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Characterization Of Switchable And Multilayered FSS Circuits Using The WCIP Method

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Abstract
In this paper, we use the Wave Concept Iterative Procedure (WCIP) to study the Switchable and multilayered FSS (Frequency Selective Surface) circuits. The Switchable part is used for the adjustment of the frequency of the HF Electronics Circuits. This adjustment is applied by the integration of RF-MEMS switches. This system is based on the use of circuit fabrication processes included. In order to initialize the iterative procedure, an incident wave is defined in the spectral domain.

I. INTRODUCTION.

The FSS circuits are composed of a periodic arrangement of metallic elements or openings in a metal plane of study circuits. They may be periodic in one or two directions. In the recent development of antennas and microwave technology[10]. These structures have an important role, they provide a total reflection or transmission of signals in certain frequency bands. We can regulate the frequency of resonance by integrating a PIN diode, FET, or RF MEMS switch [1].

Communication systems of microwave are based on the MEMS technology. They are designated by the initials RF MEMS. We can observe several types of components that come from this technology. We take the case of RF MEMS switches. The RF-MEMS switches as a mechanical movement to allocate a switching of the RF transmission line [2-3]. These switches offer several advantages, among these advantages include low power consumption, low insertion loss and quality factor [4]. Their application areas are extensive and always tend to grow. Switching techniques and the air bridge technology and technique of micro beam are the useful cases [5]. The contact switch is the equivalent of the RF-MEMS switch. It has two states of commutation: the state ‘‘off’’ and the state ‘‘on’’. In a blocked state, the switch has a capacitive behaviour, with the state passing; it is comparable to a resistance representing the losses of a metal/metal contact [1]. The study will focus on resistive switch (cantilever). These components have many advantages: abridged losses, more compact and passive components. This type of circuit simulation is one of the most important steps of modelling.

In the last few years, the FMT-WCIP method has been applied in a wide variety of microwave structures [6]. This method has most important advantages over other methods. These advantages are concerned, in special, the execution rapidity of the resolution procedure and the arbitrary form of the understudied structure. Besides this iterative technique uses a rapid FMT transformation which ensures a rapid transition between the spectral and spatial domains [6-8]. We unite the wave concept with the two dimensions fast Fourier transformation (2D-FFT) algorithm to change the domain. The use of the 2D-FFT algorithm is required to mesh the circuit plane into 2D small rectangular pixels. Hence, the boundary conditions are satisfied at each pixel. By using the 2D-FFT algorithm, a high computational speed can be achieved [7-9].

The purpose of this paper is to extend the WCIP method to the analysis of the integration of Microsystems performance (MEMS) in circuit materials, periodic FSS (infinite number of unit cells) with arbitrary angle of incidence in the one layer configuration of dielectrics [1-4]. An example will be studied; overall substrate less_FSS structure, our simulation results are validated with published data.

II. THEORY.

In the WCIP method, the FSS is seen as a periodic structure. