In Situ Antenna Far Field Estimation Based on Equivalent Sources

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***Abstract*—This paper deals with a near-field to far-field transformation, based on source identification, which allows to predict the radiation of antennas in their operating environment. It is focused on an experimental set-up which carries out the near-field measurements of UHF antennas above the ground. The predicted far-field is compared to the one calculated with a commercial electromagnetic software.**

Keywords—near-field to far-field transformation; source identification; in situ characterization

I. Introduction

In several applications, the operating environment of antennas modifies their radiating properties. This is the case, for example, for on-body communicating sensors, for embedded antennas interacting with their physical support, for HF antennas coupled to the ground, etc. Suitable techniques have to be developed to obtain a reliable knowledge of the far-field characteristics taking the surroundings into account. The near-field to far-field transformation (NF/FF transformation) is one of the techniques used to characterize antennas. The traditional NF/FF transformation uses wave mode expansions [1]. But for almost 25 years, a different approach, based on the equivalence principle has been developed [2]. This method involves equivalent sources (electric and/or magnetic currents) to derive the radiation pattern of the antenna. In the literature, most cases describe free-space configurations [3]. Only in few ones, an image theory is applied to estimate the image equivalent currents due to the ground [4]. But this approach does not allow taking into account some specific wave modes as the surface or leaky waves, for example.

The aim of the study, exposed in this paper, is to perform a NF/FF transformation which predicts all the contributions of the electric field radiated by an antenna, located in the vicinity of an actual ground, which properties are assumed to be known. In Section II, a brief description of the method is given. In Section III, the experimental set-up, used to validate the approach, is described. Theoretical and experimental results, obtained with UHF antennas, are compared. Finally, a conclusion and perspectives are drawn.

II. Near-Field to Far-Field Transformation

The transformation method is based on source identification, assuming that the antenna under test (AUT) can be replaced by a set of equivalent elementary dipoles radiating the same far field as the AUT, using, as dipole's radiation functions, the analytic formulations developed by Norton and extended by Bannister [5] to the very near field zone. These formulations comprise the sky wave, which is the sum of the direct and reflected waves, as well as the surface wave contribution of the electromagnetic field radiated by each dipole. Consider an AUT located at the plane horizontal interface between the air and the actual ground as shown in Fig. 1. The components of the electromagnetic field are supposed to be measured in the near field zone (in order to take into account the surface wave) on a surface S_M surrounding the AUT. For convenience, we will first assume that S_M is a cylindrical surface, of radius r_{SM} and height h_{SM}, centered on the AUT. The number of measured points is N_M. Consider now a second surface S_D, included inside the volume which border is the surface S_M. Also, for convenience, surface S_D is supposed to be a cylinder of radius r_{SD} and height h_{SD}, centered on the AUT.

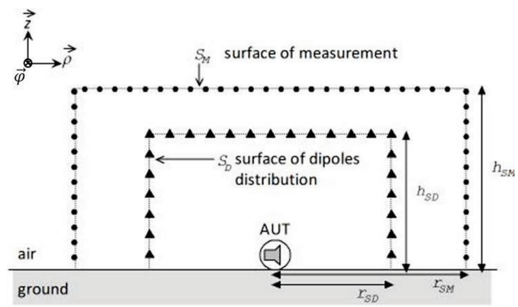

Fig. 1. Geometry associated to the method.

The number of sampling points is N_D. At each point, three elementary electric dipoles are arranged in order to form an orthogonal basis aligned with the local cylindrical basis vectors. The method states that, at each point of the surface S_M, the electromagnetic field, is equal to the sum of all the contributions coming from each of the $3N_D$ dipoles distributed over surface S_D. This leads to the following matrix equation:

$$\begin{bmatrix} \boldsymbol{D_E} \\ \boldsymbol{D_H} \end{bmatrix} \begin{bmatrix} \boldsymbol{P_{S_D}} \end{bmatrix} = \begin{bmatrix} \boldsymbol{E_{S_M}} \\ \boldsymbol{H_{S_M}} \end{bmatrix} \quad (1)$$

