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Probabilistic Approach for Deriving Immunity Levels Against Electromagnetic Disturbances

Bernd Jaekel and Darren Carpenter

Abstract: Knowledge of electromagnetic environments existing at locations where equipment is intended to be operated is an essential prerequisite for achievement of electromagnetic compatibility. The necessity of such a knowledge results from the fact that suitable immunity requirements can be concluded from corresponding data regarding the electromagnetic environment. This information should include the type as well as the characteristics of electromagnetic phenomena occurring at those locations.

Appropriate information can be obtained by various approaches, such as site surveys or technical assessments accompanied by evaluations of technical literature. It is obvious that the description of a general electromagnetic environment should consider a multitude of phenomena having a broad spectrum of parameters. However, in many cases such a general description is not helpful because it would imply that immunity against all such phenomena has to be taken into consideration.

A more practical approach consists in introducing a classification scheme which gives a correlation between locations and the electromagnetic phenomena existing there. This concept forms the basis of the EMC publication IEC 61000-2-5. Because of continuous change of existing technologies and introduction of new ones, electromagnetic environments in a certain respect change fundamentally. This is very obvious in case of all the recently introduced radio and communication services with the generation of electromagnetic fields in the frequency range above 1 GHz. Hence the need arises to monitor continuously the electromagnetic environment and to adapt its description. Such adaptation is currently being done by a working group of IEC TC 77. The results of its work is object of the next edition of IEC 61000-2-5. The present status as well as expected changes are discussed in this paper.

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B. Jaekel is with Siemens AG, Sector Industry, EMC-Center, Erlangen, Germany (e-mail: bernd.jaekel@siemens.com). D. Carpenter is with BT Design, Adastral Park, Ipswich, Suffolk, UK (e-mail: darren.carpenter@bt.com).

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1 Introduction

THE achievement of adequate immunity of electrical or electronic equipment against electromagnetic disturbances is a basic provision when ensuring electromagnetic compatibility of equipment, systems or installations. The immunity characteristics are described by specified immunity levels as well as by means of performance criteria which indicate the behaviour of equipment under test when being exposed to electromagnetic disturbances. The selection of immunity levels and performance criteria should take into account the situation at the intended location of operation as well as the characteristics of the equipment. Insofar the knowledge of the electromagnetic environment at a location is a crucial factor when determining appropriate immunity levels. Obtaining such knowledge, whereas the resultant data need to have certain evidence, represents a very challenging task, directly deducible from the definition of electromagnetic environment as totality of electromagnetic phenomena existing at a given location, where in general this totality is time-dependent and its description might need a statistical approach.

This topic has been identified to be very important within the series of basic EMC publications and immunity standards, and hence a series of relevant documents dealing with the topic of electromagnetic environments and their description has been published. The classification of these documents and their relation to the EMC publications of the series IEC 61000-X-Y are described in [1].

2 General Approach Of Achieving EMC

Both aspects of EMC represent the main challenges and tasks of an EMC-engineer: to limit emissions of devices in order not to produce a harsh electromagnetic environment and to specify immunity of devices so that they can function satisfactorily. This is a challenge insofar as there should be identified a compatibility level that is not exceeded by the emissions and that is lower than the specified immunity levels. This is done taking into account also economic constraints as setting emission limits and immunity levels causes a burden to devices which should be shared in a reasonable way.

Hence as a device is expected to have certain immunity against electromagnetic disturbances it is necessary to identify and specify appropriate immunity levels. This shall be based on the characteristics of the electromagnetic environment in which an item of equipment is intended to be operated.

3 Electromagnetic Environment

An electromagnetic environment in which electrical and electronic systems are expected to operate without any harmful interference can be very complex. There are basically three categories of environmental phenomena which contain and describe all disturbances:

- low-frequency phenomena (conducted and radiated);
- high-frequency phenomena (conducted and radiated);
- electrostatic discharge (ESD).

