Bulletin of Electrical Engineering and Informatics
ISSN: 2302-9285
Vol. 5, No. 2, June 2016, pp. 187~193, DOI: 10.11591/eei.v5i2.613

Electromagnetic Modeling of Active Circuit using Wave Concept Iterative Process

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Abstract

The wave concept iterative process is a procedure used for analyses planar circuits, this method consists in generating a recursive relationship between a wave source and reflected waves from the discontinuity plane which is divided into cells. A high computational speed has been achieved by using Fast Modal Transform (FMT). In this paper we study a patch antenna and MESFET transistor, to determine the electromagnetic characteristics of these structures.

***Keywords**: WCIP, Planar circuit, FMT, Patch antenna, MESFET*

1. Introduction

The MESFET or GaAs FET as it is also called is a high performance form of field effect transistor that is used mainly for high performance microwave applications and in semiconductor RF amplifiers. The abbreviation MESFET stands for Metal-Semiconductor Field Effect Transistor. GaAs FET standars for Gallium Arsenide, the substance from wich this FET or field effect transistor is made. [9], [10] The GaAs FET or MESFET shares many features with the standard junction FET or JFET, although the MESFET is able to offer superior performance, especially in the region of RF microwave operation, especially for use within RF amplifiers. [1]

In this paper, an iterative method is applied to active circuit, it consist in successive reflection between the circuit plan and its two sides. It also has an alternative behavior between space and spectral domains. In addition the discontinuity plan is divided into cells and characterized by scattering operator matrix depending on the boundary conditions. [2]

This analysis is applied to calculate the S parameters of rectangular waveguide including a MESFET transistor.

2. The Theoretical Basis

2.1. Definition of the WCIP

WCIP method is based on full wave transverse wave formulation and the collection at the interfaces. A multiple reflection procedure is started using initial conditions and stopped once convergence is achived. Two operators relating incident waves and scattered waves in the spatial domain and in the spectral domain governs the scattering operator $\hat{S}$ and the reflection operator $\hat{\Gamma}$.

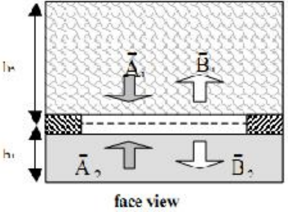


Figure 1. The Process Iterative [3]

Received November 4, 2015; Revised January 16, 2016; Accepted February 28, 2016

The wave concept iterative process WCIP is defined as [4], [5]

$$\begin{aligned}\vec{A} &= \hat{S}\vec{B} + \vec{A}_0 \\ \vec{B} &= \hat{\Gamma}\vec{A}\end{aligned} \tag{1}$$

Where the incident waves $\vec{A}$ and the scatered waves $\vec{B}$ are calculated from the tangentiel electric and magnetic fields $\vec{E}$ and $\vec{J}$:

$$\begin{aligned}\vec{A}_i &= \frac{1}{2\sqrt{Z_{0i}}}\left(\vec{E}_i + Z_{0i}\vec{J}_i\right) \\ \vec{B}_i &= \frac{1}{2\sqrt{Z_{0i}}}\left(\vec{E}_i - Z_{0i}\vec{J}_i\right)\end{aligned} \tag{2}$$

Z_{0i} is the characteristic impedance of the same medium

i indicates the medium 1 or 2

$\vec{J}_i = \vec{n} \wedge \vec{H}_i$ is the density of courant

2.2. The Reflection Operator $\hat{\Gamma}$

The reflection operator $\hat{\Gamma}$ is deduced from the admittance operator $\hat{Y}$ and the wave's definition in (3)

$$\Gamma^{\alpha}_{mn} = \sum_{mn} \left\langle f^{\alpha}_{mn} \left| \frac{1 - Z_{0i} Y^{\alpha}_{mn}}{1 + Z_{0i} Y^{\alpha}_{mn}} \right| f^{\alpha}_{mn} \right\rangle \tag{3}$$

$$\begin{aligned}Y^{TE}_{mn}(\varepsilon_r) &= \frac{\gamma_{mn}(\varepsilon_r)}{j\omega\mu_0} \\ Y^{TM}_{mn}(\varepsilon_r) &= \frac{j\omega\varepsilon_0\varepsilon_r}{\gamma_{mn}(\varepsilon_r)}\end{aligned} \tag{4}$$

