One Way to Provision of HF E-field Sensor Isotropy

Bittera M.* - Harťanský R. - Kováč K.*****

The aim of the paper is to ensure the isotropy of sensor of electric component of electromagnetic field. Sensor consists of three independent dipoles. The mathematical model of radiation pattern of each dipole is presented, as well as the methodology of final sensor characteristic and final pattern estimation. The results are verified by measurements on three resistive dipoles and compared to each other.

Introduction

Three main problems are present in a lot of practical application of elm field measurement: sensitivity, frequency independence and radiation independent measuring equipment. These problems are especially important during the EMC tests, when for measurement of electric component of electromagnetic field it is necessary to obtain intensity E at known frequency and unknown polarization of measured wave.

To point out the main problems, several demand on EMC testing equipment will be presented:

Frequency range: 80 MHz - 1 GHz, intensity E from 1 to 10 V/m with step 0.1 V/m, non-directional pattern, etc. Fulfilment of first two demands is presented in [1, 2 and 3]. This paper deals only with the third one: fulfilment of isotropicity of sensor. Basic knowledge on antenna theory refers that does not exist a non-directional scatter and not even a non-directional sensor of elm field constructed from only one component (dipole, monopole). So the mayor attention will be paid to design of dipole system, which will present the facilities of non-directionality.

Method

To construct a dipole system from several antennas is a very difficult task, so the problem must be simplified. Let us suppose that sensor to measure the electric component of elm field will consist from electrically small dipoles. Radiation pattern of electrically small dipole in E plane is octal and in H plane is circular. So in space this can be described as special case of anuloid - axoid. In case when axis of dipole is identical with z-axis, the radiation pattern can be described with equation of an axoid:

$$\left(x^2 + y^2 + z^2\right)^2 = 4a^2\left(x^2 - y^2\right) \qquad (1)$$

When considering such a radiation pattern, where maximal value is equal to 1 and parameter a (radius of circle driven round the axoid axis) equal to a = 0.5, then:

$$\left(x^2 + y^2 + z^2\right)^2 = x^2 - y^2 \qquad (2)$$

Since at detection of suitable configuration, the spherical coordinate system is used defined by r,Δ,ϕ is necessary to convert the equation (2), which is presented for Cartesian coordinate system, into spherical using the set of equations:

$$\begin{aligned} x &= r\cos\Delta\cos\phi \\ y &= r\cos\Delta\sin\phi \\ z &= r\sin\Delta \end{aligned} \qquad (3)$$

After substitution of (3) into (2), the axoid in spherical coordinate system is defined as:

$$r = \cos\Delta\sqrt{\frac{\cos^2\phi - \sin^2\phi}{\zeta}} \qquad (4)$$

* Department of Measurement, FEI STU Bratislava, e-mail: bittera@elf.stuba.sk
** Department of Mechatronic Systems, FM TnU Trenčín, e-mail: rene@mail.bcn.sk
*** Department of Measurement, FEI STU Bratislava, e-mail: kkovac@elf.stuba.sk

where parameter ζ is sum conjunction component:

$$\zeta = \cos^4\Delta\cos^4\phi + 2\cos^2\Delta\cos^2\phi\sin^2\Delta + \sin^4\Delta + 2\cos^4\Delta\cos^2\phi\sin^2\phi + 2\cos^2\Delta\sin^2\Delta\sin^2\phi + \cos^4\Delta\sin^4\phi \quad (5)$$

However, equation (4) is still not in final state, since the axoid must be rotated in space. This problem can be solved using another mathematical formula: substitution of Cartesian coordinate system *x,y,z* by spherical *r*,Δ,ϕ like:

$$\begin{aligned} x &= x'\cos\alpha_1 + y'\cos\beta_1 + z'\cos\gamma_1 \\ y &= x'\cos\alpha_2 + y'\cos\beta_2 + z'\cos\gamma_2 \\ z &= x'\cos\alpha_3 + y'\cos\beta_3 + z'\cos\gamma_3 \end{aligned} \quad (6)$$

where *x',y',z'* are the original coordinates and *x,y,z* are the coordinates of already rotated body;

$\alpha_1,\beta_1,\gamma_1$ are angles defined by first positive half-axle *x'* of system *x', y', z'* with positive half-axle of system *x, y, z*;

$\alpha_2,\beta_2,\gamma_2$ are angles defined by second positive half-axle *y'* of system *x', y', z'* with positive half-axle of system *x, y, z*

$\alpha_3,\beta_3,\gamma_3$ are angles defined by third positive half-axle *z'* of system *x', y', z'* with positive half-axle of system *x, y, z*.

