

Studying an Inductive Iris by an Optimized 1D-WCIP Method based on a Phase Jump Fast Mode Transform (PJFMT)

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ABSTRACT

The wave iterative method is an efficient tool used to study electronic circuits at high frequencies. The major problem with this method is that the required calculation time increases with the complexity of the circuit. In this article, we propose to accelerate the iterative process by using a Phase Jump Fast Mode Transform (PJFMT) based on phase jump principle in order to improve the convergence speed of this method. Preliminary numerical results are presented and show good agreement when compared to HFSS simulation.

Keywords

Inductive Iris; Iterative Method; 1D-WCIP ; PJFMT;

1. 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 [1-8]. It is based on the manipulation of incident and reflected waves instead of electromagnetic field [1-4]. It is mainly based on two equations, one in the spatial domain and the other in the spectral domain. 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) [9] ensuring the transition between spatial and spectral domains.

In fact, in recent years, the FMT-WCIP method has been applied in a wide variety of microwave structures. This method uses a Fast Fourier Transform FFT. The use of the FFT algorithm requires considering the circuit plane as an image divided into a small cells. 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 [10], because the numerical complexity is related to the number of cells describing the circuit. In previous works, several improvements have been presented as the technique of adaptive filtering [11] and contour detection [12]. In this article, we propose a new algorithm of the 1D-WCIP based on a modified 1D-FMT. This modification consists on a phase jump when performing the FFT transform 'Phase Jump Fast Mode Transform PJFMT'. In fact, the new PJFMT takes as input data only the useful information from the cells describing the structure. This useful information corresponds to high values of the electromagnetic fields, usually located in the areas of the structure discontinuity between the metal and the dielectric. In fact, the rapidity of the 1D-FMT can be ameliorated by removing operations on the input values that

are not needed. In our case, it is known in advance that parts of the input data of the 1D-FMT are not useful, so we focus only on important information while the rest will be ignored. In fact, the application of this method reduces the number of operations by the rejection of unnecessary operations and then we can accelerate the iterative process. For a simplicity reason, this new approach is first developed and tested for one-dimensional 1D TE and TM problems to be extended in future work for the 2D case. In fact, we will manipulate a sequence of vectors describing the studied structure instead of matrices.

In section 2, we present the theoretical formulation of the problem, for the 1D TE field.

In Section 3, the numerical results of convergence and computation time are given as well as a comparison of our results with HFSS simulation. Section 4 presents comparison of the classic method with the new method. Finally, section 5 deals with conclusions and perspectives.

2. THEORETICAL STUDY

2.1 1D-WCIP

The WCIP method is described on a 1D circuit formed by an inductive iris placed on a waveguide, shown in Figure 1.

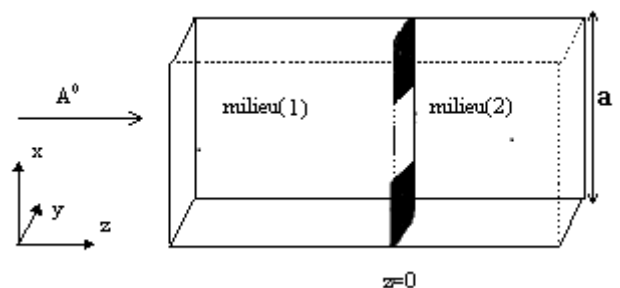


Figure 1. Inductive iris

In this case, the discontinuity is uniform along y-axis, and since the electromagnetic field is incident in the dominant TE₁₀ mode, only higher-order modes TEM₀ are generated [13].

Thus, the field is independent of y and has only the x-component, which does not vary with y. Consequently, it is the number of points along the x-axis that affect the convergence of the solution, so that only 1-dimensional discretization along the x axis is needed, as the example shown in Figure 2.

