On the Near-Field to Far-Field Transformation for the Stochastic Assessment of Unintentional Electromagnetic Radiators

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Abstract

Numerical simulations are a common procedure to characterize electromagnetic radiators. For the derivation of stochastic approaches to describe unintentional radiators, these simulations are useful. Nevertheless, the stochastic assessment comes with some important requirements. This paper presents the necessity of a uniformly distributed sampling of the far-field radiation pattern. It is shown that commercial software does not provide this kind of desired sampling. Hence, it is made use of the near-field to far-field transformation to produce a stochastically correct sampling of the far-field.

1. Introduction

Electronic devices are commonly characterized as *unintentional* electromagnetic radiators. In general, this means that the device does emit electromagnetic energy although it is not designed to do so. By implication, this means that the device is also able to receive electromagnetic energy with a possibility to be interfered or even destructed. Hence, these devices need to be investigated to determine their susceptibility to electromagnetic radiation. To avoid expensive measurements for each device, stochastic approaches were derived to predict the maximum directivity of unintentional radiators [1]. For the further development of stochastic approaches, simulations of far-field radiation patterns can be performed by the use of commercial software. This paper discusses the produced far-field radiation pattern of these commercial tools. It points out that the commercially used sampling on the sphere in the far-field is inacceptable for a stochastic assessment of electromagnetic radiators. Therefore, in this paper, the near-field to far-field transformation is applied to the simulations to produce a randomly generated, uniformly distributed sampling of the radiation pattern.

2. Unintentional Radiators

In the EMC society, the term *Unintentional Radiator* is well known. It describes electronic devices which produce electromagnetic emission whereat they are not designed to do so [2]. Nevertheless, this is only a general agreement. A more technical definition of unintentional radiators is derived in [3]. It starts with a stochastic approach which describes arbitrary radiation patterns based on the spherical wave expansion [4]. This approach was used in [1] to derive an analytical expression for the polarized term of the maximum directivity. The theoretical function can be seen as red line in Fig. 4. It shows the mean value of the maximum directivity as a function of the electrical size *ka*. The electrical size *ka* is a unitless term which sets the size of the object in relation to the frequency of the radiation. Hence, a normalization of results can be achieved, which aims to make the results of different devices comparable. This expression of the maximum directivity was used in [3] to create simulation objects which can be considered as unintentional radiators. Hence, it was defined that an object can be regarded as an unintentional radiator, if its maximum directivity follows the progression from Fig. 4.

3. Far-Field Sampling

In the previous section, a technical definition for unintentional radiators was presented. This definition was derived in [3]. It was used to derive simulation objects that are suitable to be regarded as unintentional radiators. These objects were simulated by the use of commercial software. Commercial software, e.g. CST Microwave Studio [5] or FEKO [6], does not provide the possibility to calculate far field radiation patterns with a uniformly distributed sampling. In fact, the far field monitors are created by a linear sampling of the angles θ and ϕ. Due to this procedure, the far field sampling points are not separated uniformly (see Fig. 1). The density of the sampling points is increasing towards the poles of the sphere. This kind of sampling will lead to a distorted statistic of the directivity. Hence, in [3], the sampling points were created manually by creating many far field monitors which consisted of single rings with a varying number of points. This procedure delivers a quasi-equally distributed sampling, but it is very time-consuming and is not easily accessible for changes.

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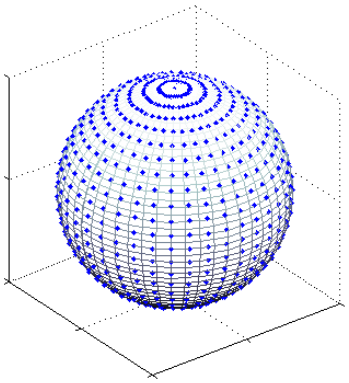

Fig. 1: Linearly spaced sampling on a sphere

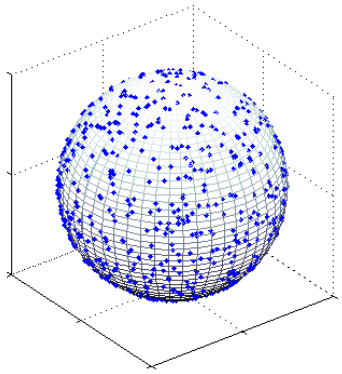

Fig. 2: Uniformly distributed and randomly generated sampling on a sphere

For the stochastic assessment of unintentional radiators, a uniformly distributed sampling on the sphere in the far field is desired. An example of a randomly created sampling is depicted in Fig. 2. Using this kind of sampling will lead to correct stochastic measures of the directivity for any radiator. The proof of this hypothesis will be presented in Section 5.

