Simulation Objects to be used as Unintentional Radiators

Benjamin Menssen, Felix Burghardt and Heyno Garbe
Institute of Electrical Engineering and Measurement Technology
Leibniz Universität Hannover
Email: menssen@ieee.org

***Abstract*—Electronic devices may act as unintentional radiators. Hence, the prediction of their breakdown behaviour is not possible by design. Instead, time-consuming measurements are necessary to determine their radiation patterns. Stochastic approaches help to do approximations, but need to be validated e.g. by numerical field simulations. In this paper, simulation objects are created by the use of the software *FEKO* which can be classified as unintentional radiators. This classification is newly defined in this paper. It refers to the characteristics of the maximum directivity in dependence on the electrical size.**

***Keywords*—unintentional radiator, radiation pattern, maximum directivity, electrical size, simulation**

I. INTRODUCTION

Electronic systems can be interfered by electromagnetic radiation. Hence, it is necessary to determine their vulnerable components and functions. However, the vulnerability of the systems is strongly dependent on the angle of incidence of the interfering signal. But, electronic devices must be regarded as unintentional radiators which means that the angle of incidence corresponding to the maximum interference is not known by design.

For that reason, the radiation pattern of the device needs to be determined to predict its breakdown behaviour. However, the determination of a radiation pattern by means of simulations or measurements is very time-consuming and therefore unreasonably expensive. Stochastic approaches are a feature to estimate whether or not a device will be interfered by electromagnetic radiation.

In earlier works, stochastic approaches have been derived to describe the probability distribution of the directivity of unintentional radiators. The directivity was defined to be chi squared distributed [1] with two degrees of freedom which is a special case, commonly known as the exponential distribution. Further works deal with the approximation of the maximum directivity based on the electrical size ka of the device [2] where k is the wave number and a is the radius of the minimum sphere enclosing the radiator. Later, Wilson et al. [3] presented an analytical simulation model based on a far field approximation combined with the Monte Carlo Method. This model was used by Menssen et. al to derive further stochastic approaches [4], [5].

Nevertheless, the stochastic approaches need to be validated by simulations and measurements. But, unintentional radiators are not defined in standards so that an ideal object cannot be built for the validations. In this paper, an approach for the classification of unintentional radiators is discussed in section II to define criteria to evaluate the radiation patterns of the created radiators. In section III, CAD models (CAD: computer-aided design) of the simulation objects will be described which will be analysed by electromagnetic field simulations based on the Method of Moments (MoM). For the simulations, the software *FEKO* of the company EM Software & Solution [6] is used. This software offers an improved algorithm for electrically large objects called Multilevel Fast Multipole Method (MLFMM) which reduces the time and memory costs of the simulations [7]. Section IV discusses the realization of an equally sampled far field pattern and finally, in section V, the simulation results will be evaluated.

II. CHARACTERIZATION OF UNINTENTIONAL RADIATORS

In the EMC community, only a general understanding of electrical devices acting as unintentional radiators exist. But, a common definition about unintentional radiators cannot be found in the open literature. However, the Federal Communications Commission (FCC) does an approach of definitions in a report about telecommunications [8]. It reports about incidental or unintentional radiators to be devices which produce radio frequency energy whereat they are not intentionally designed to emit this energy. However, this is only a rough definition which is not useful to characterize a device to be an unintentional radiator. Especially, for simulations and measurements of devices, a technical definition will be useful for the further development of stochastic approaches.

A measure for the characterization of a radiation patterns is the directivity [9]:

$$D(\phi_0,\theta_0)=\frac{P(\phi_0,\theta_0)}{\frac{1}{4\pi}\int\limits_0^{2\pi}\int\limits_0^{\pi}P(\phi,\theta)\sin(\theta)d\theta d\phi}\quad . \tag{1}$$

J. Hansen derived an approach to describe arbitrary radiation patterns by the use of stochastic assumptions about spherical wave expansion [1]. The co- and cross-polarized terms of the directivity of these arbitrary, unintentional radiation patterns could be derived to be chi squared distributed with two degrees of freedom. Using this definition, Koepke et al. derived an expression to estimate the maximum of the polarized terms of the directivity [2] which is defined in Eq. 2.

