A THEORETICAL COMPARISON BETWEEN THREE PLANAR NEAR TO FAR-FIELD TRANSFORMATION METHODS FOR ANTENNA MEASUREMENTS

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ABSTRACT

Three methods useful for predicting the radiation pattern of an Antenna Under Test (AUT) from planar near-field samples are compared in this work. Two of these methods – the classical Fast Fourier Transform (FFT) based method and an integral equation based one – are available in the literature and have already proved its usefulness for this task. Furthermore, from the principles of the equivalence theorem a new approach based on a genetic algorithm optimisation process is proposed by the authors as a versatile alternative.

INTRODUCTION

The performance of an antenna can be tested on either a near-field or far-field range using a suitable implementation. The advantages of near-field measurements include high accuracy, suppression of multipath and elimination of the effects due to weather. The most commonly used near-field techniques are planar, cylindrical and spherical [1]. Of these three, planar scanning is more frequently used for high directivity antennas, because they present an aperture distribution slightly larger than its projected area. Moreover, the main advantage of planar surfaces deals with the degree of mathematical and computational simplicity.

For planar scanning, the radiation pattern of an Antenna Under Test (AUT) can be obtained from a set of samples of the phase front of the antenna measured in the radiating near-field region, describing a planar grid. Later on, amplitude and phase at each sampling point on the grid is used by mathematical transformation methods so as to perform the near-field to far-field transformation. Two well-known methods available in the literature were investigated, and their principles are summed up in the next section, although a thorough description for both methods can be found in [2] and [3] respectively. Then, another approach based on a global optimisation technique is presented as a suitable alternative. The method proposed obtains an AUT radiation pattern in terms of a set of electric and magnetic dipoles, placed at the surface of a volume containing this AUT. Finally, a summary of results to test the performance of the new method is also included.

PLANAR NEAR-FIELD THEORY: AN OVERVIEW

Mainly, planar scanning techniques in near-field measurement of antennas are based on the Plane-Wave Spectrum (PWS) representation of fields [2]. From Maxwell equations, a relationship between the near-field samples and the PWS can be deduced (1). Then, the far-field pattern can be computed from the PWS (2). In short, using the Fast Fourier Transform (FFT) technique (1) can be solved, introducing a conversion from the spatial domain (phase front) into the spatial frequency domain (K space) which is then re-mapped into angle space using (2). Fig. 1(a) summarises the main parameters involving the method, where we can conclude that the accuracy of the results depends on the type of AUT to be analysed, the size of S_2, the sample spacing Dx, Dy and the measurement distance zs.

$$\vec{A}(kx,ky)=\frac{1}{2p}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\vec{E}_{meas}(x,y,z)e^{j\vec{k}\vec{r}}\,dx\,dy \tag{1}$$

$$\vec{E}_{far-field}(x,y,z)=\frac{je^{-jkr}}{r}kz\vec{A}(kx,ky) \tag{2}$$

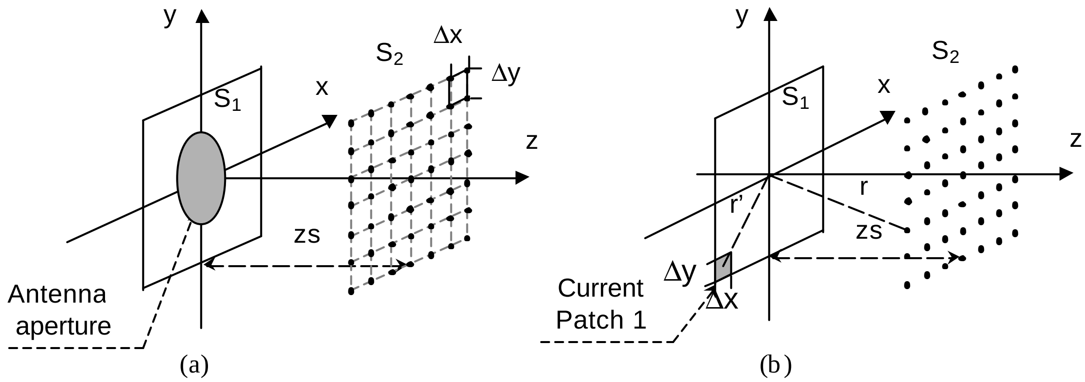

Fig. 1. Main parameters of the methods analysed. (a) FFT based method. (b) Integral equation based method.