Using the transformation formula (3) and (6) in equation (2), the result is an extreme long (non-printable) formula. To be able to solve such a formula, a several simplifications have been made. The rotation of the body is supposed to be of angles Δ_i and ϕ_i for i=1, 2 and 3 (depending on the dipole of interest). This described simplified case is sufficient and for angles from interval $\Delta_i \in \langle 0,\pi\rangle$ and $\phi_i \in \langle 0,2\pi\rangle$ the whole space is covered. Using this transformation, equation set (6) looks like:

$$\begin{aligned} x &= x'\cos\phi_i - y'\sin\phi_i \\ y &= (x'\sin\phi_i + y'\cos\phi_i)\cos\Delta_i + z'\sin\Delta_i \\ z &= (x'\sin\phi_i + y'\cos\phi_i)\sin\Delta_i + z'\cos\Delta_i \end{aligned} \quad (7)$$

So using the transformation formula (3) and (7) in equation (2) leads to:

$$r_i = \sqrt{\xi} \quad (8)$$

where:

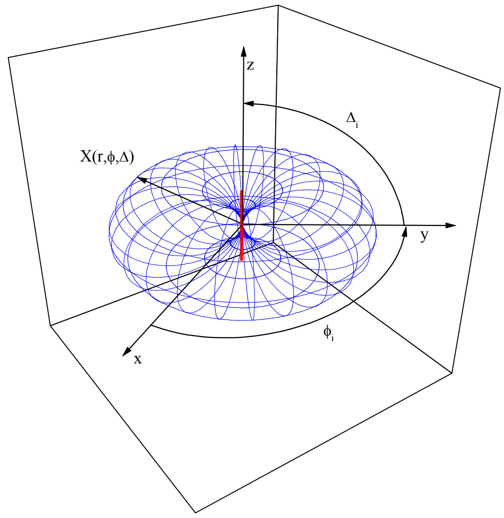


Figure 1. Radiation pattern of a resistive dipole with indicated direction of rotation.

$$\begin{aligned} \xi =\ & \cos^2\phi\cos^2\Delta\cos\phi_i + \\ & \sin^2\phi\cos^2\Delta\cos^2\phi_i\cos^2\Delta_i - \\ & 2\cos\phi\sin\phi\cos^2\Delta\cos\phi_i\sin\phi_i + \\ & 2\cos\phi\sin\phi\cos^2\Delta\cos\phi_i\sin\phi_i\cos^2\Delta_i + \\ & \cos^2\phi\cos^2\Delta\sin^2\phi_i\cos^2\Delta_i + \\ & \sin^2\phi\cos^2\Delta\sin^2\phi_i + \sin^2\Delta\sin^2\Delta_i + \\ & 2\sin\phi\cos\Delta\sin\Delta\cos\phi_i\cos\Delta_i\sin\Delta_i + \\ & 2\cos\phi\cos\Delta\sin\Delta\sin\phi_i\cos\Delta_i\sin\Delta_i \end{aligned} \quad (9)$$