$$< D_{co,max} > \approx \begin{cases} 1,55 & ,ka \leq 1 \\ \frac{1}{2}\left[0,577 + ln(N_s) + \dfrac{1}{2N_s}\right] & ,ka > 1 \end{cases} \tag{2}$$

N_s describes the number of independent samples over a full sphere in the far field and is defined by Eq. 3.

$$N_s = 4((ka)^2 + 2ka) \tag{3}$$

Herein, the term ka describes the electrical size of the device and is defined as the product of the wave number k and the radius a of the minimum sphere enclosing the radiator. In Fig. 1, the maximum directivity in dependence of the electrical size ka is illustrated.

The expression of the electrical size ka is a term without units which sets the size of the object into relation with the wavelength of the emission. Therefore, a normalization of the frequency dependence of objects can be achieved for a better comparison of different devices.

This progression of the maximum directivity in dependence of the electrical size ka is a technical definition for the characterization of unintentional radiators and will be used for the further simulations. Therefore, the simulated objects will be defined as unintentional radiators, if the maximum of the calculated directivity patterns follows Eq. 2.

III. SIMULATION MODEL

After having defined the criteria for the characterization of unintentional radiators, simulations will be performed using numerical field simulation software based on the Method of Moments (MoM).

In order to achieve a simple model which can be easily modified regarding its form and dimensions, a metallic enclosure was constructed with the software integrated CAD tool. The enclosure can be seen in Fig. 2. The enclosure is built as an ideal thin rectangular surface of perfect electric conductor (PEC) with the dimensions $(m \, \mathrm{x} \, m \, \mathrm{x} \, \sqrt{2}\, m)$. These dimensions correspond to a radius $a = m$ of the minimum sphere enclosing the radiator. The advantage of this definition of the dimensions is that the radius can be easily adjusted by only changing the parameter m. In this paper, the radius $a = 0.4\,\mathrm{m}$ will be exemplarily evaluated and is illustrated in Fig. 2, whereat further radii were investigated.

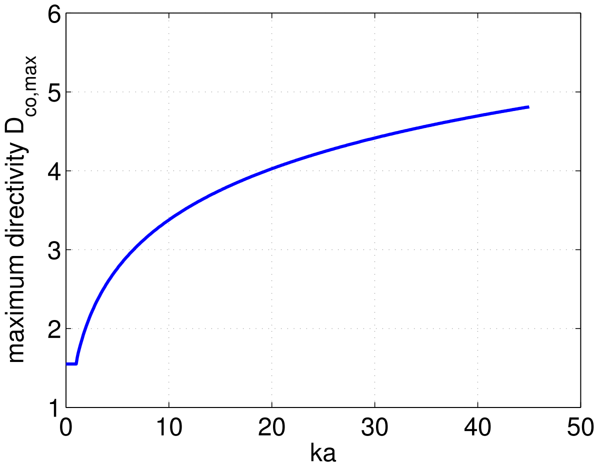

Fig. 1: Maximum of the polarized term of the directivity

Fig. 2: Metallic enclosures for an exemplary radius of $a = 0.4\,\mathrm{m}$

Moreover, the enclosure has six circular holes on each side of the rectangular surface. These holes are placed randomly on each side and they are chosen to have different diameters between $50\,\mathrm{mm}$ and $100\,\mathrm{mm}$. The idea of choosing random positions and varying sizes of the holes should provide a randomness of radiation pattern because of an unintentional scattering due to the varying resonances and the aperture coupling [9].

The excitation of the radiation is produced by the simplest available source, a Hertzian Dipole, which is placed at the center inside the enclosure. The dipole is excited by a frequency sweep which is changed for the different radii so that the sweep corresponds to an electrical size $ka \leq 45$ with a constant step width of $\Delta ka = 0.2$.

IV. FAR FIELD SAMPLING

For the simulations of the presented metallic models, the sampling of the far field needs to be regarded more detailed. Following the definition of the directivity from Eq. 1, the power radiated into one direction (ϕ_0, θ_0) needs to be divided by the mean value of the radiated power into all directions. Therefore, there is a need for paying attention to the sampling of the far field.

