Analysis of Dual-Mode Microstrip Patch Filter using Multiscale Wave Concept Iterative Process

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Abstract ─ An iterative method based on the multiscale approach named multiscale wave concept iterative process (MWCIP) is introduced in this paper. This new approach is an extension of the known wave concept iterative process (WCIP). The specificity of the MWCIP method is the non-uniform meshing with macropixels used to improve the time delay computations of the classical iterative procedure. The method is applied successfully to a nondegenerate dual-mode microstrip patch filter. Comparison between the new and classical iterative methods shows that with the presented approach the CPU time and memory requirement have been considerably reduced.

Index Terms ─ Macropixel, microstrip patch filter, multiscale wave concept iterative process (MWCIP), wave concept iterative process (WCIP).

I. INTRODUCTION

Nowadays, the development of the microwaves domain is accompanied by an increase of the complexity of the circuits with requirement of prohibitive computation time and memory storage. In order to solve these problems, the researches, using multiresolution methods, focus on the multiscale concept appearing in different microwave fields since 1981 by Kunz and Simpson [1] with their "expansion technique" and, also, by Kim and Hoefer in 1990 [2].

Recently, these methods have been used to investigate microstrip circuits in order to employ different meshes as function of the complexity of these features. The different numerical approaches (FEM, FDFD, TLM…) are the subject of very significant evolutions in this field using adaptive grids [3, 4].

For instance, in the moment method, an adaptive multiscale moment method (AMMM) was introduced in 1998 by Su and Sarkar and applied to large diffracted structures with small cavities [5].

In addition, multi-grid approaches based on the wave concept iterative process (WCIP) method, developed by H. Baudrand in 1995 [6], were investigated. In [7], the non-uniform cells are substituted by their equivalent impedances and reintroduced into the coarse grid.

In [8], the authors studied separately the refined mesh parts of the whole structure and introduced the spectral connection to reduce the calculation time. This approach presents some difficulties especially with complex circuits.

In this paper, an original multiscale approach is proposed. It consists in introducing a new meshing grid without extracting the studied zones from the structure. The developed technique is based on the WCIP method. A program in FORTRAN has been elaborated to validate our multiscale approach. It was successfully applied to microstrip transmission line and bandpass filter with a considerable reduction of the computation time.

II. WCIP FORMULATION

The WCIP method was explained in detail in different published articles [9-12]. Therefore, in this section, the general formulation is introduced. This method is a full wave method based on transverse wave formulation. The wave concept is described by writing the transverse electric and current density fields, respectively, E_i and J_i, on the interface Ω, in terms of incident and reflected waves A_i and B_i, respectively. It leads to the following set of equations:

$$\begin{cases} A_i = \dfrac{1}{2\sqrt{Z_{0i}}}\left(E_i + Z_{0i}J_i\right) & (1) \\ B_i = \dfrac{1}{2\sqrt{Z_{0i}}}\left(E_i - Z_{0i}J_i\right) & (2) \end{cases},$$

where Z_{oi} is the characteristic impedance of the ith medium (i=1,2) [9].

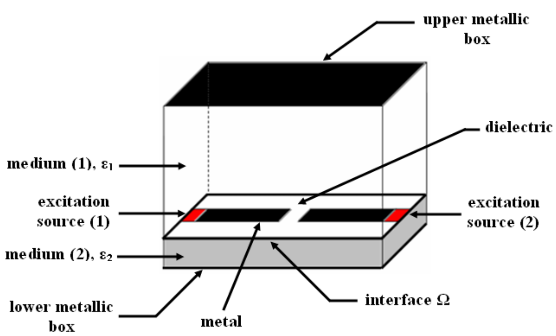

Fig. 1. Configuration of planar circuit structure in the waveguide box.

The air-dielectric interface Ω is divided into pixels and characterized by scattering operation matrix, depending on boundary conditions required on three sub-domains corresponding to metal, dielectric and excitation source shown in Fig. 1. The structure is excited by a planar electric source which generates two waves on both sides of the interface Ω.