As the electromagnetic environment is the totality of phenomena existing at a location of interest, its description can be very substantial and voluminous. However, in practice it is neither possible nor absolutely necessary to describe an electromagnetic environment completely and hence any description is limited to a certain extent. The first step of such a specification could be to select those phenomena that can create electromagnetic disturbances (for example, from the list given in Table 1).

Several documents have been published in the series IEC 61000-2-Y which deal with a description related to the topic of electromagnetic environment from a fundamental point of view [2]. Most of these documents cover only limited aspects of electromagnetic environment. This refers to both the category of considered electromagnetic phenomena and to a special class of location (e.g. public medium voltage power supply networks). Solely the document IEC 61000-2-5 [3] gives an overview of the whole spectrum of electromagnetic phenomena (except for the HEMP high-altitude electromagnetic pulse) in various types of location classes. Insofar it represents the general starting point when determining immunity levels related to electromagnetic environment.

The individual documents of the IEC 61000-2-Y series were worked on and published during different periods depending on the actual interest of the responsible working group and the availability of relevant data. Hence there could be slight differences in data of the respective documents. A plausible reason for such variances is the fact that electromagnetic environment is not a static and constant value; it constantly changes because of different tendencies such as the introduction of new technologies or the increasing spread and distribution of equipment which could act as an interference source. One task when working on IEC 61000-2-5 consists of harmonized consideration of the data in the individual documents of that series.

The situation of permanent change causes a need to track continuously the characteristics of an electromagnetic environment and to adapt its description according

Table 1. Phenomena causing electromagnetic disturbances

•	Conducted low-frequency phenomena
•	harmonics, interharmonics
•	signalling voltages
•	voltage fluctuations
•	voltage dips and interruptions
•	voltage unbalance
•	power-frequency variations
•	induced low-frequency voltages
•	DC in AC networks
•	broadband signals
•	common mode voltages
•	Radiated low-frequency phenomena
•	magnetic fields
•	electric fields
•	Conducted high-frequency phenomena
•	induced CW voltages or currents
•	broad band signals (PLC, power drive systems, etc.)
•	unidirectional transients
•	oscillatory transients
•	Radiated high-frequency phenomena
•	magnetic fields
•	electric fields
•	electromagnetic fields
•	continuous waves
•	transients
•	modulations (FM, AM, FSK, CDMA, CMA, TDMA, etc.)
•	Electrostatic discharge phenomena (ESD)

to the actual status of, for example, new technologies being operated. Such an adaptation is currently being discussed and assessed, and the relevant work is being done by a working group (WG 13) of the IEC technical committee TC 77. Besides the adaptation with respect to changes in types and amplitudes of electromagnetic phenomena, there is a discussion on how to classify relevant types of electromagnetic environments.

4 Structure And Contents of IEC 61000-2-5

The document IEC 61000-2-5 contains a nearly complete description of the electromagnetic environment with respect to all the relevant electromagnetic phenomena. It introduces the basic term compatibility level for assessment of the phenomenon specific level of an electromagnetic disturbance. That term stands for a specified maximum electromagnetic disturbance level expected to be impressed on a device, equipment or system operated in particular conditions. Conditions mean among others the type of the actual electromagnetic environment at a location under consideration, for example in the rural area, the industrial area or the medical area. Furthermore the term maximum should not be understood literally because an absolute maximum value cannot be stated in a reasonable way under special circumstances there is always a scenario imaginable in which such a maximum value is exceeded. Hence the compatibility level actually describes such a level which in praxis is exceeded with a very low probability only.

In order to provide a data basis for deduction of immunity levels by applying IEC 61000-2-5, there is a need to consider all relevant electromagnetic phenomena and to state the relevant compatibility levels. This need is reflected in the following main chapters of that document:

- Guide for understanding the concept of the document;
- Low- and high frequency phenomena (conducted as well as radiated phenomena);
- Electrostatic discharge;
- Classification scheme for types of electromagnetic environments;
- Principles to conclude on immunity levels;
- Compatibility levels for various types of electromagnetic environments.