2.3. The Scattering (Diffraction) Operator $\hat{S}$

The scattering operator $\hat{S}$ is deduced from the equivalent circuit on each sub domain of the interface S. the boundary conditions is expressed for fields in the next equation:

$$\begin{aligned}&\vec{E}_1 = \vec{E}_2 = \vec{0} && \text{on the metal} \\ &\vec{E}_1 = \vec{E}_2 \neq \vec{0} \text{ and } \vec{J}_1 + \vec{J}_2 = \vec{0} && \text{on the isolante} \\ &\vec{E}_1 = \vec{E}_0 - Z_0\left(\vec{J}_1 + \vec{J}_2\right) = \vec{0} && \text{on the source}\end{aligned}$$

Moreover, since operators ($\hat{\Gamma}$ and $\hat{S}$) are defined in both the space and the spectral domains, the iterative process implies switching between these domains, which is ensured by the fast mode transform (FMT) and its inverse.

2.4. Definition of Fast Modal Transformation FMT in Periodic Wave Guide

The classic 2D Fast Fourier Transformation of the waves A_{ix}, A_{iy} is defined as following:

$$\begin{aligned}\left| A_x(x, y) \right\rangle &= \sum_{mn} A_{xmn} \left| e^{-j\beta_{xm} x} e^{-j\beta_{ny} y} \right\rangle \\ \left| A_y(x, y) \right\rangle &= \sum_{mn} A_{ymn} \left| e^{-j\beta_{xm} x} e^{-j\beta_{ny} y} \right\rangle \\ \beta_{xm} &= \frac{2m\pi}{a} \quad \beta_{ym} = \frac{2m\pi}{b}\end{aligned} \tag{5}$$

Where $\beta_{xm} = \frac{2m\pi}{a}$ $\beta_{ym} = \frac{2m\pi}{b}$ are the Fourier coefficients

We project the vectors $A(x,y)$ in the complete set of modes corresponding to rectangular periodic wave guide $\left| f^{\alpha} \right\rangle$.

$$\begin{aligned} \left| A_x(x,y) \right\rangle &= \sum_{mn} A_{xmn}^{TE} \left| f_{mn,x}^{TE} \right\rangle + \sum_{mn} A_{xmn}^{TM} \left| f_{mn,x}^{TM} \right\rangle \\ \left| A_y(x,y) \right\rangle &= \sum_{mn} A_{ymn}^{TE} \left| f_{mn,y}^{TE} \right\rangle + \sum_{mn} A_{ymn}^{TM} \left| f_{mn,y}^{TM} \right\rangle \end{aligned} \tag{6}$$

Projecting the equation (6) in the set of modes, we can deduce:

$$\begin{aligned} \sum_{mn} A_{mn}^{TE} &= \left\langle f_{mn,x}^{TE} \middle| A_x(x,y) \right\rangle + \left\langle f_{mn,y}^{TE} \middle| A_y(x,y) \right\rangle \\ \sum_{mn} A_{mn}^{TM} &= \left\langle f_{mn,x}^{TM} \middle| A_x(x,y) \right\rangle + \left\langle f_{mn,y}^{TM} \middle| A_y(x,y) \right\rangle \end{aligned}$$

(7)[6][8]

3. Modelisation and Resultes

The new formulation of the iterative method is applied to two different structures: a patch antenna and multilayered structure.

