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NEAR-FIELD DATA COMPRESSION FOR THE FAR-FIELD COMPUTATION IN FDTD

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ABSTRACT: *This paper presents a technique to compress the near-field data required to compute the radiated fields using FDTD. This technique is applied to the study of a UWB planar diamond antenna. The results show a 99.8% gain in memory storage, while maintaining good accuracy: less than 1% error on the far-field radiation patterns.* Microwave Opt Technol Lett 48: 1155–1157, 2006; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.21553

Key words: *FDTD; far-field computation; wavelets; DWT*

1. INTRODUCTION

The finite-difference time-domain (FDTD) [1] method has been extensively used to simulate open problems. However, a near-to-far-field transformation is commonly used to compute radiation patterns. This transformation is usually carried out as post-processing according to the equivalence principle. A virtual Huygens surface is defined to store the tangential components of the near-fields *E* and *H* at each time step. Later on, the radiated fields can be evaluated at any frequency while calculating and integrating the equivalent currents according to the equivalence principle. In practice, the near-field data storage can easily lead to a huge data file because of the large number of time iterations and cells on the Huygens surface. Actually, the large number of cells results from the small cell size that is usually required to obtain good accuracy in the FDTD near-field computation. Such a fine grid is not needed for the far-field computation. Data compression can be used to overcome the spatial oversampling problem.

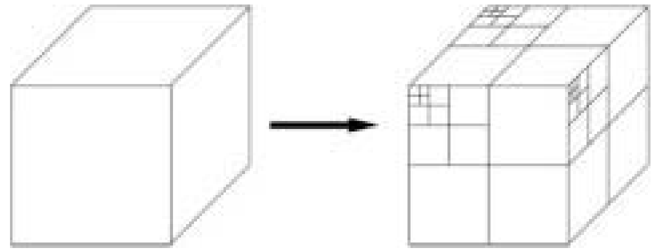

Figure 1 DWT 2D applied on each face of the Huygens surface

Recently, a discrete cosine transform (DCT) has been used to compress the near-field data on the surface of a Huygens box [2]. A compression rate of 92.5% has been obtained with good accuracy in the radiated fields. In [3], a compression technique was presented based on the multiresolution analysis scheme, in which the scaling coefficients are stored. The required near-field data have been reduced by 98%.

In this paper, the proposed technique consists of a multiresolution analysis where the scaling and wavelet coefficients superior to a threshold are kept. Section 2 explains the compression principle in detail. In section 3, this compression technique is applied to the near-field data of an UWB antenna, and the radiation patterns are computed and compared with the initial ones. Finally, some conclusions are discussed in section 4.

2. PRINCIPLE

The proposed compression technique is based on the multiresolution analysis principle. A discrete wavelet transform in two dimensions (DWT 2D) is spatially applied as post-processing on the near-field components on each face of the Huygens surface (Fig. 1). For each time step, electric and magnetic fields are decomposed on a Haar basis according to the multiresolution analysis scheme. During the decomposition, the maximum resolution level is reached: one scaling coefficient is used as a coarse approximation of the signal, while details at various resolution levels are brought by wavelet coefficients [4]. For example, Figure 2(a) presents the magnitude of the near-field component E_z on one face of the Huygens surface at a particular time step, and Figure 2(b) the resulting scaling and wavelet coefficients. The useful information is concentrated on a small number of coefficients (the clearest ones

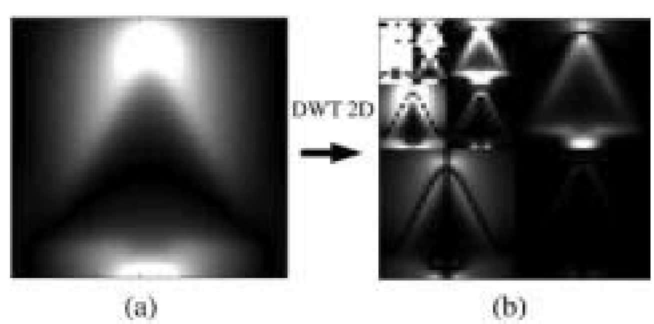

Figure 2 E_z on one face of the Huygens surface at a particular time step: (a) direct representation; (b) DWT 2D representation