5 Compatibility Levels for Electro-Magnetic Disturbances

A description of an electromagnetic environment should not be limited to a list of phenomena only that occur at the location of interest. It should rather combine the relevant phenomena with their characteristics, such as amplitudes, frequency ranges, rise times, modulation, etc.

IEC 61000-2-5 has always followed the concept of describing amplitudes of electromagnetic disturbances by means of compatibility levels. They are defined as specified maximum electromagnetic disturbance levels expected to be impressed on a device, equipment or system operated in particular conditions. However, it should be mentioned that in practice a compatibility level is not an absolute maximum level as there are often situations thinkable where this level is exceeded. But this is expected to take place with a small probability only. Hence a compatibility level takes into account the probabilistic nature of most electromagnetic disturbances.

6 Probabilistic Approach Of Determining Compatibility Levels

Most of those electromagnetic phenomena do not occur constantly in time and space. They rather appear randomly or in a statistical manner and in both cases showing a wide range of parameters such as in amplitudes, frequencies, rise times, etc.

The probabilistic nature of many disturbances needs to consider two aspects: a disturbance can be probabilistic in its occurrence on one hand or it can be probabilistic with respect to its parameters on the other. The phenomenon of electrostatic discharge (ESD) for example, does not occur constantly and regularly, rather it depends on factors such as how frequently human beings touch devices, what shoes they wear when they approach the device, etc. The amplitude of the discharge depends also on many factors as the humidity of the air, the speed of how the discharging surfaces approach each other, etc.

There are probabilistic and statistical data available for some of the electromagnetic phenomena that can be used to conclude on appropriate compatibility levels. Beside those pure technical aspects there are also economical aspects to be considered when concluding on compatibility levels and subsequently on immunity levels.

For some of the phenomena such probabilistic and statistical data are nearly impossible to achieve and to evaluate as there are so many factors involved. In such cases a heuristic approach can be applied that follows some simple assumptions as it is demonstrated in the following in case of the phenomenon of high-frequency electromagnetic fields.

Such fields are produced by both fixed and portable radio transmitters. As portable transmitters (e.g. walkie-talkies, mobile phones, etc.) are widespread and can be taken very near to devices, their electromagnetic fields represent a severe interference source that require appropriate immunity levels to be achieved. The determination of compatibility levels taking into account probabilistic and economical aspects in a heuristic way can be based on the following relation:

$$p(E \geq E_L) = \frac{E_o(E_i - E_L)}{E_L(E_i - E_o)} \tag{1}$$

with $p(E \geq E_L)$ being the probability that at locations of interest the electromagnetic field strength E exceeds the a specified level E_L, E_i is an upper limit to the radiated field level determined through human exposure limits, E_o is a lower limit to the radiated field level determined by the minimum, threshold value of radio reception.

Application of (1) leads for example to a probability of 0.1% that in the high frequency range (e.g. 80 - 1000 MHz) and in areas where radio transmitters are in operation a field strength level of 10 V/m is exceeded.

7 Derivation of immunity levels

Electromagnetic environments at locations of interest are a fact on their own and in most cases they can not be related one-to-one to the descriptions of phenomena as they are given, for example, in the EMC basic standards of the IEC 61000-4 series. The detailed manifestation of electromagnetic phenomena depends on many parameters and conditions, such as the characteristics of equipment operating at a location of interest or the installation practice applied, and in most cases those phenomena do not show the same characteristics as described in the corresponding EMC basic standard.

However, when immunity requirements which reflect the stress due to an electromagnetic environment should be specified, it is in most cases not a very practical approach to develop immunity tests which actually consider the particular manifestation of electromagnetic phenomena at a location of interest. Such specific immunity tests would consider a single condition at a single point in time only.

On the other hand, there are already a lot of standardized immunity tests available, such as those of the IEC 61000-4 series. In many cases those basic standards can be taken advantage of when their immunity tests reflect electromagnetic phenomena at a location of interest to a certain extent. This means that such standardized tests can be used, either directly or partly modified, to derive adequate immunity requirements. Hence in many cases there can be followed an approach where the stress due to an electromagnetic environment is reflected by the application of appropriate standardized immunity standards. However, the assessment to which extent a standardized immunity test reflects an electromagnetic phenomenon in real environments represents a crucial task and needs careful evaluation.