Commercial software as *Feko* usually simply meshes the far field by setting an angular resolution for the azimuth ϕ and the elevation θ (see Fig. 3 left). This leads to the fact that the distance between the sampling points gets smaller with a higher elevation θ. The extremest constellation therefore happens at the elevations of $\theta = 0\,°$ and $\theta = 180\,°$ where the

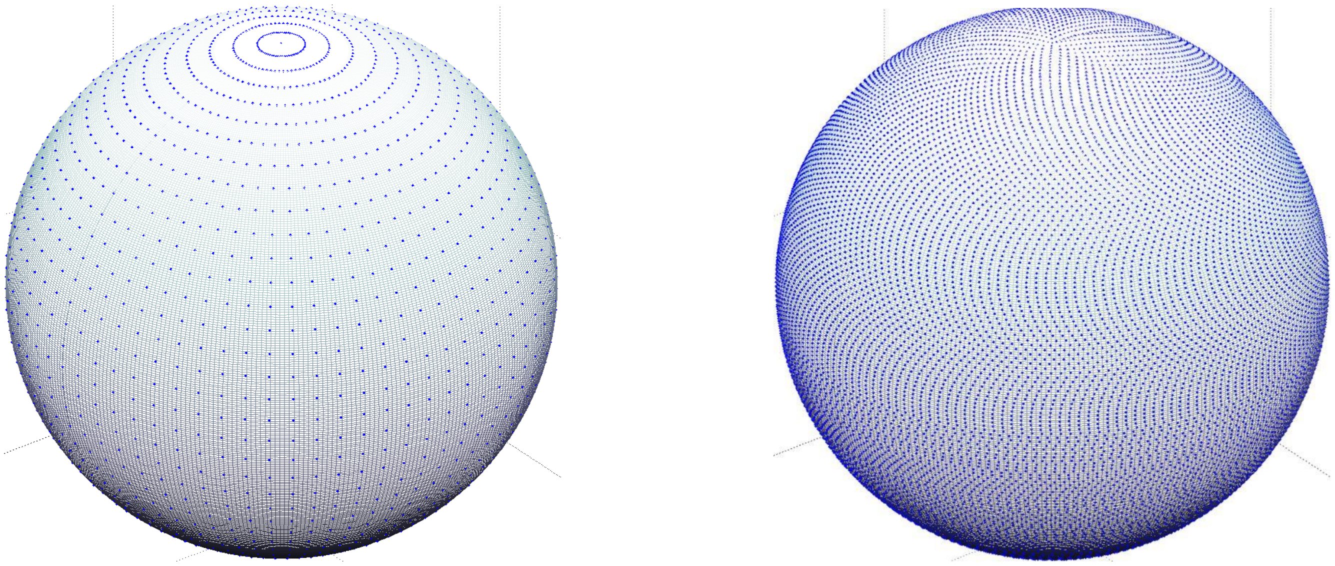

Fig. 3: Far field sampling with a standard distribution (left) and a manually produced *quasi-equally* spaced distribution (right)

same point is sampled as many times as the sampling number for the azimuth ϕ is chosen. Imagining that the maximum or minimum of the radiation pattern of the unintentional radiator would point into one of these directions, the calculation of the directivity will be erroneous because the mean value of the radiated power would be incorrect.

For that reason, it is important to have the far field sampled equally around the model. But, as mentioned before, commercial software does not offer the feature to set the far field equally distributed. Therefore, it is necessary to produce the sampling manually by producing single rings of the far field sampling for each elevation angle θ where the number of samples for the azimuthal angle ϕ is adjusted to receive a *quasi-equally* distributed far field pattern (see Fig. 3 right).

V. EVALUATION OF THE SIMULATIONS

After having introduced the simulation model and having prepared the far field sampling, the simulations can be executed and evaluated. As described in section III, the size of the model can be easily varied by changing the radius a of the object. Furthermore, the simulations can be modified by changing the orientation of the Hertzian Dipole within the enclosure. The result of one single orientation of the dipole is depicted in Fig. 4. It can be seen that the θ- and the ϕ-component of the maximum directivity show an accordance with the theoretical shape of the maximum directivity so that the object can be regarded as an unintentional radiator in a first approximation.