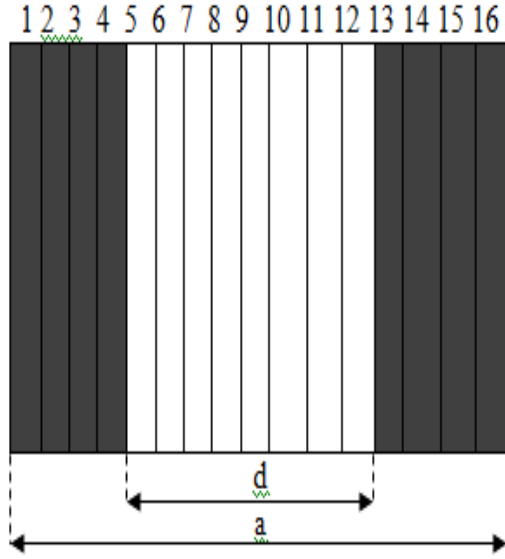


Figure 2. Exemple of Discretization of the iris surface on 16 cells

If we consider only the TE mode, A_0 is along y-axis, which makes that the generated waves are also along y-axis. The process of WCIP is based on the manipulation of incident A_i and reflected B_i waves at the meshed surface (where 'i' is the domain number 1 or 2 in Figure 1). These waves are defined by equations (1) and (2):

$$\begin{cases} A_i = \frac{1}{2\sqrt{Z_{0i}}} (E_i + Z_{0i} J_i) \\ B_i = \frac{1}{2\sqrt{Z_{0i}}} (E_i - Z_{0i} J_i) \end{cases} \quad (1)$$

(2)

The current density is defined by: $\vec{J}_i = \vec{H}_i \wedge \vec{n}_i$, \vec{n}_i is oriented to the area $i \in \{1, 2\}$.

\vec{H}_i and \vec{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 the following equations [14].

$$A = \Gamma B + A_0 \quad (3)$$

$$B = \Gamma_{\Omega} A \quad (4)$$

Where the source is specified through a known vector A_0 added in equation (3).

The transition from the spatial domain (pixel representation) to the spectral domain (modal representation) is insured by the Fast Mode Transformation (1D-FMT) and the reverse Transformation (FMT^{-1}_{1D}) which will be described in the next paragraph. Figure 3 summarizes the iterative process.

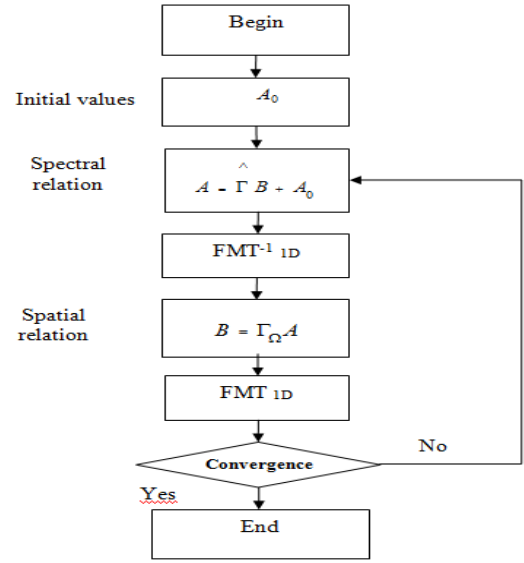


Figure 3. Classic iterative process for spectral the excitation case

2.2 FMT 1D

The 1D-FMT and the 1D-FMT-1 are respectively based on a Fast Fourier transform FFT and an Inverse Fast Fourier Transform FFT-1.

We consider a complex field $E(x, y)$ defined in the spatial domain as:

$$E(x, y) = \begin{cases} e_x(x, y) \\ e_y(x, y) \end{cases} \quad (5)$$

The decomposition of $E(x, y)$ along the modal base is given by:

$$E = \sum_{mn} e^{TE} |f_{mn}^{TE}\rangle + e^{TM} |f_{mn}^{TM}\rangle \quad (6)$$

In the studied case, we consider only TEM0 modes, so that:

$$E_m = \sum_{m0} e^{TE} |f_{m0}^{TE}\rangle \quad (7)$$

With:

$$e^{TE} = \left\langle f_{m0}^{TE} \left| \begin{matrix} e_x(x, y) \\ e_y(x, y) \end{matrix} \right\rangle = \left\langle f_{m0x}^{TE} \left| e_x(x, y) \right\rangle + \left\langle f_{m0y}^{TE} \left| e_y(x, y) \right\rangle \quad (8)$$

The modal functions are given by:

$$\begin{cases} f_{m0x}^{TE} = -N_2 \cos\left(\frac{m\pi x}{a}\right) \sin\left(\frac{0\pi y}{b}\right) \\ f_{m0y}^{TE} = N_1 \sin\left(\frac{m\pi x}{a}\right) \cos\left(\frac{0\pi y}{b}\right) \\ \begin{matrix} 0 \\ N_1 \sin\left(\frac{m\pi x}{a}\right) \end{matrix} \end{cases} = \quad (9)$$