Nevertheless, commercial software does not support an option to define the sampling points of the far field monitor manually by e.g. importing a file with the desired sampling points. Therefore, this paper will make use of the near-field to far-field transformation. Using this method, the field values can be calculated in the near-field by the use of the software *CST Microwave Studio*. It provides the possibility to export the near-field values at user defined positions. Afterwards, these values can be transformed into the far-field by the use of a math tool (e.g. Matlab [7]). In this way, it is possible to calculate the far-field radiation pattern at uniformly distributed, randomly generated sampling points.

4. Near-Field to Far-Field Transformation

The near-field to far-field transformation is a method from basics of the theoretical electrical engineering and can be derived from the Maxwell's equations. A description can be found in [8] and will be summed up in the following. As described in the previous section, the values of the electric and magnetic field $\vec{E}(\vec{\rho})$ and $\vec{H}(\vec{\rho})$ will be determined in the near-field. For this procedure, the sampling points with its position vectors $\vec{\rho}$ will be defined on a closed surface enclosing the radiator (e.g. a cubic surface). The first step of the transformation is to calculate equivalent electric and magnetic surface current densities $\vec{J}_E(\vec{\rho})$ and $\vec{J}_M(\vec{\rho})$ from the near-field values.

$$\vec{J}_E(\vec{\rho}) = \vec{n}(\vec{\rho}) \times \vec{H}(\vec{\rho}) \tag{1}$$

$$\vec{J}_M(\vec{\rho}) = -\vec{n}(\vec{\rho}) \times \vec{E}(\vec{\rho}) \tag{2}$$

The vector $\vec{n}(\vec{\rho})$ describes the surface normal vector in for each sampling point. From the surface current densities $\vec{J}_E(\vec{\rho})$ and $\vec{J}_M(\vec{\rho})$, the electric and magnetic vector potentials $\vec{A}(\vec{r})$ and $\vec{F}(\vec{r})$ can be calculated in an arbitrary position $\vec{r}$ in the far-field by integrating over the surface S.

$$\vec{A}(\vec{r}) = \frac{\mu_0}{4\pi} \cdot \frac{e^{-jk_0 \cdot r}}{r} \cdot \iint_S \vec{J}_E(\vec{\rho}) \cdot e^{jk_0 \cdot \vec{u}_r \cdot \vec{\rho}} dS \tag{3}$$

$$\vec{F}(\vec{r}) = \frac{\varepsilon_0}{4\pi} \cdot \frac{e^{-jk_0 \cdot r}}{r} \cdot \iint_S \vec{J}_M(\vec{\rho}) \cdot e^{jk_0 \cdot \vec{u}_r \cdot \vec{\rho}} dS \tag{4}$$

Here, μ_0 is the permeability and ε_0 is the permittivity of the free space. Furthermore, k_0 is the wave number, r is the norm of the position vector $\vec{r}$ in the far field, and $\vec{u}_r$ is the unit vector of the position in the far field. From the Maxwell's equations, the electric field $\vec{E}(\vec{r})$ can be calculated. By further assuming free-space radiation and far-field conditions, the electric field can be simplified to the following equations:

$$\vec{E}(\vec{r}) = \frac{1}{j\omega\mu_0\varepsilon_0} \cdot \mathrm{rot}\,\mathrm{rot}\vec{A}(\vec{r}) - \frac{1}{\varepsilon_0} \cdot \mathrm{rot}\vec{F}(\vec{r}) \tag{5}$$

$$\vec{E}(\vec{r}) = \frac{j}{\omega\mu_0\varepsilon_0} \cdot \vec{k} \times (\vec{k} \times \vec{A}(\vec{r})) + \frac{j}{\varepsilon_0} \cdot \vec{k} \times \vec{F}(\vec{r}) \tag{6}$$