However, a high deviation of the progression with strong peaks can be observed and the values of the ϕ-component seem to be higher as the theoretical values for the whole sweep. This behaviour may be explained by the fact that one single configuration of the enclosure and dipole orientation is evaluated. This distinct configuration obviously leads to specific radiation patterns for the frequency sweep which is influenced by the resonances of the cavity, the size of the wholes and the constellation of the wholes.

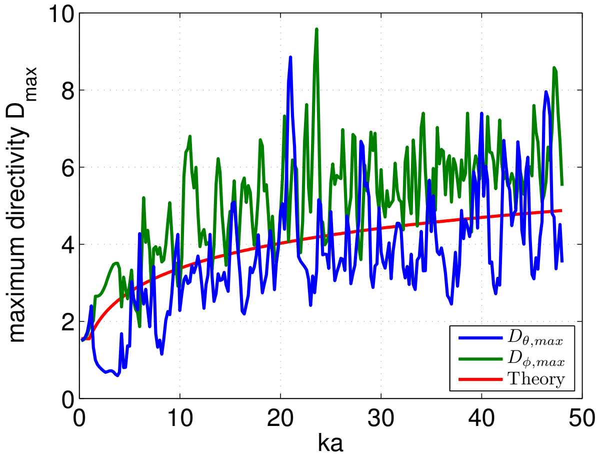

Fig. 4: Maximum directivity for one single orientation of the Hertzian Dipole

A further influence on the peaks of the radiation patterns may be produced by the Hertzian Dipole because it already radiates a distinct pattern that may affect the unintentional radiation. Hence, the simulation is extended by varying the orientation of the dipole in 45 °-steps for all combinations of the azimuth and elevation angles ϕ and θ while considering the symmetry of the radiation pattern. This leads to a number of 13 simulation models for one radius a of the object. The results of these simulations are averaged to achieve a smoothing of the shape of the maximum directivity in the sense of a Monte Carlo Simulation. The results of the averaged shapes can be seen in Fig. 5. It is observable that, compared to Fig. 4, the deviation could be reduced due to the averaging so that a better accordance to the theoretical values is achieved.

Following the theory by Hansen [1], the two polarized components of the directivity are independent from each other, but should be described by the same probability distribution.

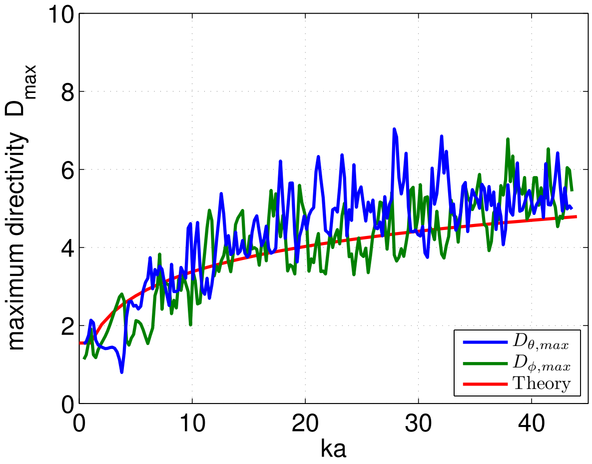

Fig. 5: Average of the maximum directivity of the θ- and ϕ-component for 13 orientations of the Hertzian Dipole

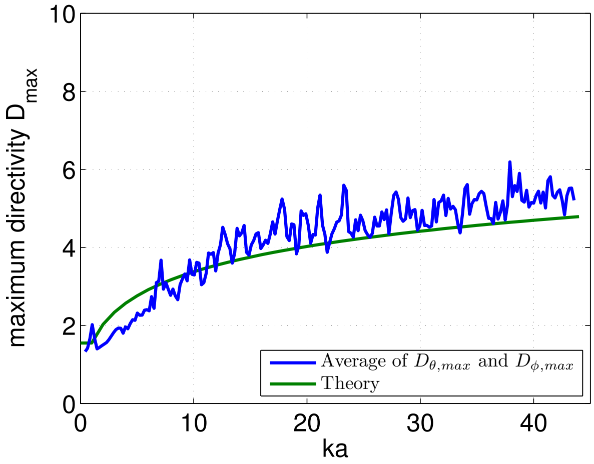

Fig. 6: Average of the θ- and ϕ-components of the maximum directivity

For that reason, the results of the simulations can be further smoothed by averaging the results of both polarized components. This can be seen in Fig. 6. It is obvious that the results in Fig. 6 show an even better accordance to the theoretical curve of the maximum directivity than the results in Fig. 5.