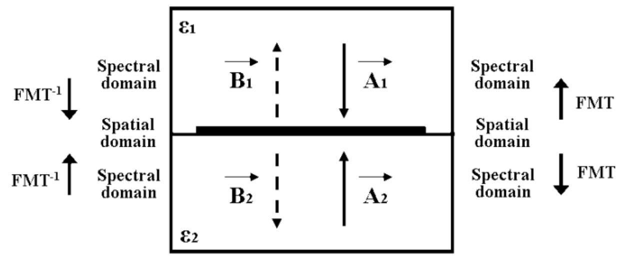

Fig. 2. Illustration of waves on both sides of the interface Ω.

Two operators establish the relations between these waves as follows: the scattering operator $\hat{S}$, related to the spatial domain, links the waves relative to the two different media separated by the surface Ω as shown in Fig. 2.

$$\vec{A}_i = \hat{S}\,\vec{B}_i + \vec{A}_{0i}\,. \qquad (3)$$

The reflection operator $\hat{\Gamma}$, related to the spectral domain, links the incident and reflected waves relative to the corresponding medium as:

$$\vec{B}_i = \hat{\Gamma}\,\vec{A}_i\,. \qquad (4)$$

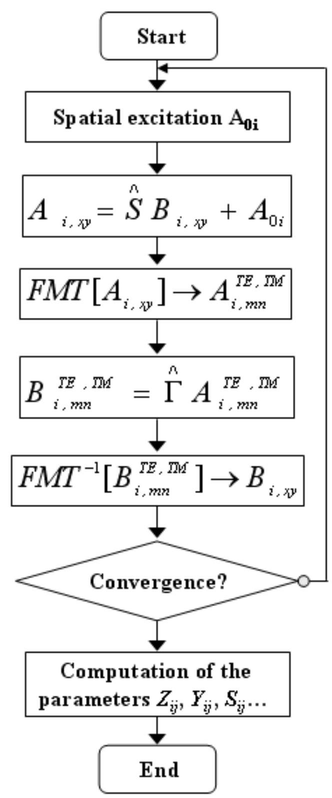

Fig. 3. Schematic description of the classical iterative process.

The implementation of the iterative process consists in establishing a recursive relationship between the waves in both media by using the reflection and scattering operators [9].

A fast modal transform (FMT) and its inverse (FMT^{-1}), based on a fast Fourier transform (FFT), allow the toggling between the spectral and spatial domains given by Fig. 2.

At the n^{th} iteration, the transverse electric and current density fields on the interface Ω are computed. Then, we can calculate the impedance, admittance, and scattering parameters Z_{ij}, Y_{ij}, and S_{ij} respectively, deduced from the following expression:

$$[S] = [1-[Y]]\,[1+[Y]]^{-1}. \qquad (5)$$

The successive iterations are established to determine the relationship between $(A_i,B_i)^{n-1}$ and $(A_i,B_i)^{n}$ corresponding to the $(n-1)^{th}$ and n^{th} iteration. The iterative process continues until reaching the convergence of E_i and J_i fields calculated from (1) and (2) equations above. A schematic description of the classical WCIP algorithm is illustrated in Fig. 3.

III. MULTISCALE APPROACH

A. Coupling between two macropixels

In this part, the coupling between two consecutive macropixels of the grid is realised only by the "fundamental modes" which are the slightly attenuated modes. So, the high-order modes are localized on their macropixels. The coupling between two high-order modes can be neglected if it is smaller than a ten percent of the coupling between fundamental modes [13]. The fundamental and high-order modes are defined as transverse electric field of a waveguide bounded by periodic walls.

B. Definition of a new meshing grid

The contribution introduced, in this paper, consists in considering non-uniform meshing but with the classical iterative method where all cells have the same surface. In the spatial domain of the improved method, the whole structure is divided into macropixels which are subdivided into pixels as function of the necessary precision. This new meshing grid is shown in Fig. 4.