$$\vec{E}(\vec{r}) = \frac{j}{4\pi\omega\varepsilon_0} \cdot \frac{e^{-jk_0 \cdot r}}{r} \cdot \iint_S \vec{k} \times (\vec{k} \times \vec{J}_E(\vec{\rho})) \cdot e^{jk_0 \cdot \vec{u}_r \cdot \vec{\rho}} dS + \frac{j}{4\pi} \cdot \frac{e^{-jk_0 \cdot r}}{r} \cdot \iint_S \vec{k} \times \vec{J}_M(\vec{\rho}) \cdot e^{jk_0 \cdot \vec{u}_r \cdot \vec{\rho}} dS \tag{7}$$

$$\vec{E}(\vec{r}) = \frac{j}{2\lambda_0} \cdot \frac{e^{-jk_0 \cdot r}}{r} \cdot \iint_S \left\{ \vec{u}_r \times \left[(Z_0 \cdot \vec{u}_r \times \vec{J}_E(\vec{\rho})) + \vec{J}_M(\vec{\rho}) \right] \cdot e^{jk_0 \cdot \vec{u}_r \cdot \vec{\rho}} \right\} dS \quad , \tag{8}$$

where Z_0 describes the free-space wave impedance and λ_0 is the wave length of the corresponding to the frequency of interest.

5. Simulation Results

After having described the analytical expressions of the near-field to far-field transformation, the different approaches of the sampling of the far-field pattern can be investigated. As discussed in Section 3, from a stochastic point of view, the linear sampling of commercial software should lead to erroneous results of the directivity. To prove this hypothesis, an *intentional* radiator is investigated. Hence, the far-field radiation pattern of a simple dipole is simulated with three different approaches. First of all, the far-field pattern is simulated directly with the commercial software *CST* which uses the linear sampling (see Fig. 1). Secondly, the near-field values are exported and the near-field to far-field transformation is performed whereat also the linear sampling of the far-field is used for comparison purposes. Finally, the near-field to far-field transformation is performed again, but with a randomly generated, uniformly distributed sampling of the far-field (see Fig. 2). Additionally, the investigation is performed for two different dipoles, horizontally and vertically oriented. The different orientations of the dipole have differently polarized radiation patterns so that the influence of the sampling schemes should be evident.

Typical measures in stochastics are the mean value and the standard deviation of a distribution. From a stochastic point of view, the mean value and the standard deviation should be independent of the orientation of the dipole. Furthermore, for the directivity, it is known per definition that the mean value should be unity. Hence, these measures will be investigated for the different approaches and orientations of the dipole. Additionally, the maximum directivity of a Hertzian Dipole is known to be $D_0 = 1.5$. Here, the dipole was chosen to be short which means that the maximum directivity should be close 1.5. Therefore, the maximum directivity will also be investigated to check whether the approach calculates the correct pattern.

Table 1 sums up the results of the different approaches both for the horizontal and the vertical orientation of the dipole. It shows that for each approach, the maximum directivity is approximately equal to 1.5 which proves that each approach does the correct calculation of the radiation pattern and delivers the correct maximum.

More importantly, the results of the mean value and the standard deviation are varying for the different approaches and provide evidence for the necessity of the near-field to far-field transformation. The mean of the directivity from the CST simulations shows the effect of the different orientation of the dipole. On the one hand, if the dipole is horizontally oriented, the mean is greater than unity and on the other hand, if the dipole is vertically oriented, the mean is remarkably smaller than unity. In comparison, the mean from the randomly sampled far-field is very close to unity. The same effect can be seen for the standard deviation of the directivity. The results from the CST simulation vary for the different orientations of the dipole, whereas the standard deviation from the random sampling provides approximately the same value for both orientations.

These results prove that for the stochastic investigation of electromagnetic radiators, a uniformly distributed sampling on the surface in the far-field is necessary. The near-field to far-field transformation provides the possibility to create this kind of sampling in a random manner.