Whith N1 is a constant which depend on the mode nature.

$$N_1 = \frac{m}{a\sqrt{\left(\frac{n}{b}\right)^2 + \left(\frac{m}{a}\right)^2}} \sqrt{\frac{2\sigma_{mn}}{ab}} \quad (10)$$

$$\sigma_{mn} = 1 \quad \text{if} \quad m.n = 0$$

In this case, we have $m.n = 0$, then N1 became

$$N_1 = \sqrt{\frac{2}{ab}}$$

Returning to equation (8), we will obtain:

$$e^{TE} = \langle f_{m0x}^{TE} | e_x(x, y) \rangle + \langle f_{m0y}^{TE} | e_y(x, y) \rangle = \langle 0 | e_x(x, y) \rangle + \left\langle N_1 \sin\left(\frac{m\pi x}{a}\right) | e_y(x, y) \right\rangle \quad (11)$$

Since we have invariance according to y-axis, then e^{TE} can be calculated as:

$$e^{TE} = \left\langle N_1 \sin\left(\frac{m\pi x}{a}\right) | e_y(x) \right\rangle \quad (12)$$

Discretizing the variable x, we obtain $\frac{i}{M} = \frac{x}{a}$

The scalar product becomes:

$$\langle f_{m0y}^{TE} | e_y(x) \rangle = \sum_i^M e_y(i) \sin\left(\frac{m\pi i}{M}\right) \quad (13)$$

Thus, we can define the fast modal transformation 1D-FMT noted Em of Ey as equation (14):

$$E_m = FFT(E_y) e^{i\pi x} \cdot 2.i \cdot \sqrt{\frac{2}{a}} \quad (14)$$

With analogy to the 1D-FMT, the FMT-11D is given by:

$$E_y = \frac{(IFFT(E_m) e^{i\pi x})}{2.i \cdot \sqrt{\frac{2}{a}}} \quad (15)$$

Our goal is to modify the blocs of the 1D-FMT and the 1D-FMT-1 in the classic iterative process and to propose a new algorithm in which we replace the basic FFT and FFT-1 by modified ones taking as input only the relevant data based on a phase jump, in order to perform the calculation without loss of information. The formulation of the new 1D-FMT is developed in the following paragraph.

2.3 New 1D-FMT based on Phase Jump

Our goal is to propose a modified 1D-FMT called PJFMT able to perform the calculation only on the important points from the original vector and to neglect the others without information loss. In order to reduce the computation time, we apply the fast modal transform to the new vector and we should have the same phase and the same amplitude when performing the FFT as if we work with original vectors, in order to converge to the same final result. This will be done

using phase jump when performing the FFT. The relation between the 1D-FMT and the Discret Fourier Transform DFT was given in the previous paragraph.

The discret fourier transform DFT is given by :

$$X_m = \sum_{k=1}^{M-1} x_k w_M^{-mk} \quad (16)$$

With: $w_M = e^{2i\pi/M}$

If we consider a basic vector V of length M containing all the points (x_k) with $0 \leq k \leq M$, from which we extract a reduced set of points ($x_{k'}$) forming a new vector V' of a length M', with $0 \leq k' \leq M'$. We define a new indice s, with $0 \leq s \leq M'$ verifying $x_{k'} = x_s$.

We aim to have this final result:

$$X_m = \sum_{k'} x_{k'} w_M^{-mk'} \quad (17)$$

If we apply the DFT_{1D} to the new vector V' we will have the following result:

$$X_m = \sum_{s=0}^{M'-1} x_s w_{M'}^{-ms} \quad (18)$$

With: $w_{M'} = e^{2i\pi/M'}$

We should have:

$$x_s = x_{k'} \quad (19)$$

But the equality of these two terms doesn't mean the equality of their indices, so we must have:

$$w_{M'}^{-ms} = w_M^{-mk'} \quad (20)$$

If we consider that $M = C \cdot M'$, we should have, with $C = \text{constant}$

$$s = \frac{k'}{C} \quad (21)$$

In fact, if we respect this condition, we will reduce the number of performed operation, and hence we gain in term computation time, without loss of information, since the calculation is done using a phase jump principle in order to have the same phase and amplitude when working with few numbers of points.