Another theoretical method was analysed [3]. In this approach, the AUT is replaced by equivalent magnetic currents that reside on a fictitious surface, S_1, encompassing the antenna, see Fig. 1(b). The aperture is divided into N equally spaced rectangular patches and the amplitudes for each of the N magnetic currents are the unknowns of the problem. An integral equation linking the near-field samples to the equivalent magnetic currents can be postulated from (3), and a Moment Method procedure (MoM) can be used to transform them into matrix equations (4), solved using the method of least squares with singular value decomposition. Once this is accomplished, far fields can be determined in all regions in front of the AUT from the equivalent magnetic currents, Mx, My obtained. The size of S_1, S_2, and the number of patches used to model the AUT have to be set thoroughly in order to achieve good results.

$$\overline{E}(\overline{r}) = -\iint_{Se} \overline{M}(\overline{r}') \times \nabla' g(\overline{r}, \overline{r}') \quad ds' \tag{3}$$

$$\left.\begin{matrix} [E_{meas}] = -[G]\times[M] \\ [G] \equiv Moment\ matrix \end{matrix}\right\} \begin{matrix} [E_{meas,x}] = -[G]\times[My] \\ [E_{meas,y}] = -[G]\times[Mx] \end{matrix} \tag{4}$$

DESCRIPTION OF A NEW METHOD

According to the equivalence theorem, an AUT can be replaced by equivalent electric and magnetic currents distributed over the surface enclosing the volume of the antenna. In this approach, these currents are modelled by means of electric and magnetic dipoles uniformly spaced on the surface of a parallelepiped, as it is shown in Fig. 2(a), and their dipolar moment is optimised by computer simulation using Genetic Algorithms (GAs) [4] and the reference information provided by a grid of planar near-field samples. From then on, the set of dipoles obtained from optimisation substitute the AUT, and its far-field radiation pattern can be easily computed from the analytical radiation formulas of an elemental dipole.

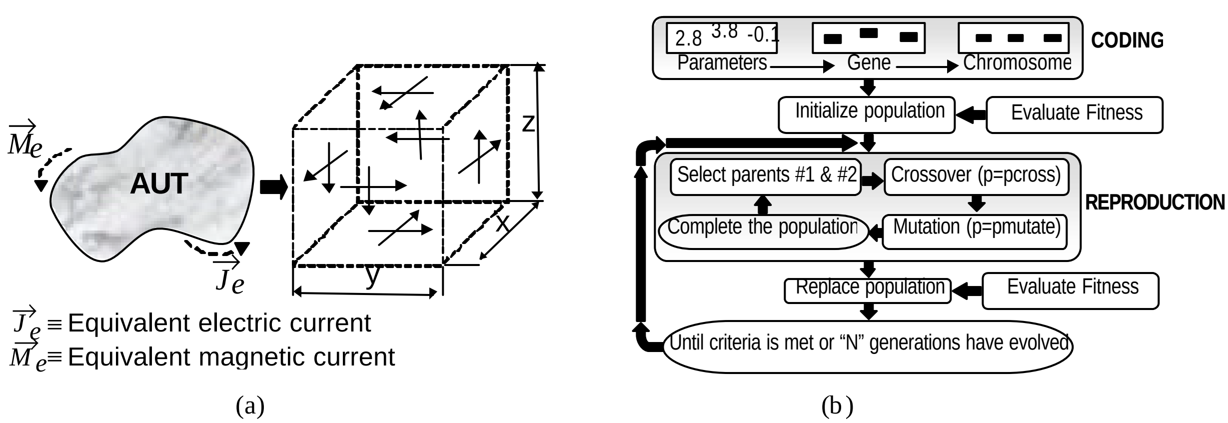

Fig. 2. Principles of the method. (a) Model of the AUT. (b) Basic block diagram of a Genetic Algorithm (GA)