Table 1: Characteristic values of the directivity of a simple dipole (horizontal and vertical orientation) – Comparison of the far-field calculated by CST and by the use of the near-field to far-field transformation

	CST		Calculated (linear sampling)		Calculated (random sampling)	
Directivity	horizontal	vertical	horizontal	vertical	horizontal	vertical
mean	1.1311	0.7268	1.1309	0.7258	1.0004	0.9971
standard deviation	0.4214	0.5368	0.4186	0.5340	0.4468	0.4449
maximum	1.5040	1.5041	1.4971	1.4915	1.4970	1.4915

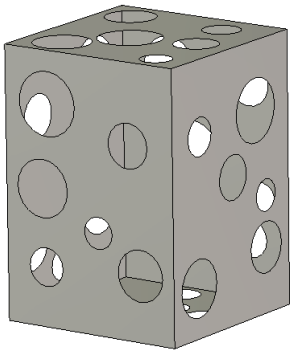

Fig. 3: Metallic simulation object enclosing a radiating dipole

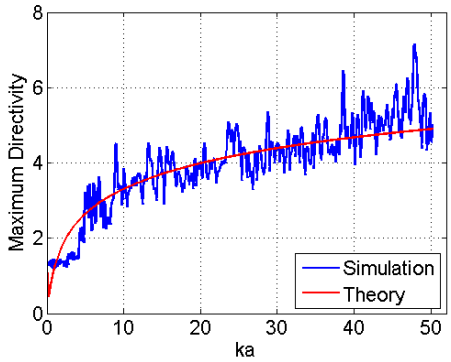

Fig. 4: Maximum directivity of the simulation object

With the knowledge of the necessity of the random sampling, the near-field to far-field transformation is applied to a simulation object which, following [3], should be an unintentional radiator. The simulation object can be seen in Fig. 3. It consists of a metallic rectangular sheet with arbitrary apertures which encloses a radiating dipole. In Fig. 4, the result of the maximum directivity of this simulation object can be seen. It shows that the maximum directivity follows the progression of the theoretical function. Hence, the object can be regarded as an unintentional radiator. Accordingly, the near-field to far-field transformation can be used to assess the stochastic behavior of unintentional radiators.

6. Conclusion

In this paper, the simulation of far-field radiation patterns is discussed. It was pointed out that commercial software usually provides a linearly spaced sampling of the angles θ and ϕ on the surface of a sphere. In general, this is suitable for determining antenna parameters. For a stochastic assessment in the field of EMC, it could be shown that this kind of sampling leads to erroneous measures of the mean value and the standard deviation of the directivity. This effect was exemplarily investigated for a short dipole with two different orientations. However, for the assessment of unintentional radiators, these stochastic measures need to be independent on the orientation and the physical dimensions of the radiator. For this reason, a randomly generated uniform sampling of the far-field radiation pattern is desired.

To perform stochastically correct assessments, the near-field to far-field transformation was used in this paper to generate the desired uniformly distributed sampling of the radiation pattern. It was proved that, due to this procedure, the mean value of the directivity equals unity and the standard deviation is approximately constant, independently of the orientation of the radiator.

Finally, the near-field to far-field transformation was applied to a simulation object which was shown to be an unintentional radiator in earlier works [3]. The evaluation of the maximum directivity of this simulation object, produced by the near-field to far-field transformation, validated the unintentional characteristic of the object. Hence, the method is verified for the further assessment of stochastic investigations of unintentional radiators.

7. References

1. 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.
2. Federal Communications Commission, “Title 47 - Telecommunication: Chapter I - FEDERAL COMMUNICATIONS COMMISSION: Subchapter A - GENERAL: Part 15 - RADIO FREQUENCY DEVICES,” Tech. Rep., October 2009
3. B. Menssen, F. Burghardt, and H. Garbe, „Simulation Objects to be used as Unintentional Radiators“, 2014 Asia-Pacific International Symposium on Electromagnetic Compatibility, May 12 - 16, 2014, Tokyo, Japan
4. J. Hansen, Spherical Near-field Antenna Measurements. London: Peter Peregrinus Ltd., 1988.
5. MATLAB version 8.2.0.701 (R2013b). Natick, Massachusetts: The MathWorks Inc., http://www.mathworks.com
6. CST Computer Simulation Technology AG, *CST Microwave Studio 2013,* http://www.cst.com
7. EM Software & Systems-S.A. (Pty) Ltd, *FEKO 6.3*, http://www.feko.info
8. C. A. Balanis, Antenna Theory - Analysis and Design. John Wiley & Sons Inc., 2005