Iteration method of computation of dipole array

Let's suppose that the final result of radiation pattern is given by combining the radiation patterns of separate dipoles. Equation (8) is not in the presented form is not non-advisable. This form is necessary because three radiation patterns have to be added together for any combination of angles $\Delta \in \langle 0,\pi\rangle$ and $\phi \in \langle 0,2\pi\rangle$, respectively in discrete points (Δ,ϕ) homogeneously distributed in whole space. Since parameter *r* in this case is a value of electric field intensity E, the final intensity of electric field can be rewritten as:

$$|E| \approx |r| = \sqrt{|r_1|^2 + |r_2|^2 + |r_3|^2} \quad (10)$$

where |r| is a value of complete measured intensity, which should be constant for any combination of (Δ,ϕ).
To fulfil this, a program in environment of *Mathematica 2.2* has been build. This program plots dependence of r and/or E on angle values of Δ and ϕ.
Since this task is very complicated, let's define the conditions of examination:

$$\Delta_1 = \Delta_2 = \Delta_3 \tag{11}$$

and

$$\begin{aligned} \phi_1 &= 0 \\ \phi_2 &= 2\pi/3 \\ \phi_3 &= 4\pi/3 \end{aligned} \tag{12}$$

When defining the input conditions as described above, only angle $\Delta_1 = \Delta_2 = \Delta_3$ has to be found. Using a consecutive iteration method, when decreasing the interval Δ_i according to the flatness of displayed characteristic. This program has also been assembled in environment of *Mathematica*. The starting value, the final value as well as the basic step of iteration can be chosen. The number of iteration steps depends on required accuracy of Δ_i generally can be said that after each run of program the accuracy is improved by one decimal place. Using this technique, a following result has been obtained:

$$\Delta_1 = \Delta_2 = \Delta_3 = 0{,}95532\,\text{rad} = 54{,}73561°$$

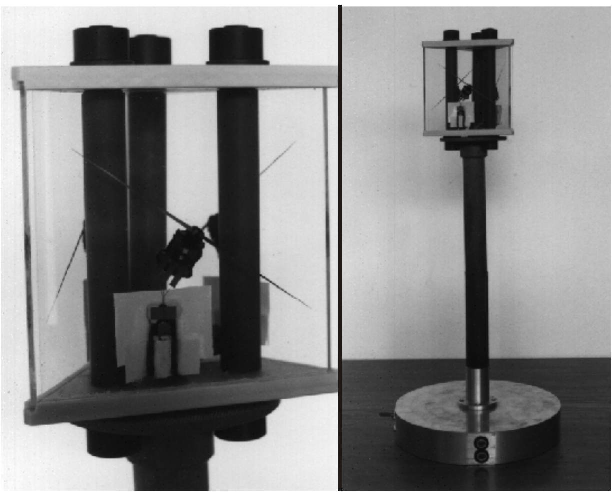
The accuracy, as can be seen, is five decimal places. Using this angle, the final value of $|r|$ will not be unit value (equivalent to value of 0 dB), but will be equal to:

$$|r| = \sqrt{2} \approx 3\,\text{dB}$$

This can be taken into account when processing the results. Nevertheless, the final radiation pattern of measured equipment will be spherical.

Verification and measurement

During the measurements, an electromagnetic field sensor, constructed in Lab EMC FEI STU according to [3], has been used. The decoding facilities, which are already build in, have been constructed as presented in [4]. The measuring probe has been evaluated as described above, for resistive dipole sizes *2h=73.5 mm* and *2d = 1 mm* (see fig. 2).



a) b)
Figure 2. Electromagnetic field sensor (b) and detail of measuring probe (a).

When measuring the radiation patterns, several demands must be fulfilled:

- The direction of incident electromagnetic waves must be known and must be able to change it according to the choice of operator;
- During the whole measurement, the size and direction of the electric field intensity must be constant;
- It is necessary to achieve the homogenous electromagnetic field in the probe neighbourhood;
- Reflection from walls, floor and object near the measuring must be minimized.

According to these demands, the strip line has been chosen as a source of electromagnetic field, where the direction of generated electric field is well known - tangential - electric field acts in direction between strips. Measurement has been made for frequency *f = 100 MHz*, when a homogenous electromagnetic field is achieved in whole radiator (concerning the antenna sizes and wavelength of *100 MHz* frequency). Radiation patterns of the probe could be scanned in any plain, using the suitable position of antenna and a non-conducting rotary stand. The measurement has been done in semianechoical cabin of Laboratory EMC FEI STU; strip line was placed on *80-cm* high wooden table. Reflections of electromagnetic waves were minimized by distribution of ferrite and scummy absorbers. Using a coaxial directive waveguide immediately before of the scatter and a measuring receiver, the size of electric field has been verified and the input voltage held constant.