GAs are stochastic search procedures based on the evolution of a set of potential solutions or chromosomes, where a chromosome represents the whole set of parameters to be optimised. Fig. 2(b) shows the basic process involving a binary GA, where a set of chromosomes is made to evolve towards a global optimal solution as a result of the pressure exerted by three mechanisms: selection, crossover and mutation. The GA based optimisation process proposed in this paper uses tournament selection with $n=2$, uniform crossover with *pcross Î [0.7-0.75]* and creep mutation with *pmutate Î [0.05-0.1]*, as the main strategies. For the problem in hands, the accuracy of the solution depends on the set of dipoles used for modelling the AUT, directly related to the frequency, the type of AUT and the grid of near-field samples.

Let us take a set of N dipoles to reproduce the radiation pattern of an arbitrary AUT from K near-field measurements E_k. The goal is to configure each dipole within the model in such a way that the whole set radiates as close as possible to the AUT. The fields radiated by an isolated dipole is a function of a seven-parameter set: position $r(x,y,z)$, orientation (q,f), type of source (electric or magnetic) and dipolar moment. Nevertheless, from Fig. 2(a), the only parameters available to model the AUT are the amplitude and phase, M and P, of the dipolar moment for each dipole. For the test set on N dipoles, the vector C in (5) includes all the parameters to be optimised.

$$C=(M_1,P_1,\ldots,M_j,P_j,\ldots,M_N,P_N) \tag{5}$$

Any vector C represents a potential solution to the problem. Moreover, the fields radiated by the N dipoles at any of the K measurement points is a function of C, so we can propose a fitness or cost function (6), whose maximisation using GAs leads to that vector C which best fits the K near-field samples.

$$F=\sum_{n=1}^{N}\frac{1}{1+\left|E_{meas}-E_{GA}\right|^2} \tag{6}$$

RESULTS

The performance of the methods proposed was tested with several theoretical problems. The advantages, limitations and accuracy of each method will be summarised in this section. As an example, Fig. 3 shows the far-field pattern of a test set made up of an electric and a magnetic dipole computed at 1.8GHz at a flat surface 6000λ away from the source. The parameters of the source are presented in Table 1. Although the dipolar moment of the magnetic dipole is twice that for the electric dipole, it is too low so as to influence the far-field pattern, which is very close to the radiation pattern of an electric dipole. The all three methods used as reference the information provided by a grid of planar near-field samples computed analytically.

Table 1. Parameters of the AUT to be modelled.

Parameter	*Electric dipole*	*Magnetic dipole*
r(x,y,z) (m)	(0,0,0.02)	(0,0,-0.02)
(q,f) (º)	(90,90)	(90,90)
I.l (A.m)	0.007×10^{-3}	0.014×10^{-3}

The FFT based method used a 256x256 FFT processing to compute the far-field pattern from (1) and (2), taking as reference the analytically computed x and y components of the E-fields radiated by the source at a planar surface 84λ x84λ in size and 2.4λ away from it. The method presents good results with up to 1 dB ripple due to filtering of fields outside S_2, even though this method works better with directive antennas, which concentrate almost all its energy on the measurement plane. The integral equation method used a set of 10x10 patches to represent the source, placed at a surface S_1 λxλ in size. In this case the lack of accuracy may be justified by the type of source or by any limitation within the algorithm used by the authors to solve the matrix equations in (4), which is being analysed at the moment. Nevertheless, the method was also tested with different aperture antennas, achieving optimum results. Moreover, in terms of CPU time this method is faster than the other ones. The GA based method used an equivalent model for the AUT made up of 64 electric and magnetic dipoles, placed at the surface of a parallelepiped λ/2xλ/4xλ/2 in size, according to Fig. 2(a). From the results shown in Fig. 3(d) we can conclude about the good performance of the method.

Nevertheless, the main drawback of this technique deals with the simulation time, justified because it involves an iterative optimisation process, whereas the previous methods outlined have only to apply mathematical data processing. On the other hand, GAs prove to be a versatile alternative which can be also useful for other tasks: prediction of radiation patterns from phaseless information or for electromagnetic compatibility issues.

