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A new WCIP method based on 2D Discrete Wavelet Transform

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***Abstract*— The wave concept iterative procedure (WCIP) is used as an efficient tool to study electronic circuits at high frequencies. The major issue with this method is that the required calculation time increases with the circuit's complexity. In this article, we propose to accelerate the WCIP method by using an image processing technique based on 2D Discrete Wavelet Transform (2D DWT). This method is used to reduce the size of information manipulated by the iterative process in order to obtain a fast computing time.**

***Keywords*— Iterative Method; 2D Discrete Wavelet Transform; fast computing time**

I. INTRODUCTION

The wave iterative method (WCIP) (Wave Concept Iterative Process) is an integral method based on wave concept for solving problems of electromagnetic diffraction and analysis of planar circuits. It is based on the manipulation of incident and reflected waves instead of electromagnetic field [1]-[2]. It has very attractive benefits for microwave circuits' designers. Among these benefits, its facility of implementation and execution speed, mainly due to the absence of test functions (replaced by a pixel description of the interface containing the circuit) and the use of the FMT (Fast Modal Transform) [3] ensuring the transition between spatial and spectral domains.

By using the FFT algorithm, a high computing speed can be obtained. But, in the case of complex circuits requiring a fine mesh, the time calculation increases [4], because the numerical complexity is related to the number of cells describing the circuit. Considering the circuit plane as an image, the new approach proposed in this paper improve the convergence speed of the WCIP method by using a technique of image processing, which ensure good results in a minimum computing time. This technique is based on 2D Discrete Wavelet Transform (2D DWT). In fact we use this transform to focus on the important part of the studied structure in which the electromagnetic fields are important. The 2D DWT separates low-frequency components from the high frequency ones of the studied image and can locate the position of rapid variation of an image.

The use of this wavelet-based new method reduces the number of operations by the rejection of unnecessary operations and then we can accelerate the iterative process. In section II, we present the theoretical formulation of the WCIP method and we briefly describe the mathematical background of the wavelet transform. In Section III, the numerical results of convergence and computation time are given. Finally, section IV, deals with conclusions and perspectives.

II. THEORY

A. WCIP

The process of WCIP is based on the manipulation of incident Ai and reflected Bi waves at the meshed surface (where 'i' is the domain number 1 or 2 in Fig.1).

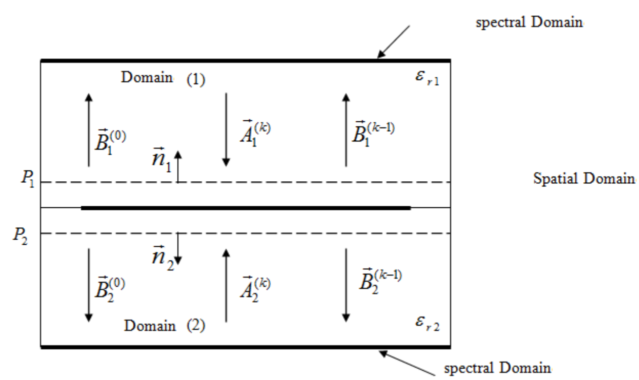

Fig.1. Definition of incident and reflected waves

These waves are defined by (1) and (2):

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$$A_i = \frac{1}{2\sqrt{Z_{0i}}}\left(E_i + Z_{0i} J_i\right) \quad (1)$$

$$B_i = \frac{1}{2\sqrt{Z_{0i}}}\left(E_i - Z_{0i} J_i\right) \quad (2)$$

With:

The current density is defined by (3):

$$\vec{J}_i = \vec{H}_i \wedge \vec{n}_i \quad (3)$$

$\vec{n}_i$ is oriented to the area $i \in \{1,2\}$.

$\vec{H}_i$ and E_i indicate respectively the tangential magnetic and electric field at the surface.

Z_{0i} is the impedance of the medium (i).

The iterative process establishes a recurrent relation between the incident waves and the reflected waves in the two different areas as indicated by (4) and (5).

$$A = \Gamma B + A_0 \quad (4)$$

$$B = \Gamma_\Omega A \quad (5)$$

Where the source is specified through a known vector A_0 added in (4).

Fig. 2 summarizes the iterative process.

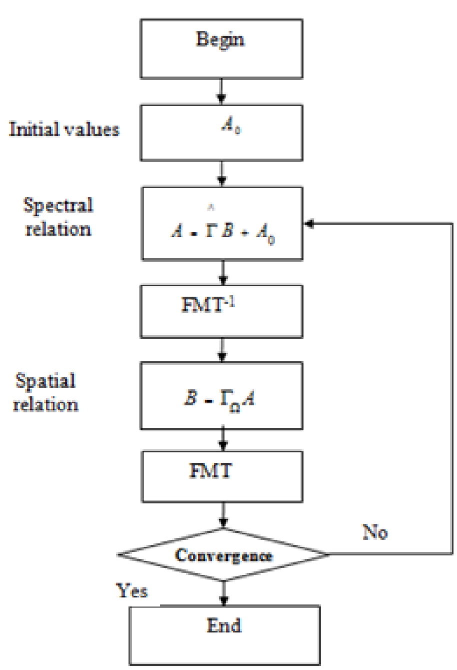

Fig. 2. Classic iterative process for spectral excitation

The transition from the spatial domain (pixel representation) to the spectral domain (modal representation) is insured by the Fast Mode Transformation (FMT) and the reverse Transformation (FMT^{-1}).

