Determination of a complex incident field based on electromagnetic measurements

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Abstract In this paper, a low-cost measurement method for the extraction of the polarization of electromagnetic fields for in-the-field measurements using six magnitude measurements only, will be presented. Using this method we are able to model the incident field and to determine more accurately the actual absorption of electromagnetic fields in humans.

Introduction

If one wants to determine the incident field in complex environments both magnitude and polarization of the electromagnetic field have to be determined. The polarization of the incident field can be determined if one knows the relative phases between the orthogonal components of the field. Field measurements around broadcast and telecommunication antennas are usually performed using a spectrum analyzer (SA). The use of a SA for the measurements makes it possible to identify the individual sources of exposure and to make accurate and sensitive measurements. A network analyzer – which is more expensive – for example cannot be used for in-the-field compliance measurements of antennas because the source is mostly not accessible. In [1], [2], three orthogonal magnitudes are measured and from these three magnitudes ($E_i$, $i = 1, 2, 3$) the total field $E_{tot} = \sqrt{E_1^2 + E_2^2 + E_3^2}$ is obtained. But using this method of three orthogonal components, the polarization cannot be obtained. When a SA is used, only power measurements are possible. Therefore we use the algebraic method of [3] for the reconstruction of the relative phases, which offers substantial reduction in computing time over methods that use nonlinear optimization. Those methods are too slow for real-time application because they are based on iterative schemes. By determining 6 magnitudes, the relative phases can be obtained [3].

The incident field can then be used to determine more accurately the actual absorption using a correct model of a human body.

Method

We use an algebraic method [3] for the reconstruction of the relative phases. Suppose $X$ is a real vector in $n$ dimensions. The components of $X$ vary sinusoidally with time. $X$ can be represented by an $n$-dimensional complex vector $Ze^{j\omega t}$ with real part $X$. The method is based on the determination of $n$ components of the magnitude in an orthogonal coordinate system and at least $(2n-3)$ additional amplitude measurements in different directions. Thus in total $3(n-1)$ magnitude measurements are necessary to determine the relative phases. For $n = 3$ this results in 6 magnitude measurements. Let $A_1$, $A_2$, and $A_3$ be the magnitudes of the sinusoidally time-varying components of a real vector $X$ in an orthogonal coordinate system. Let $B_1$, $B_2$, and $B_3$ be the magnitudes of $X$ in 3 additional directions. In [3] it is shown that when $B_1$, $B_2$, and $B_3$ are determined in the directions $(1, 1, 0)$, $(1, 0, 1)$ and $(0, 1, 1)$ a unique reconstruction is obtained. These directions are named the three standard directions. $X = \text{Re}(Ze^{j\omega t})$ describes an ellipse in a plane as function of
time, with the complex vector $Z$ defined as $Z_i = A_i e^{ij\theta}$ (i = 1, 2, 3). This ellipse is called the polarization ellipse. Once the phases of the components of $Z$ are known, the polarization ellipse can be determined. Without harming the generality of the method, $\phi_i$, the phase of the first component of $Z$ can be set to zero. The semi-major axis $V$ and semi-minor axis $R$ of the ellipse will then have components $V_i$ and $R_i$ (i = 1, 2, 3) defined by:

\begin{align}
V_i &= A_i \cos(\phi_i - \zeta) \\
R_i &= A_i \sin(\phi_i - \zeta)
\end{align}

(1)

(2)

with $\zeta = \frac{1}{2} \text{arg}(Z^* Z)$. We define the maximum field $X_{\text{max}} = \sqrt{V_1^2 + V_2^2 + V_3^2}$ (X = E or H) as the magnitude of $V$, the vector of the semi-major axis of the polarization ellipse and the minimum field $X_{\text{min}} = \sqrt{R_1^2 + R_2^2 + R_3^2}$ (X = E or H) as the magnitude of $R$, the vector of the semi-minor axis of the polarization ellipse.