The choice of this improved meshing grid should appear a maximum number of uniform macropixels where the scattering operator $\hat{S}$ is constant (-1 for metal and 1 for dielectric). So the computation time is reduced significantly because its calculation became useless.

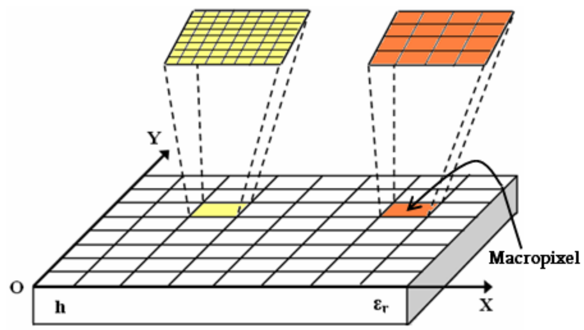

Fig. 4. The new meshing grid.

The whole structure is meshed with $N_1 \times N_2$ pixels in classical iterative method. But, in the improved WCIP method, it is meshed with $N_{01} \times N_{02}$ macropixels where each one is divided into $n_{01}^{\alpha\beta} \times n_{02}^{\alpha\beta}$ pixels as shown in Fig. 5. The indexes α and β represent the position of the considered macropixel in the new meshing grid where:

α is the macropixel position in the X-direction.

β is the macropixel position in the Y-direction.

The number of operations decreases with this new meshing from $[N_1 \times N_2 \times \ln(N_1 \times N_2)]$ to $[N_{01} \times N_{02} \times \ln(N_{01} \times N_{02}) + n_{01}^{\alpha\beta} \times n_{02}^{\alpha\beta} \times \ln(n_{01}^{\alpha\beta} \times n_{02}^{\alpha\beta})]$ and it can be reduced more in the presence of uniform macropixels considering that $(N_1 \times N_2) \rangle\rangle (N_{01} \times N_{02})$.

This reduction is significant especially when complex structures, requiring an important resolution, are investigated. Therefore, it avoids an excessive computational storage and simulation times for bulky devices.

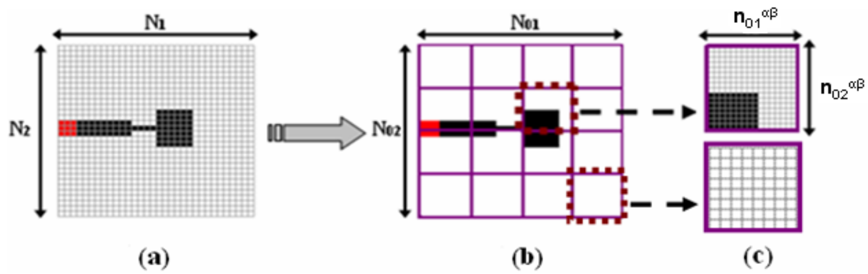

Fig. 5. (a) Classical WCIP meshing, (b) whole structure's meshing in MWCIP, (c) uniform and non-uniform macropixels meshing.

C. Multiscale wave concept iterative process (MWCIP)

In this section, the improved iterative method named multiscale wave concept iterative process (MWCIP) is described.

For each iteration, the fundamental modes $A_{ix,y}{}^{\alpha\beta}$ relative to the (α,β) macropixel are computed as follows:

$$A^{\alpha\beta}_{i,xy} = \frac{1}{k^{\alpha\beta}} \sum_{M=1}^{k^{\alpha\beta}} a^{\alpha\beta\ M}_{i,xy}\, e^{j\left(\frac{2\pi p}{a}x + \frac{2\pi q}{b}y\right)}, \qquad (6)$$

where

$$k^{\alpha\beta} = n^{\alpha\beta}_{01} \times n^{\alpha\beta}_{02}.$$

a and b are the (α,β) macropixel's dimensions.