where $\boldsymbol{E_{S_M}}$ and $\boldsymbol{H_{S_M}}$ respectively denote the electric and magnetic vector fields of size $3N_M$, measured at each point on surface S_M. $\boldsymbol{D_E}$ and $\boldsymbol{D_M}$ are respectively the electric and magnetic radiation matrices, each of size $3N_M$ x $3N_D$, of the $3N_D$ electric (horizontal and vertical) dipoles located at each point of the surface S_D. $\boldsymbol{P_{SD}}$ is the unknown vector, of size $3N_D$, gathering the electric moments of the previous dipoles. Equations (1) can be solved by inversion of the matrix $\begin{bmatrix}\boldsymbol{D_E}\\ \boldsymbol{D_H}\end{bmatrix}$ in order to compute the vector $\boldsymbol{P_{DS}}$. To achieve that goal, this inversion is carried out by applying the singular value decomposition (SVD) associated with a threshold power criterion applied to select the relevant eigenvalues. This criterion is linked to the total power radiated by the AUT, in the near field zone, and is calculated from the measurement of the electromagnetic field on surface S_M. Once the vector $\boldsymbol{P_{SD}}$ is obtained, the electric far field can be easily computed. Detailed description of the procedure is given in [6] and [7].

III. Experimental Set-Up

An experimental set-up has been designed in order to characterize antennas, in operating environment, in the UHF band. The main elements of this set-up are the following. An electro-optic probe measures the magnitude and phase of the component of the electric field, parallel to the axis of the probe head. This axis can be modified, thanks to a mechanical device, in order to successively access the three components of the electric field. Three motorized and computer driven linear guides allow the displacement of the probe in the working volume. The AUT is located on a horizontal plane interface which dielectric properties can be chosen (perfect electric conductor, lossy ground, metasurface, etc.). A rotating axis adjusts the azimuthal position of the AUT. The working volume is surrounded by electromagnetic absorbers. A vector network analyser feeds the antenna and collects the output of the probe. The transmission coefficient gives then the value of the electric field, in magnitude and phase. The electric field (its three components) and position data are stored for each measurement point on the surface S_M. The standard antialiasing criterion defines the steps $\Delta\rho$, $\Delta\varphi$ and Δz between two adjacent points and can be expressed as

$$\Delta\rho \le \frac{\lambda}{2} \quad \Delta\varphi \le \frac{\lambda}{2r_{SM}} \quad \Delta z \le \frac{\lambda}{2} \qquad (2)$$

where λ is the free-space wavelength.

IV. Numerical and Experimental Results

The results presented in this paper deal with a quarter-wave monopole, operating at 1 GHz and located on a metallic interface. The near-field measurements have been conducted using the experimental set-up previously described. They have been compared to numerical results obtained with the commercial electromagnetic software FEKO® and to analytic results obtained via the Norton formulation [5]. Fig. 2 shows the magnitude of the cylindrical components E_ρ and E_z of the electric field, along a vertical line at $r_{SM} = \lambda$. The results are in very good agreement. Near-field measurements have been used as input data of the NF/FF transformation. The obtained far-field has been compared with those calculated with FEKO® and with Norton formulation. Fig. 3 shows the magnitude of the spherical component E_θ of the electric field, at the distance 1000λ. The far field predicted by the NF/FF transformation is very close to those given by the two other methods.

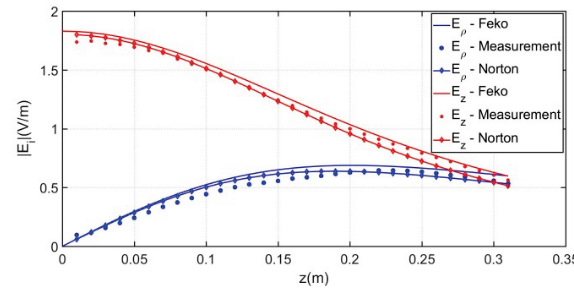

Fig. 2. Near-field measurements and calculations.

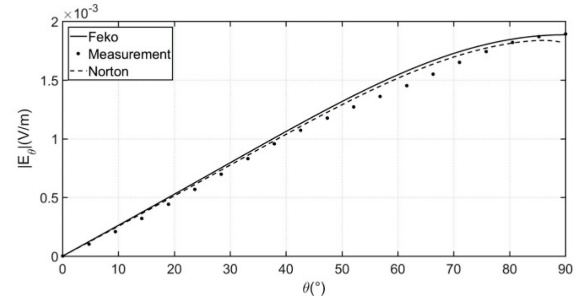

Fig. 3. NF/FF transformation and far-field calculations.

V. Conclusion and Perspectives

The first results, presented in this paper and reinforced by a good agreement between numerical and experimental data, show the ability of the NF/FF transformation to predict the radiation of antennas in operating environment. Other results are available and will be discussed during the conference. They concern broadband antenna and antenna array located on dielectric and lossy ground.

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