that if not all parts of the system are exactly 50Ω, reflection occurs, which can interfere with the incoming signal increasing measurement uncertainty. By using an attenuator, the reflected signals can be attenuated also. Because the simulated excitation is connected directly to the antenna, its power value was lowered by 10dBm and 50Ω renormalization was set on both end of the antenna, which means that the effects of reflection are negligible. The Figure 7 shows the excitation model.

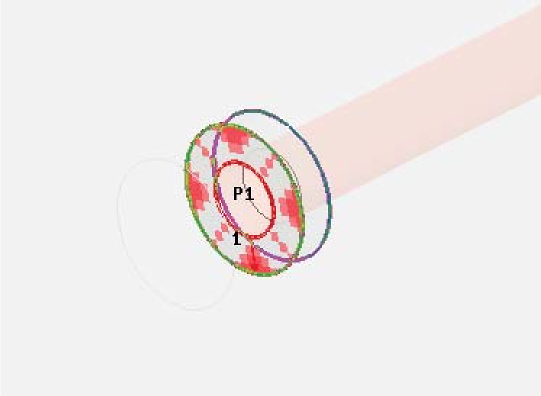

Fig 7 The 3D model of the excitation

The frequency range set in the simulation was determined according to the standard. The figures in the standard shows the model for the 30MHz - 200MHz frequency range, so it was known which parts of the system is represented to implement the simulation.

The standard contains equivalent field strength values in 1MHz increments in this frequency range; so the simulation is set accordingly.

The results of the analysis are shown on the Figure 8.

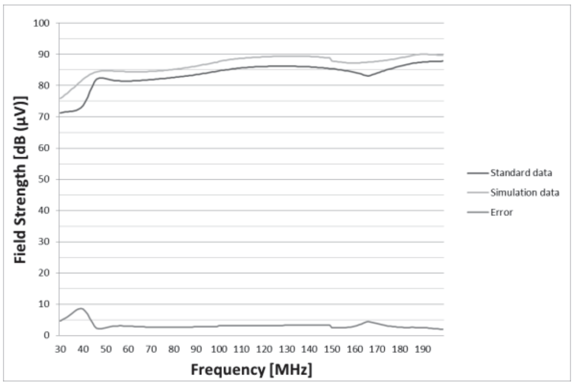

Fig 8 Comparison of data from the CISPR25 Standard and the Simulation results

It can be seen that the values in the standard and the simulation result do not overlap. The highest difference is seen at low frequencies, where a larger slope is included by standard, the error over 50MHz is mostly an offset error.

There can be several reasons for the discrepancies. Firstly, the height of the grounding plane, should be between 90 cm and 100 cm according to the CISPR25 standard, but this is not detailed in the description of the ALSE long wire method. Another source of error can be the size of the floor. ALSE describes the floor as a grounded metal surface, so it can affect the field strength in the test area. Although the floor is shown in the figures given in the standard, its size is not specified.

Despite the errors, the correlation between the two data sets is 0.81, which means a high connection, so the experiment proved that the desired result can be achieved by further refining the simulation model. This was calculated using the following formula.

$$C(X,Y) = \frac{\sum(x-\bar{x})(y-\bar{y})}{\sqrt{\sum(x-\bar{x})^2(y-\bar{y})^2}} \tag{5}$$

VI. SUMMARY

The research included a simulation development to examine how different deviations from the test layout specified in the standard affect the measurement uncertainty in a validated virtual environment.

These deviations may include for example a hole in the ground plane of the test bench. When compiling the ALSE Long Wire method, the standard recommends fastening the radiating antenna to the test table with plastic clamps or screws. In theory, screws reduce the contact resistance, which has a beneficial effect on the measurement uncertainty, but the effect of the hole - left in the ground plane of the table - to the subsequent measurements is not known. Another example is placing the artificial network on the test table. The standard specifies where to place it in relation to other equipment and how to ground its enclosure through its feet. However, these artificial networks can vary in size and thus in weight, depending on performance, which can affect the degree of contact resistance created through the feet. The other issue with these devices is the orientation, as the orientation of placing on the test table is not specified in the standard. These networks have a shielded enclosure, but in the GHz range the efficiency of this shielding can be lower and reflections on its surface might happen. This can cause unexpected measurement results and can increase the measurement uncertainty.

The research is continued by development of the simulation environment in order to have minimal deviation from the values reported in the standard. Then, using that virtual environment, development and execution of two phases systematic test procedures can be performed. In the first phase virtual conditions, in the second real conditions will be used.

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