Then, they are extracted from the reflected waves $a_{ix,y}{}^{\alpha\beta}$ to give the high-order ones $a'_{ix,y}{}^{\alpha\beta}$.

To toggle to the spectral domain, a FMT is applied either to the fundamental modes or the high-order ones. After multiplying the modes' amplitudes $a'^{\,TE,TM\,\alpha\beta}_{i,mn}$ by the corresponding reflection operators $\hat{\Gamma}_i^{\alpha\beta}$, a FMT^{-1} allows to return to the spatial domain where the incident waves $B_{ix,y}$ and $b'_{ix,y}{}^{\alpha\beta}$ are recombined.

In order to calculate the amplitudes of the reflected waves relative to the next iteration, the scattering operators $\hat{S}^{\alpha\beta}$ relative to each macropixel are introduced.

In the same way, the iterative process of the improved scheme, depicted in Fig. 6, continues until reaching the convergence of the transverse electric E_i and current density J_i fields.

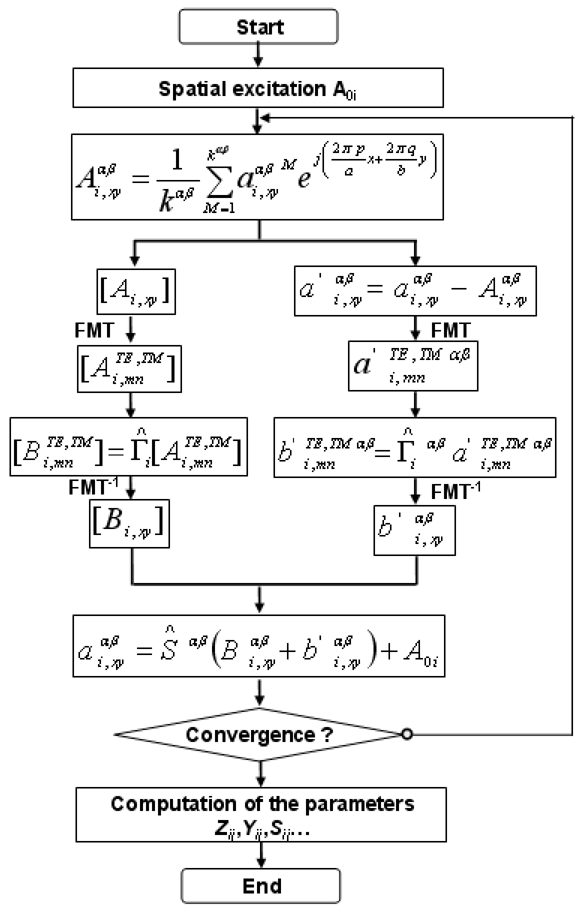

Fig. 6. Schematic description of the MWCIP.

IV. APPLICATIONS

A. Microstrip transmission line

To validate our new multiscale approach, a microstrip transmission line was studied. It is characterized by its length L=21.0 mm and its width w=4.0 mm. The substrate dielectric parameters are fixed with h=1.0 mm and ε_r=9.6. The waveguide box parameters are W=8.0 mm and H=4.0 mm. Fig. 7 shows the layout of the investigated structure.

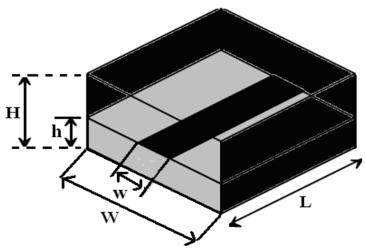

Fig. 7. Layout of the microstrip transmission line.

If the length of this transmission line is L=λ/2, the corresponding theoretic resonant frequency would be:

$$f_{res} = \frac{C}{2 \times L \times \sqrt{\varepsilon_r}} = 2.3GHz \qquad (7)$$

where λ is the wavelength and C is the velocity of electromagnetic wave in free space.

The convergence of the return loss coefficient S_{11} was reached at the 150th iteration as shown in Fig. 8.