In conclusion, the proposed 1D-FMT treats new vectors without loss of information.

In fact, instead of making the sum of all points, the sum is only done on selected points around the discontinuity which form the new vectors having a length M'. The calculation of the FFT is done on new vectors with phase jump in order to converge to the same result. These points are reinsured later, at the end of the iterative process to reconstruct the original vectors describing the structure. Consequently, we gain in terms of calculation time, since the computation is held only on relevant points.

Vectors 'x' and 'X' in the theoretical study designate thereafter the incident and reflected waves A and B in both domains.

2.4 New algorithm

Our goal is to reduce the computation time by the new algorithm. We use the phase jump FMT technique that works on useful points; these ones are located around the discontinuity dielectric - metal of the studied structure. Useful information is extracted from the original vector of length M, describing the structure, and then we construct a new vector of length M'. We do not consider negligible values so that much of points are rejected. In the proposed new algorithm given in Figure 4, the calculation is performed by the phase jump 1D-FMT in order to have the same phase and amplitude when performing the FFT.

The new whole process starts with the classic 1D-FMT which performs a few number of iterations (n) applied to the initial vectors having basic lengths M, until the stability of the process. Then we apply the new algorithm of the 1D-WCIP based on phase jump 1D-FMT to continue the remaining iterations and to achieve the convergence after "N" iterations. At the end, we reconstruct the original vectors. The new algorithm operates with a new 1D-FMT which uses a reduced set of points describing the circuit as input, based on a phase jump when performing the FFT, in order to reduce the computation time and to get a good result.

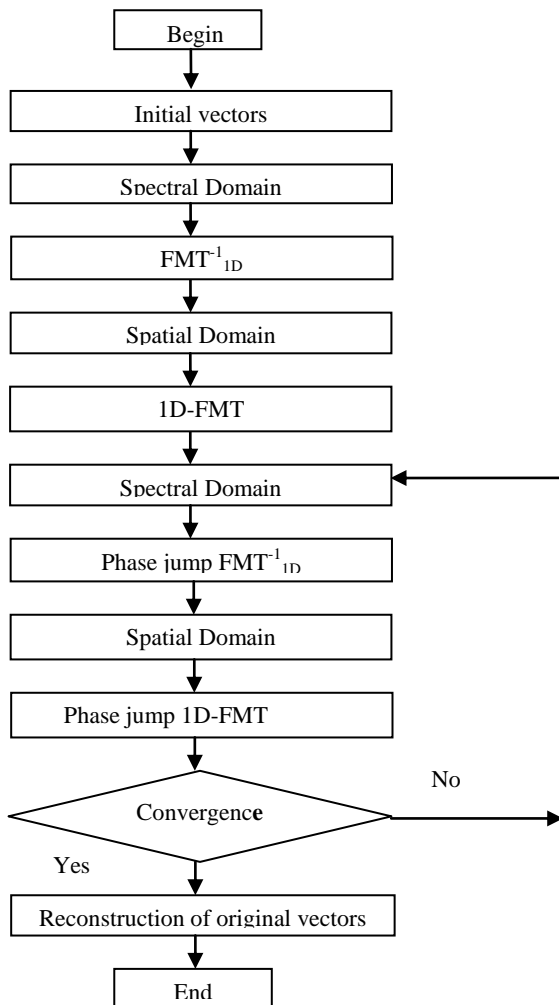


Figure 4. New algorithm

3. SIMULATION RESULTS

Along all that it follows, the studied structure is a vertical iris described by a vector of 32 points, since the electromagnetic field is invariant along y axis.

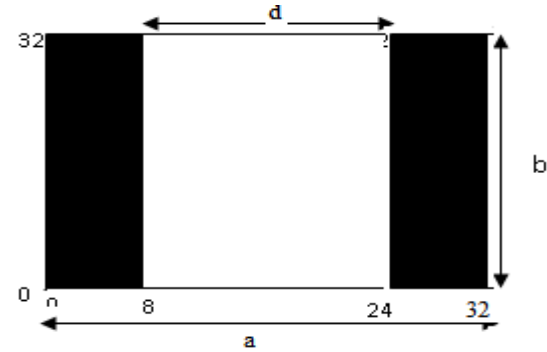


Figure 5. The inductive Iris

The set of geometric features are: $a = 6.4$ cm, $b = 3.2$ mm. The working frequency is $f = 3.24$ GHz.