B. 2D Discrete Wavelet Transform

2D Discrete Wavelet Transform (2D DWT) [5-10] , is a powerful tool used in image processing such as image analysis, de-noising, image segmentation and other applications.

2D DWT is based on a convolution of a given wavelet function with an original image or it can be considered as a set of two matrices of filters, high pass and low pass one. Using the basic DWT property which is the separation between low and high frequency information of the studied image, the first step of the decomposition process consists on the application of row filters to the original image. The column filters are used for further decomposition of image resulting from the first level. This decomposition of image [6] can be mathematically described by Eq. (5).

$$C=X.I.Y \quad (5)$$

Where C represents the final matrix of wavelet coefficients, I is the original image, X is the matrix of row filters and Y is the matrix of column filters.

In the first step of decomposition of 2D DWT, the image is decomposed into four parts. Each part has a quarter size of the original image [10]. These parts are called approximation coefficients noted Low Low or LL, horizontal coefficients noted Low High or LH, vertical coefficients noted High Low or HL and detail coefficients noted HighHigh or HH) [6, 10], described in Fig.3.

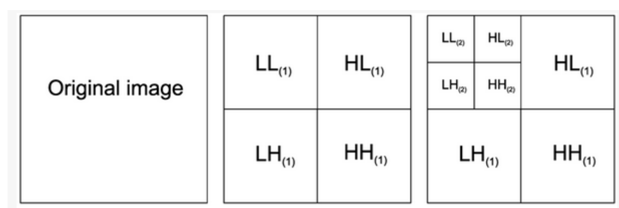

Fig. 3. 2D DWT decomposition principle for two levels

Approximation coefficients obtained in the first step are used for the next decomposition level. The Inverse 2D Discrete Wavelet Transform (2D IDWT) used to reconstruct the original image is defined by Eq. (6).

$$I_{rec}=X^{-1}.C.Y^{-1} \quad (6)$$

Generally we deal with orthogonal matrices so the Eq. (6) can be simplified into Eq. (7)

$$Ir_{ec}=X^{T}.C.Y^{T} \quad (7)$$

C. New algorithm

This paper deals with the application of the 2D DWT in the acceleration of the WCIP method.

We use this technique to locate the zone where information is important. In fact, 2D DWT decomposition decomposes an image into four parts, having a quarter sizes; each of these parts represents different information from the original image. Detail coefficients represent the useful information in the image since they are formed by the points of rapid variation of an image while approximation coefficients are considered to be a noise, so that they will be ignored. Our contribution consists of a good modification of approximation coefficients to reduce the amount of the data manipulated by the iterative process and to reduce the computation time. The easiest method is based on setting all approximation coefficients to zeros. This modification removes low frequencies from the image X(i,j), supposed to be a noise and representing unuseful information. The image is then reconstructed using only the remaining wavelet coefficients.

In our research we use the simplest wavelet function which is Haar wavelet for two levels of decomposition.

X(i,j), in the theoretical part, will be designated later by the incident Ai and reflected Bi waves.

By means of this method the most important points, in which the values of the electromagnetic fields are important are considered, while the negligible values are rejected. In the new proposed algorithm of the WCIP, the calculation is carried out on reduced data which represent the incident and reflected waves.

The new algorithm is depicted in Fig.4.