The input impedance imaginary part against frequency is simulated. The comparison between the WCIP and the MWCIP results, illustrated by Fig. 9, shows a good agreement. It can also confirm the theoretical resonant frequency calculated.

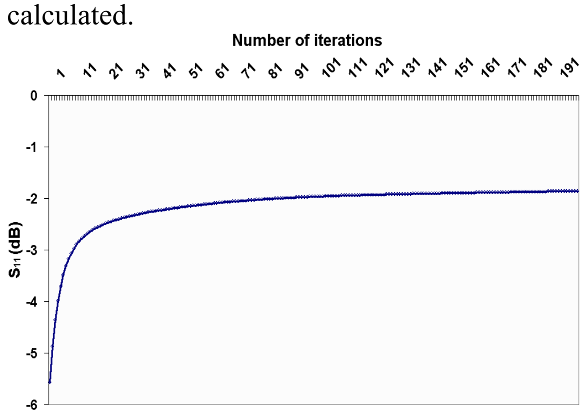

Fig. 8. The convergence of the return loss S_{11}.

In the WCIP method, 64×16 pixels are used corresponding to $N_1 \times N_2$ pixels. However, in our improved method MWCIP, 8×2 macropixels are used corresponding to $N_{01} \times N_{02}$ resolution. Each one is subdivided into 8×8 pixels corresponding to $n_{01}^{\alpha\beta} \times n_{02}^{\alpha\beta}$ resolution.

The number of operations is reduced more than three times, from 7100 operations with the classical WCIP method to 2174 operations with the improved one.

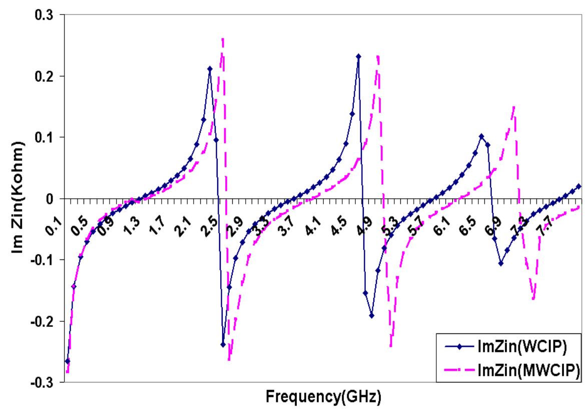

Fig. 9. Simulation of the input impedance imaginary part against frequency.

B. Dual-mode bandpass filter

After validating our new approach for a simple structure, a nondegenerate dual-mode microstrip patch filter is investigated. The proposed filter is based on a square microstrip patch with four symmetrically etched slots as shown in Fig. 10.

The square patch has a length of W=17.0 mm, while the slots have equal lengths L=6.0 mm and widths S=1.0 mm. It is excited with asymmetric direct-feed 50 Ω microstrip lines of 1.0 mm length at the corners, as shown in the patch filter's layout. The studied filter is developed on duroid material with ε_r=10.2 and 0.635 mm thickness [14].

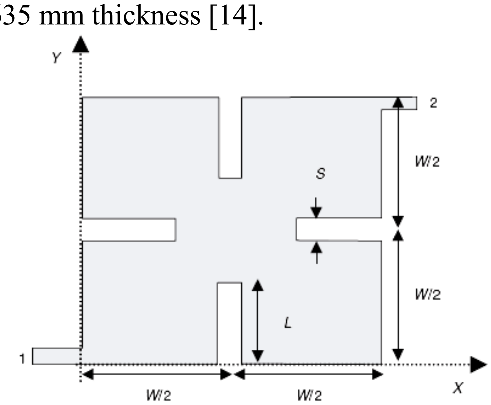

Fig. 10. Layout of the dual-mode bandpass filter.