As various types of location classes are characterized by electromagnetic phenomena, different with respect to their occurrence as well as with respect to their disturbance degrees, different immunity requirements result for equipment intended to be used at those types of locations, and hence different sets of EMC basic standards may apply, partly also different in the applied immunity test levels. However, special attention should be paid to situations when equipment is intended to be used at locations which are assigned to different location classes.

The compatibility level as derived in the previous sub-clause can be directly used for specifying immunity levels for equipment. As the level of 10 V/m is exceeded with a relatively low probability only this level can be considered as reasonable immunity level and represents a practical and economical approach as the required immunity is not too high and the remaining number of potential interference cases is reasonably low. Under circumstances where a higher amount of potential interference cases is acceptable or where there are relatively fewer occurrences of field transmitters a lower immunity level (e.g. 3 V/m) can be used.

8 Classification Of Electromagnetic Environments

The description of a general electromagnetic environment, i.e. generally applicable to all types of locations, has to consider a big variety of electromagnetic phenomena with a broad range of various parameters, such as frequency, amplitudes, rise time, etc. Such a general description is not very helpful in practice, as it would imply that immunity has to be achieved against all such electromagnetic phenomena.

A more practical approach consists in introducing a classification scheme for electromagnetic environments, namely in such a way that typical location classes are described by electromagnetic phenomena more or less specific and relevant for those areas. The current edition of IEC 61000-2-5 lists eight types of location classes which are given in Table 2 [1]. The respective compatibility levels together with a short list of attributes connected to the location class are given in the referenced annexes (A.1 to A.8) of that document [3].

However, the working group is currently discussing a needed modification of the compatibility levels published in 1995 and a consideration of new compatibility levels, especially for the radiated phenomena in the frequency range above 1 GHz.

Moreover, the whole concept of classification, i.e. the types of location classes, may need to be revised. It is getting more and more obvious that different types of location classes do not generally have different electromagnetic phenomena with different compatibility levels, making it difficult to strictly allocate phenomena and compatibility levels to a certain location class.

Furthermore, location classes have become less and less specific; they often show a kind of overlap of characteristics of different location classes. So the location class railway environment could, for example, consist of the location classes commercial location (e.g., inside a station building), heavy industrial location (e.g., in a sub-station) and light industrial location (e.g., in signal rooms). Hence descriptions of three generic location classes should be considered, and then outlined by means of some attributes or characteristics. These attributes may include a listing of typical potential interference sources, a consideration of the location boundaries and the relevant system ports for this location class.

A further step would be to introduce some more specific sub-classes to a location class and to describe their electromagnetic environments with respect to the general ones applicable to the superior location class. This would allow the application of a general description when, for example, concluding on immunity levels and to take into account some particularities for a special sub-class of locations. As three generic types of locations classes the following could be identified: Industrial, Residential and Office/Public.

9 Conclusion

For the determination of immunity levels for equipment the characteristics of the electromagnetic environment have to be taken into account in which equipment is intended to be operated. However, the remaining challenging task is to derive appropriate immunity levels out of all the data that describe the electromagnetic environment. This paper showed a heuristic approach applied to the phenomenon of radiated electromagnetic fields. Application of this approach to other phenomena could help to justify immunity levels related to other phenomena or even to modify them.

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References

[1] B. W. Jaekel, "Description and classification of electromagnetic environments revision of iec 61000-2-5," in *IEEE International Symposium on Electromagnetic Compatibility*, Detroit, Michigan, USA, 2008, ISBN 978-1-4244-1699-8.

[2] IEC 61000-1-1, *Electromagnetic compatibility (EMC) - Part 1: General - Section 1: Application and interpretation of fundamental definitions and terms*, Geneva, Switzerland, 1992.

[3] IEC 61000-2-5, *Electromagnetic compatibility (EMC) - Part 2: Environment - Section 5: Classification of electromagnetic environments*, Geneva, Switzerland, 1995.