3.1. Simulation of Patch Antenna

The proposed approach is first checked by considering the structure given in Figure 2. This structure consists of a patch antenna connected to a microstrip line section. The box size is 35*64 mm. The substrate characteristics are ε =4.78 with a thickness of 0.79 mm. The line is 20 mm long and 2.34 mm wide, and the patch is 0.11387 mm wide and 1.5 mm long. Here, the patch is simulated using an iterative method. First, verified the convergence of the method (Figure 6a). The patch must be 1.5 mm long and the excitation frequency is f = 19.6 GHz. The results of frequency simulation have printed in the Figure 6b.

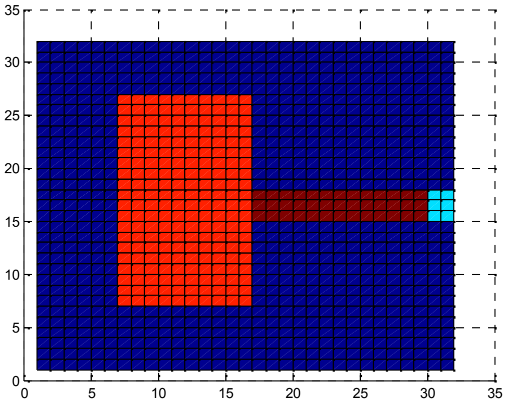


Figure 2. The Electromagnetic Structure

The previous boundary conditions in the sub domains composites the dielectric interface have verified by the following three-dimensional curves.

The convergence test of the input impedance viewed by the source exciting is shown in Figure 5a. We see that, it is enough, approximately 144 iterations, to ensure the convergence of the iterative method WCIP.

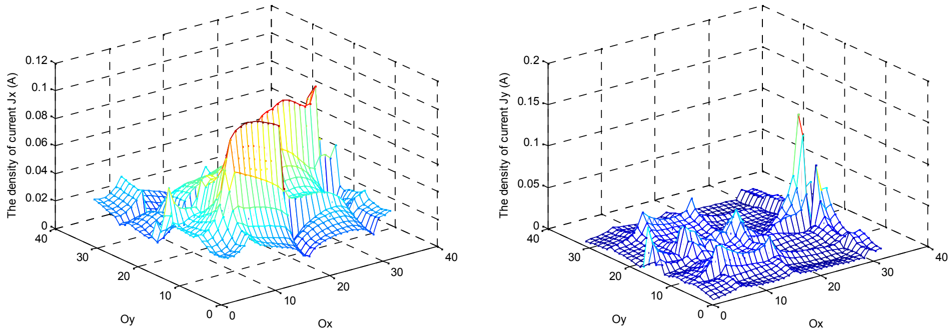


Figure 3. Current density Ji of Patch Antenna

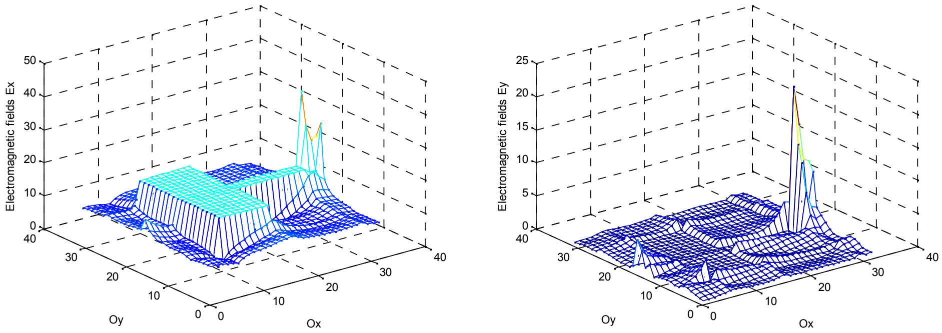
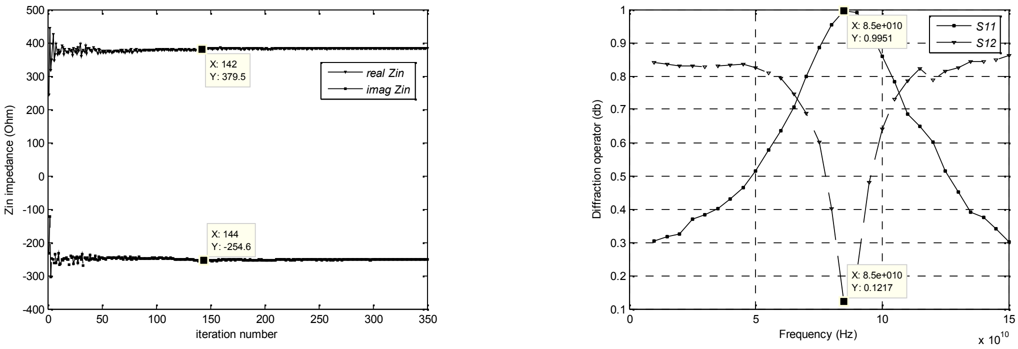