The MWCIP is applied to this structure in order to simulate the return loss against frequency for two different values of the slot length (L=4.0 mm and L=6.0 mm) and the same width S=1.0 mm. The results shown in Fig. 11 confirm the effect of the slot length on the investigated filter; when L increases the filter behavior shifts to lower frequencies and the bandwidth becomes narrower [14].

Good agreement between simulated results given by our new approach and the IE3D simulator is observed particularly for L=6.0 mm. It confirms the accuracy of the MWCIP method.

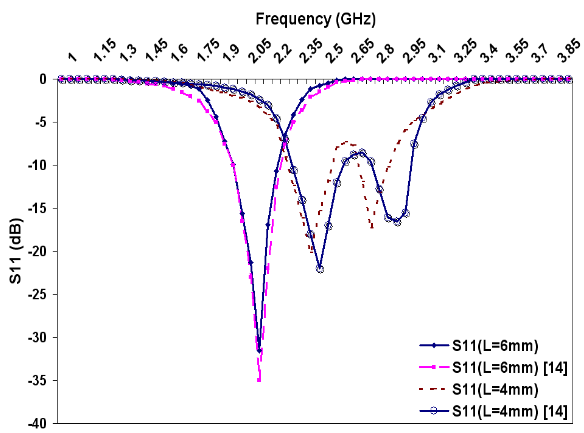

Fig. 11. Comparison of the simulated returns loss against frequency between MWCIP and [14] for two slot lengths.

For this simulation, 4×4 macropixels are subdivided to 16×16 pixels each one as shown in Fig. 12. The total computation time was 17mn 12s for 60 frequency points (17.2s per frequency point).

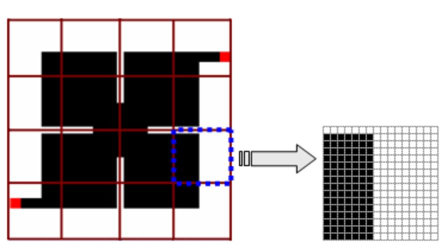

Fig. 12. Meshing applied to the bandpass filter in MWCIP method.

A wider bandwidth is investigated using the WCIP and MWCIP methods in order to compare their results with the simulated and measured ones [14] shown by Fig. 13 that reveals a good agreement. Four resonant frequencies and a better rejection are observed.

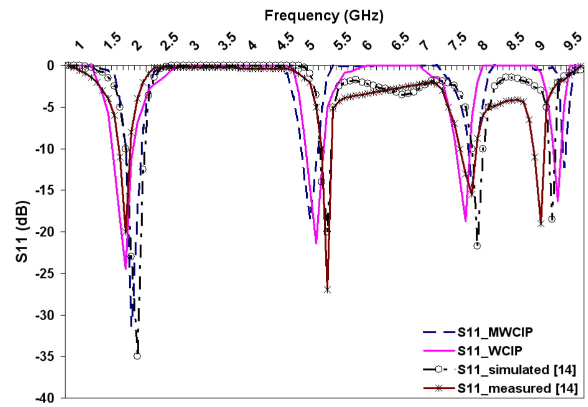

Fig. 13. Simulated return loss against frequency.

Table1: Comparison of the CPU time between WCIP and MWCIP methods

	WCIP	MWCIP
Pixel number	128×128	8×8 macropixels + 16×16(for each macropixel)
Iteration number	300	300
Computation time	1h 16mn 37s	45mn 33s
1 iteration CPU time	51s	30.48s
Operatio N number	159×10^3	91119

The computation time and the number of operations between the classical iterative method and the improved one are criticized.

The table shows that the CPU time computation is reduced for the same number of iterations. Also, the number of operations decreases from 159×10^3 to 91119 with the MWCIP which gives a ratio of 1.75.

V. CONCLUSION

The formulation of the multiscale iterative method was described. The computation time and the requirements in data-processing memory were considerably reduced in relation to the classical WCIP. The results obtained with the two investigated circuits prove the efficiency of our approach and its agreement with the published ones.

Consequently, the present approach will be studied for further new applications and its performances will have to be improved.

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