3.1 Convergence

In figures 6 and 7, we show the variation of S11 and S21 coefficients in function of the number of iterations using two methods: the classic 1D-WCIP with basic 1D-FMT and the new method with phase jump 1D-FMT 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 based on a basic 1D-FMT. Since this number is quite high, it requires an important calculation time. So, to reduce the calculation time required to have a good result, we propose to use a new iterative process in which the basic 1D-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 a phase jump 1D-FMT, which does not take much time to achieve convergence. This new process uses two algorithms: one uses the classic 1D-FMT in which is added a second one in which we use the new 1D-FMT. We show that the final result of the hole system converge also to the optimal values of S11 and S21 when compared to the classic 1D-WCIP .

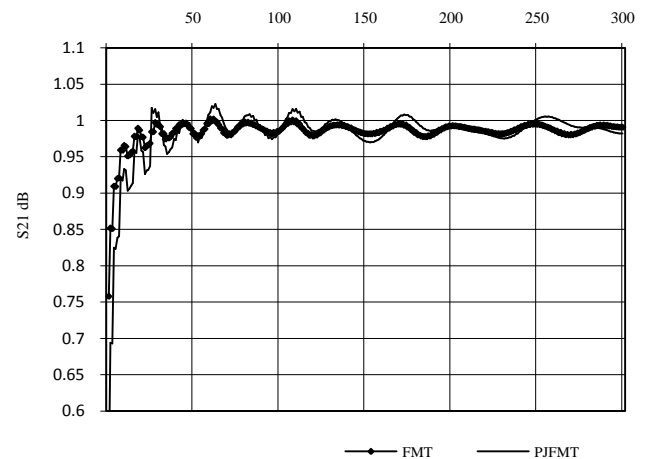


Figure 6. Variation of S21 by both methods

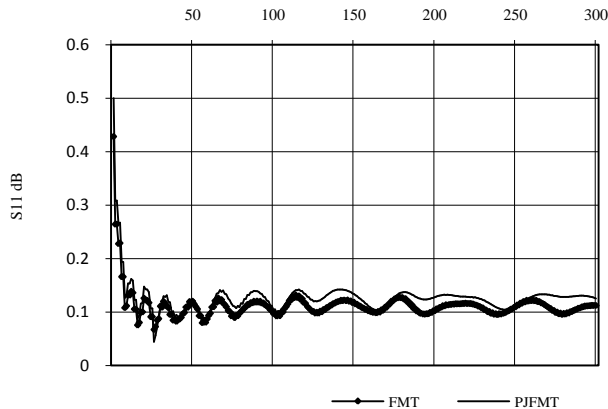


Figure 7. Variation of S11 by both methods

3.2 Variation of S11 and S21 in function of frequency

In figure 8 we show the variation of the coefficients S11 and S21 in function of the frequency. These coefficients are calculated by our new method. These results are compared with those calculated by the basic 1D-WCIP method in order to make sure that our results are optimal ones. The number of iterations calculated by both methods is “N=300” iterations. In the new WCIP 1D method, n is set to 20 basic iterations. Good results are obtained in comparison with the classic method. In fact, in our new method, the basic algorithm with basic FMT 1D which have a large input data is used to calculate only 20 iterations and the following iterations are calculated by the new iterative process based on a phase jump 1D-FMT which works with fewer numbers of input points selected from the original vectors, until the completion of the whole 300 iterations. That is why the new approach takes less calculation time, unlike the classic method WCIP 1D, where all iterations (300) are calculated on vectors of high sizes containing all the points (useful and not useful information). Thus, our main goal which is the reduction of computation time needed to reach the optimal results is performed. Good and optimal results are obtained by the new method. These results were compared to HFSS simulation.