Figure 4. Electromagnetic Fields Ei of Patch Antenna



(a) (b)

Figure 5. (a) Imaginary and Real Part of Zin as Function of Iteration Number (b) Diffraction Operator asFunction of Frequency

The resonance frequencies of antenna patch can be detected by the evolution of the diffraction operator as function of frequency as shown in the previous figure. This resonance frequency is 8.5GHz.

3.2. Application of The WCIP to the MESFET

The analysis structure is composed of a rectangular waveguide closed from both sides. As described in Figure 2, the discontinuity plane Ω is divided into cells and includes four sub domains: isolated, metal, source and MESFET transistor. The dimensions of the electromagnetic structure are a=b=25mm and the substrate characteristics are epsr=4.73 and thickness of 1.47 mm. We simulate this structure with 32*32 resolutions.

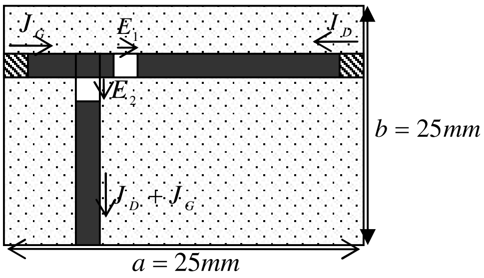


Figure 6. The discontinuity plane Ω

The boundary conditions to the sub domains have verified with the graphics of Figure 7.

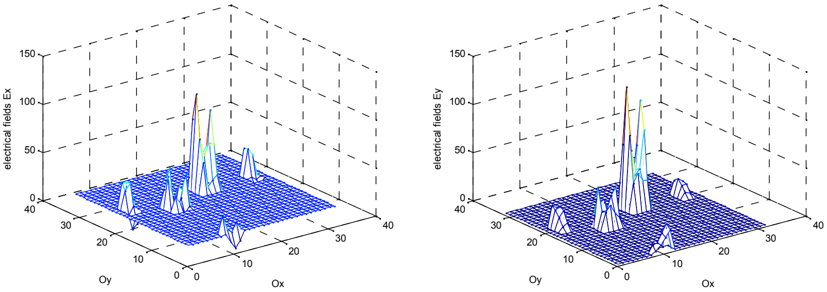
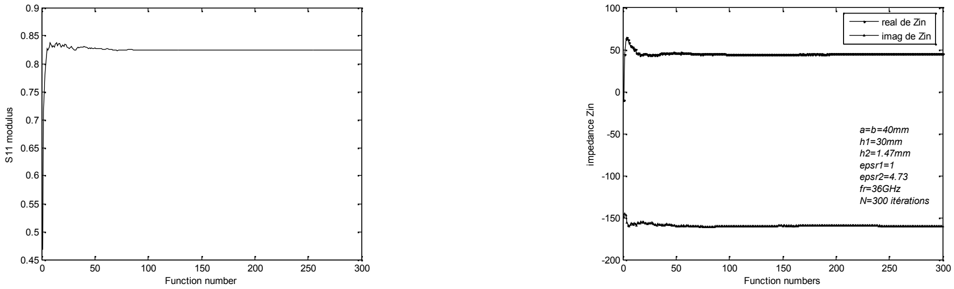