Summarizing, the derived objects can be identified as unintentional radiators. However, the quality of the simulations can be increased, if various models with different orientations of the Hertzian Dipole are created and the results are averaged.

VI. CONCLUSION

Stochastic approaches for the description of unintentional receivers help to reduce measurement costs for the characterization of the breakdown behaviour respectively the emission limits of electronic devices. However, the verification of these approaches requires numerical simulations or measurements.

But, until now unintentional radiators are not defined in terms of technical measures. Only a general understanding about electrical devices which accidentally radiate RF energy although they are not designed to do so. Therefore, this paper starts by defining a criterion to characterize an object as an unintentional radiator, if the maximum directivity of the radiation follows the progression which was defined in earlier works by Koepke et al. [2].

Based on this criterion, a simulation model was created which consists of a rectangular metallic enclosure with randomly placed wholes in the surface and a Hertzian Dipole at the center of the enclosure. The results of the simulation show a good accordance with the defined criterion so that the objects can be identified as unintentional radiators. For an improvement, the orientation of the dipole was varied to produce various independent results. These independent results can be averaged in the sense of a Monte Carlo Simulation which produces a smoothing.

This simulation object can be used in further research to produce radiation patterns that fulfil the properties of unintentional radiators. Hence, simulations can be performed to validate new stochastic approaches for unintentional radiators which help do estimations about the breakdown behaviour respectively the emission limits of electronic devices.

ACKNOWLEDGEMENT

The results presented here were produced by the use of the software *FEKO* from the company EM Software & Solutions and were (partially) carried out on the cluster system at the Leibniz Universität Hannover, Germany.

REFERENCES

[1] J. Hansen, *Spherical Near-field Antenna Measurements*. London: Peter Peregrinus Ltd., 1988.

[2] G. Koepke, D. Hill, and J. Ladbury, “Directivity of the test device in EMC measurements,” in *Electromagnetic Compatibility, 2000. IEEE International Symposium on*, vol. 2, 2000, pp. 535 – 539.

[3] P. Wilson, D. Hill, and C. Holloway, “On determining the maximum emissions from electrically large sources,” *Electromagnetic Compatibility, IEEE Transactions on*, vol. 44, no. 1, pp. 79 –86, feb 2002.

[4] B. Menssen, E. Genender, A. Kreth, and H. Garbe, “Investigation of the frequency correlation between radiation patterns of unintentional emitters for large frequency bands,” in *Electromagnetic Compatibility (EMC EUROPE), 2012 International Symposium on*, sept. 2012, pp. 1 – 5.

[5] B. Menssen, E. Genender, T. Peikert, and H. Garbe, “Derivation of a stochastic distribution for the radiated energy of unintentional emitters for large frequency bands,” in *Electromagnetic Compatibility (EMC EUROPE), 2012 International Symposium on*, sept. 2013, pp. 34 – 39.

[6] EM Software & Systems, http://www.feko.info.

[7] J. van Tonder and U. Jakobus, “Fast multipole solution of metallic and dielectric scattering problems in feko,” in *Wireless Communications and Applied Computational Electromagnetics, 2005. IEEE/ACES International Conference on*, 2005, pp. 511–514.

[8] F. C. Commission *et al.*, “Title 47 - Telecommunication: Chapter I - FEDERAL COMMUNICATIONS COMMISSION: Subchapter A - GENERAL: Part 15 - RADIO FREQUENCY DEVICES,” Tech. Rep., October 2009.

[9] C. A. Balanis, *Antenna Theory - Analysis and Design*. John Wiley & Sons Inc., 2005.