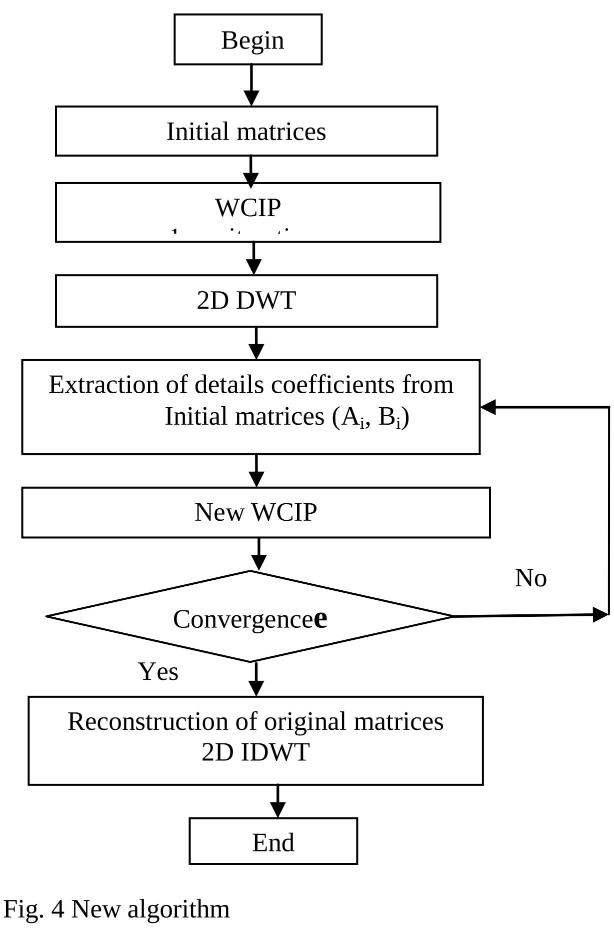

Fig. 4 New algorithm

The new whole process starts with the classic iterative process which performs a few number of iterations (n) applied to the initial matrices having basic lengths M*N, until the stability of the process. Then we apply the new algorithm based on 2D DWT to continue the remaining iterations and to achieve the convergence after "N" iterations. This new algorithm operates only on useful information formed by detail coefficients having reduced sizes compared to original matrices, until reaching the convergence. At the end, we reconstruct the original matrices using the inverse 2D DWT. The new wavelet based method is used to reduce the computation time and to get a good result.

III. SIMULATION RESULTS

The studied circuit in “Fig. 5” is a transmission line placed in a metal cavity (perfect conductor).

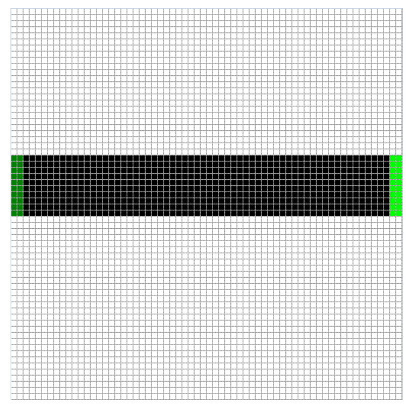

Fig. 5 Transmission line descritized in 64×64 pixels

In Fig.6., we show the variation of S11 coefficient in function of the number of iterations using two methods: the classic WCIP and the new method with 2D DWT to prove that our approach gives good results. The classic method needs 300 iterations to achieve the convergence. Those iterations are calculated by a classic iterative process. Since this number is quite high, it requires an important calculation time. So, this method takes a long time to achieve the optimal result. In fact, to reduce the calculation time required to have a good result, we propose to use a new iterative process in which the basic WCIP method is used to calculate a few number of iteration “n” set to 20 to reach the stability, while the remaining important number of iterations “N” is calculated by the new approach based on wavelet transform, which does not take much time to achieve convergence, since this method works only on important information which have a reduced size. We show that the final result of the whole algorithm converge also to the optimal values of S11 when compared to the classic WCIP, in less time.

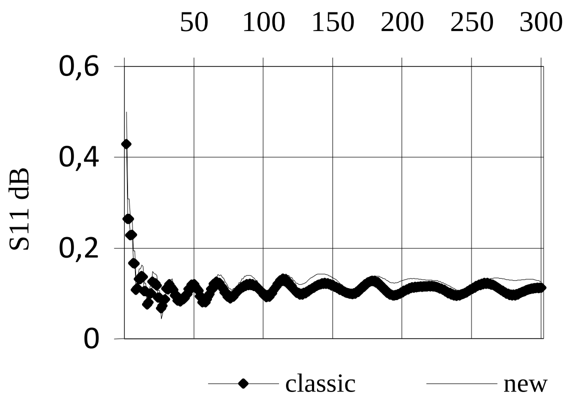

Fig. 6. Variation of |S11| as function of iterations number

This gain of time, shown in Tab.1, is achieved by the new method because we use 2D DWT transform, so that the calculation is performed on detail coefficients which represent the useful information in the image formed by the points of rapid variation of an image to converge to the same result in less time. In addition, we note that our algorithm reaches the convergence faster than the classic method of WCIP.

TABLE I. COMPARAISON OF TIME BETWEEN THE TWO METHODS

n	Classic WCIP for 300 iterations Time (s)	New 2D DWT-based WCIP for 300 iterations Time (s)	Gain (%)
20	1.6	0.2	87.5%

IV. CONCLUSION

In this work, we have proposed a new method to improve the speed of the iterative method WCIP. This method is based on 2D DWT and it performs the calculation only on the useful information of the input matrices describing the structure. This approach has been tested firstly, on a simple electromagnetic structure which consists on a transmission line. As perspective we will apply our method to more complex circuits requiring fine mesh and described by larger matrices.

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