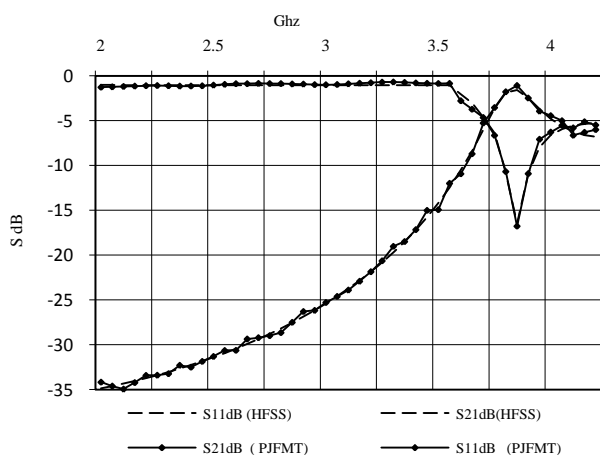


Figure 8. Variation of S21 and S11 by both methods

3.3 Inductive Obstacle Analysis

Figure 9 presents the input reactance of the inductive iris in a frequency range from 2 to 6 GHz, for different values of the ratio of obstacle and waveguide width (d/a). We show that, when the obstacle width increases, the reactance will also increase, what is consistent with the properties of the inductor.

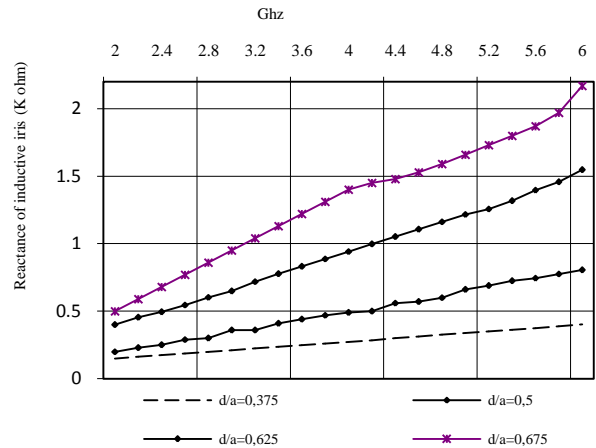


Figure 9. Variation of the reactance for different d/a values

3.4 Gain in time calculation

In this paragraph, the two methods: the classic method 1D-WCIP with basic 1D-FMT and the new method based on a phase jump 1D-FMT are used to calculate the same number of iterations $N=300$ in order to make a comparison between them in term of computation time. In the table below, we observe a significant gain in the time of convergence when calculating the values of the scattering parameters S11 and S21 after N iterations by both methods.

This gain of time is achieved by the new method because we added a modified 1D-FMT based on phase jump which performs the calculation on a fewer numbers of input points doing a phase jump when calculating the FFT 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 1D-WCIP.

Table 1. Gain in time calculation for the initial iteration number $n=20$

n	1D-FMT N=300	1D-PJFMTfor N=300	GAIN
	« Time second »	« Time second »	
20	1.4	0.3	78%

4. COMPARISON AND ANALYSIS

In this section, we compare the results given by the two methods, the classic method 1D WCIP with basic 1D-FMT and the new method based on a phase jump 1D-FMT in order to prove that the new method provides better results.

In fact, if we analyse the results presented in the last paragraphs, we notice that we enhance the convergence of the classic wave iterative method because the new proposed algorithm based on phase jump gives good results and it doesn't take much time to converge to the optimal result. So if we consider the comparison table presented, an important gain in convergence time when calculating S11 and S21 values by the new method “phase jump WCIP” compared to the classical WCIP method, is noticed. This gain of time is provided by the new method for the same number of iteration $N=300$ and the same iris structure discretized in 32×32 pixels.

We can then conclude that the new method provides the same results as the classical WCIP method, but it is very rapid in terms of calculation time. We can explain this by the fact that the WCIP method uses only the classic iterative algorithm to calculate all the 300 iterations which takes much time, while the proposed method uses the classical iterative algorithm to calculate only a few number of 20 iterations when the remaining iterations until 300 are calculated by phase jump algorithm which is more rapid and faster than the classical one. That's why we have this large gain in computing time which is our principal goal and then we have a fast convergence compared to the classic iterative algorithm.

5. CONCLUSION

In this work, we have proposed a new method to improve the speed of the iterative method 1D-WCIP. This method is based on a phase jump 1D-FMT, which perform the calculation only on the useful points of the input vector describing the structure. This approach has been tested firstly, on a simple one-dimensional electromagnetic structure which consists on an inductive iris. The future scope of this idea consists on adapting this new method to more complex circuits in two dimensions 2D described by large matrices, using a correct modification of the FFT2 based on the phase jump principle, and then including this approach in the WCIP_{2D} process.

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