The radiation pattern is interesting especially in horizontal plane. So it is necessary to know the sizes of electric field intensities detected by single dipole. The direction of incident electromagnetic wave ϕ must be changed from 0° to 360° (keeping the angle theta constant - $\theta = 90°$). The antenna has to be turned so that the electric field excited by strip line will act in horizontal plane. The electromagnetic field sensor must be meanwhile placed on rotary stage.

The graphical dependence of radiation pattern F(dB) on angle ϕ for radiation pattern, when changing the angle ϕ (horizontal plane), can be seen in fig. 3.

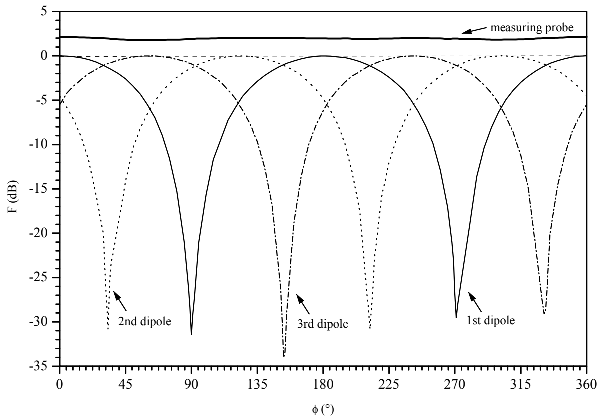


Figure 3. The radiation pattern of single dipoles and the final pattern of measuring probe.

From measured results in horizontal plane (fig. 3) it can be seen that the radiation pattern is relatively flat. The largest difference is +0.2 dB or –0.16 dB, what is comparable value with commercially produced types of measuring sounds. The average value is 1.95 dB instead of 3 dB. This must be taken into account when calibrating the measuring sound.

This measurement confirms the theoretical knowledge as well as the results obtained in previous chapter.

Conclusion

The very simple method of computation of dipole array radiation pattern is presented in the paper. The method expects the pattern to be non-directional. A 3D model substituted the real radiation pattern. Based on mathematical formulas, the distribution of three dipoles in space was obtained in that way that the non-directionality is guaranteed. The mathematical formulas results were verified by practical measurement, which confirmed the correctness of computation. The presented method can be used not only to design the non-directionality of small dipoles, but also to design the monopoles and travelling wave antennas. This means that the presented method has a very wide range of application.

References

[1] Harťanský, R., Kováč, K., Hallon, J.: *Manufacturing Imperfection Effect on Resistive Dipole Characteristics*, 7-th Internat. Scientific Conference Radioelektro-nika '97, pp. 287-290, Bratislava, Slovak Republic, 23 - 24 April 1997.

[2] Harťanský, R., Kováč, K., Smieško, V., Hallon, J., Szolik, I.: *Analysis of the Parallel Detector Influence on the Resistive Dipole Characteristics*, 8th Internat. Scientific Conference Radioelektronika '98, pp. 287 - 290, Brno, Czech Republic 28 - 29 April 1998.

[3] Harťanský, R.*: Senzory elektromagnetického poľa pre použitie v elektromagnetickej kompatibilite*, Bratislava: FEI STU, 1999, 68 p., Doctoral Thesis.

[4] Jancura, A.: *Inteligentný senzor intenzity poľa,* Bratislava : FEI STU, 1996, 37 p., Masters Thesis.

[5] Maga, D., Wagner, J.: *Numerické riešenie elektromagnetických polí v elektrických strojoch*, EE Odborný časopis pre elektrotechniku a energetiku, roč. 5., October 1999, special issue, ELOSYS 99 - Conference Electrical and Power Engineering '99, 19. – 20. 10. 1999, Trenčín, Slovakia, pp. 77 – 79.