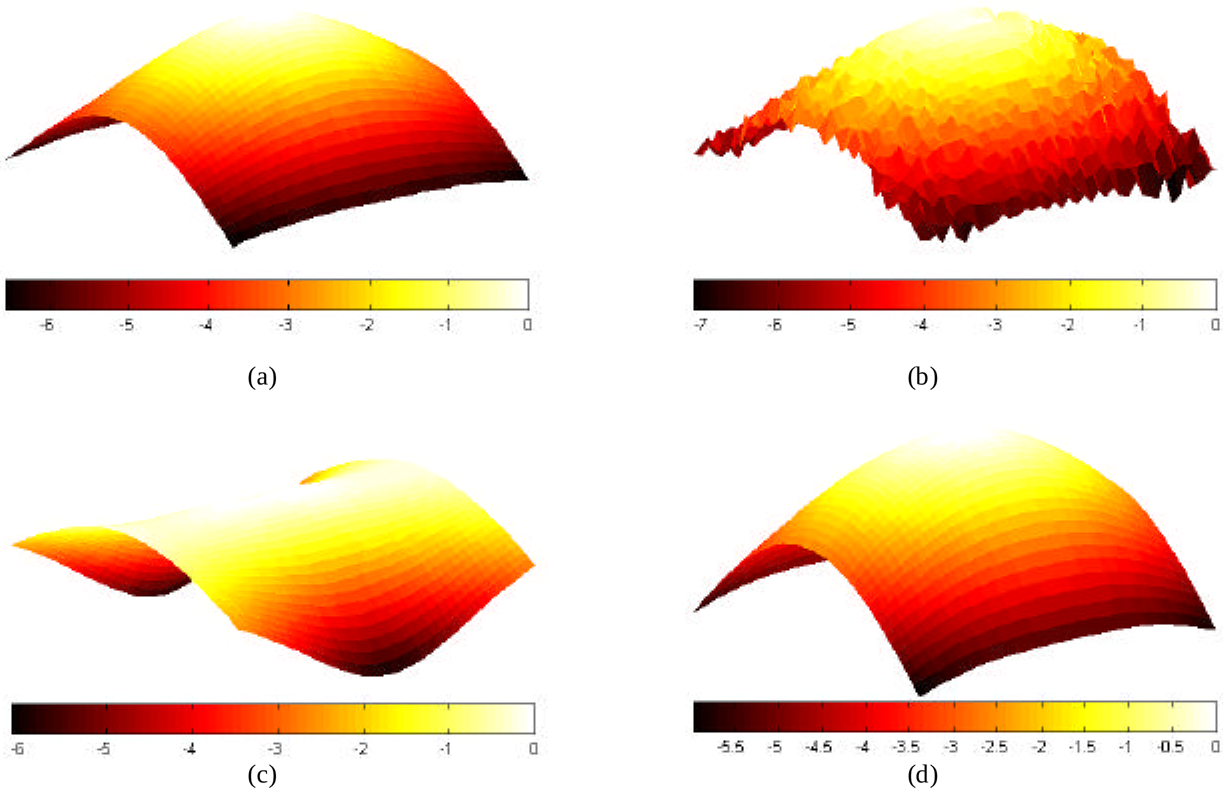

Fig. 3. Far-Field radiation pattern of the test source. (a) Theoretical. (b) FFT based method. (c) Integral equation based method. (d) GAs based method.

CONCLUSIONS

Different methods useful for predicting far-field patterns from planar near-field samples were compared by computer simulation. Two of them have been widely used by many authors and have been considered in this work as a reference so as to validate the results obtained with a new approach, a GA based optimisation process. The all three methods have been analysed theoretically showing encouraging results for the new method proposed.

ACKNOWLEDGEMENTS

This work was partly supported by CICYT/FEDER projects 1FD97-0594-C03-02/TIC and 1FD1997-1975/TIC. It was also supported by a grant given by the *Secretaría de Estado de Educación y Universidades*.

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