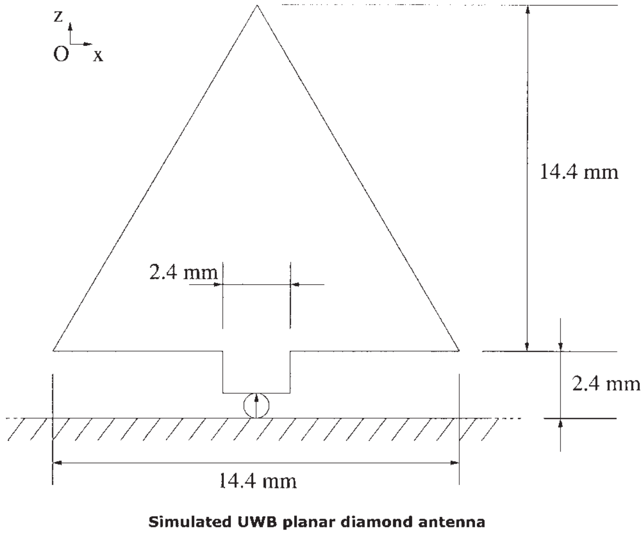

Figure 3 Simulated UWB planar diamond antenna

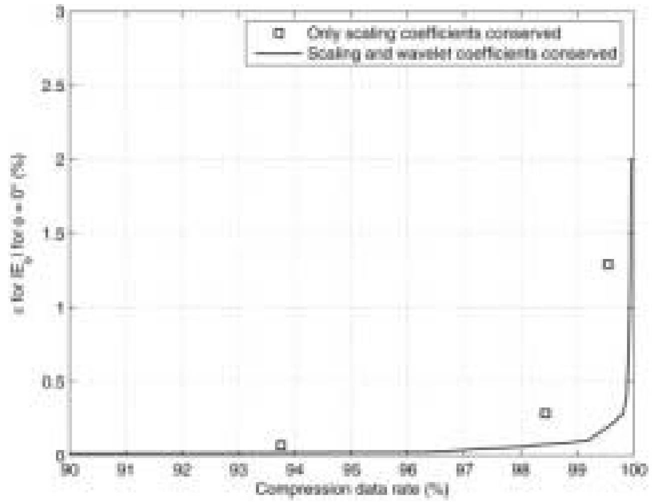

Figure 4 Error on $|E^{\phi}|$ as a function of the compression rate for both techniques with $\phi = 0°$

in the figure), and only a few of them need to be stored. In practice, we save all the coefficients that are superior to a global threshold, whatever the field component. Before computing the radiated fields, the near-field data are reconstructed at the fine level thanks to an inverse discrete wavelet transform in two dimensions (IDWT 2D).

To evaluate the interest of keeping some wavelet coefficients, we compare the following techniques:

- in the first one, only the scaling coefficients are kept, and this technique is equivalent to defining a uniform coarse grid;
- in the second one, the scaling and wavelet coefficients that are superior to a predefined threshold are kept.

3. NUMERICAL EXAMPLE

The simulations are performed for the ultra-wideband (UWB) planar diamond antenna shown in Figure 3 and described in [5]. For UWB antennas, FDTD simulation is recommended. Indeed, only one simulation in the time domain is required to characterize the antenna over a large range of frequencies. The antenna is fed with a Gaussian pulse, which is narrow enough in the time domain to cover the overall antenna bandwidth.

Here, the FDTD volume size is 36 × 9 × 27 mm, and is discretized into 120 × 30 × 90 uniform cells with a $\lambda_0/140$ cell size at the central frequency (7 GHz). The antenna geometry (oblique edges) justifies the small cell size. Such a spatial discretization is needed to obtain good accuracy in the FDTD near-field computation, whereas for the far-field calculation it is oversampled. The Huygens box is made up of 5 faces (64 × 8 × 64 small cells). To compute the far fields, their images are taken since the antenna is placed over an infinite ground plane.

Various compression rates are applied to the initial near-field data. After the data are reconstructed, radiation patterns are calculated for ten frequency points from 5 to 9.5 GHz. This radiation patterns are compared with the initial ones (without compression) by evaluating the normalized mean squared error, given by

$$\varepsilon = \sqrt{\frac{1}{M}\sum_{k=1}^{M}\frac{|E_{uNCk} - E_{uCk}|^2}{|E_{uNC\max}|^2}}, \tag{1}$$

where u is either θ or ϕ, depending on the field component. NC stands for not compressed whereas C is for compressed. M is the total number of frequency points. Figure 4 presents this error for the $|E_{\phi}|$ component in the $\phi = 0°$ plane, plotted as a function of the compression rate for the two techniques. The number of nonsaved coefficients over the total number of initial data gives the compression rate.

These results show that both techniques make a reduction of 98% of the required data possible with good accuracy in the far-field patterns. However, the compression rate for a same error is better when wavelet coefficients are conserved. Indeed, compression rates up to 99.8% can be reached with good accuracy in the radiated fields. For example, Figure 5 shows the radiation patterns using original data and reconstructed ones. Concerning the reconstructed radiated fields, both techniques use a 99.8% compression rate of the near-field data.

No major differences exist between the original far-field and the reconstructed one using scaling and wavelet coefficients. On the contrary, we observe a 2-dB difference for $\theta = 90°$ when a uniform coarse grid is defined (only scaling coefficients con-

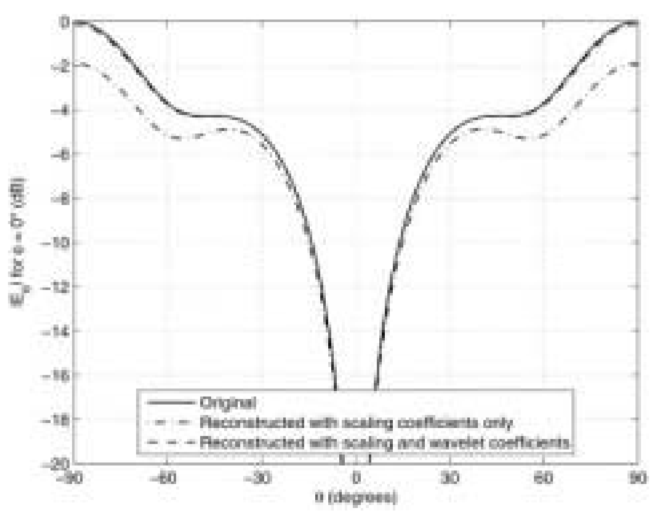

Figure 5 Comparison between original and reconstructed radiation patterns at 9.5 GHz with $\phi = 0°$ and with a 99.8% compression rate

served). In this case, a uniform grid does not make a good approximation of the near-field components. Some local near-field variations are not taken into account. On the contrary, our technique conserves wavelet coefficients that traduce these variations. This technique can be viewed as a kind of adaptive mesh that is refined where the spatial variations of the near-field are not negligible.

4. CONCLUSION

In this paper, we have presented an efficient technique to compress the near-field data used to compute radiated fields. This technique optimizes memory storage. Indeed, compression rates up to 99% were obtained for the UWB antenna with good accuracy in far-field radiation patterns. Based on this example, the utility of keeping wavelet coefficients has been validated.

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