We can determine $A_i$ and $B_i$ (i = 1, 2, 3) by performing power measurements with the SA and using the antenna factor of the measurement probe. When magnitude measurements are performed using the SA, the power at the investigated frequencies is displayed. These powers are converted into field values using the following formula:

$X_{i,\text{meas}}^{\text{max}} = \frac{1}{\sqrt{20}} \cdot 10^{\frac{P_{i,\text{meas}}^{\text{max}} + L}{20}}$ with $X = E$ or H

(3)

Where $X_{i,\text{meas}}^{\text{max}}$ is the magnitude of component i of the electric (X = E) or magnetic (X = H) field, $P_{i,\text{meas}}^{\text{max}}$ is the power measured with the SA in dBm, $AF_X$ is the antenna factor of the measurement probe, and $L$ is the cable loss at the investigated frequency.

The measurements are performed with an HP8561B spectrum analyzer. We have changed the system of [1], [2] for the measurement of six components by using two different holders, which we can rotate each time 120°. One holder is constructed in such a way that the measurement probe has an angle of 54.74° (see Fig. 1) for the measurement of the amplitudes $A_1$, $A_2$, and $A_3$ and the other one such that the measurement probe has an angle of 35.26° (see Fig. 1) for the measurement of the amplitudes $B_1$, $B_2$, and $B_3$ with the rotation axis, respectively. We place the measurement probe in the appropriate holders and determine each time the different amplitudes by rotating the holders around the rotation axis. The measurement system is also able to perform measurements as function of the height above the ground. We use a conical dipole antenna of type PCD 8250 with a frequency range of 80 MHz – 2.5 GHz for the electrical field measurements. For the magnetic-field measurements a split-shield loop antenna with diameter of 5 cm and thickness of 0.5 mm has been designed. The split-shield loop antenna is chosen to reject the contribution of the electric field to the magnetic-field measurement.
Figure 1: Set-up for in-the-field measurement with a spectrum analyzer.

In-the-field application

We perform FM measurements with an HP8561B spectrum analyzer at a rural area in the environment of Tiel, Belgium. We use a frequency span of 21 MHz and a center frequency of 98 MHz. The FM antennas are mounted at a height of 290 m and the measurement is performed in line of sight at 3300 m from the FM antenna. We investigate the signal at 100.1 MHz because this signal delivers the highest total fields.

Fig. 2 shows the variation of $E_{tot}$, $E_{max}$, and $E_{min}$ as function of the height above the ground from 75 cm to 1.75 m. This range corresponds with the height of head and trunk of an average man (the basic restrictions for the limbs are less restrictive than those for the head and trunk [4]). Using the classical methods [1], [2], the maximum FM signal at 100.1 MHz (87 mV/m) is about 320 times below the ICNIRP reference level for general public exposure of 28 V/m [4].

Figure 2: Measured and modelled value of $E_{tot}$, $E_{max}$ and $E_{min}$ of the investigated FM signal as function of the height above the ground.

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Because the measurements are performed in line of sight and in the far field of the FM antenna in a rural area, we can model the incident field (magnitude and polarization) as the sum of incident plane waves on an "average" ground (conductivity $\sigma = 0.005 \, \text{S/m}$ and relative permittivity $\varepsilon_r = 13$). By fitting the model to the measurements using a Nelder-Mead simplex minimization method we obtain the amplitudes and angles of incidence of the plane waves. As model for the incident field we use a combination of two plane waves (TE and TM) on an "average" ground. Fig. 2 compares the results of the fit of the simple plane-wave model and the measurements for $E_{\text{tot}}, E_{\text{max}}$, and $E_{\text{min}}$. This figure shows that theory and measurement correspond reasonably well.

Using the fit of the incident plane-wave model we obtain the angle of incidence and the magnitude of the different incident plane waves. By selecting an appropriate phantom model and using this incident plane-wave excitation model as incident field in an electromagnetic simulation tool, we are able to determine the whole-body absorption and compare this absorption to the limits.

Conclusions

We presented a low-cost measurement method for the extraction of the polarization of electromagnetic fields of antennas for in-the-field measurements using six magnitude measurements only. We are able to determine real-time the amplitudes and polarization of the electromagnetic field at a measurement site. Using the method described in this paper and thus by determining the polarization of the incident field we are able to determine more accurately the actual absorption for in-the-field measurements and compare the absorption with the basic restrictions instead of only comparing the field values with the reference levels.

References