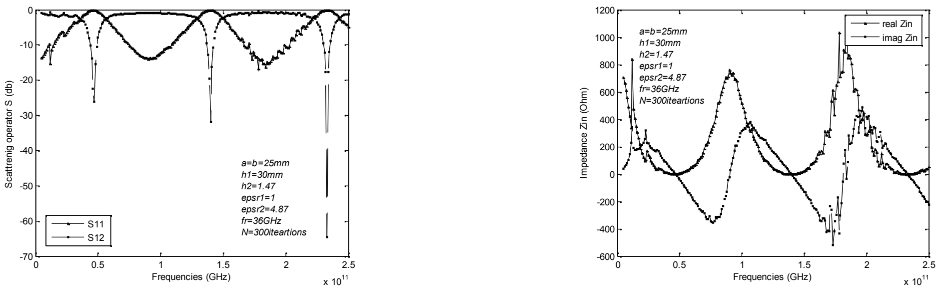
Figure 7. The electrical fields to the sub domains: metal, dielectric, source and transistor.

The determination of the discontinuity's characteristics requires a convergence study, Figure 8 shows that, the modulus of the transmission coefficients converge (90 trial functions with 300), and the Zin converge with 50 functions.



(a) (b)

Figure 8. Convergence of WCIP (a) variation of S11 against number of functions; (b) variation of Zinagainst number of functions



(a) (b)

Figure 9. (a) The diffraction operator S; (b) The impedance Zin as a fuction of frequency

In the figure 10 the diffraction operator is ploted against frequency, this traces shows the schift in resonnant frequency f= “45 – 140 – 235 GHz”

After this simulation, we study the effect of the box characteristic on the diffraction operator values, from the following traces,

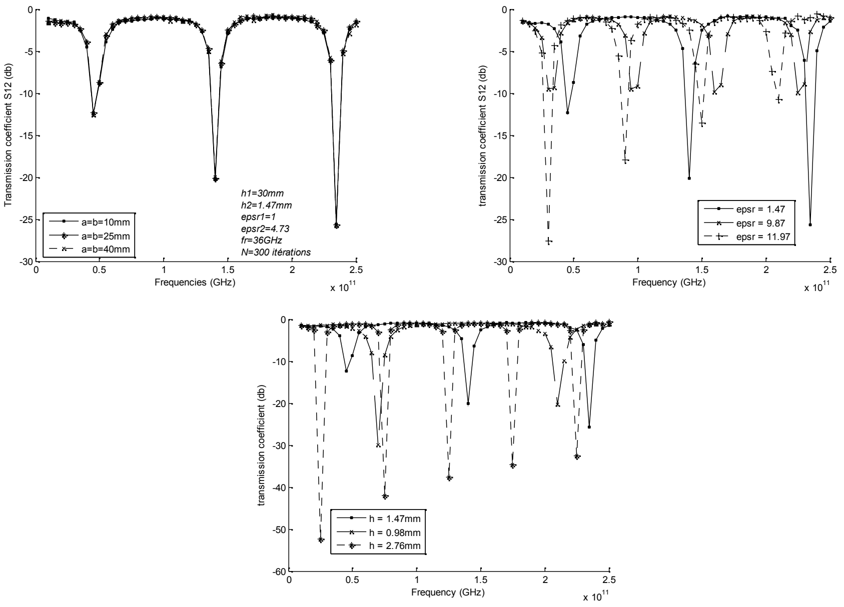


Figure 10. The transmission coefficient S12 as a function of frequency

The previously figures determined the effect of the boxing characteristics of the transmission coefficient when the box size does not matter on the resonance frequency, but the material and the thikness of the dielectric substrate changes the values of the reflection coefficient and the resonance.

This change has been created from the composition and atomic structures of dielectric or semi conductor substrate, then we recall, the silicium is well suited for the diffraction and transmission of electromagnetic waves in the MESFET structures.

4. Conclusion

This paper is performed the transmission of electromagnetic waves on patch antenna and MESFETs, she confirms that the WCIP method is also highly flexible and efficient for this type of electronic components

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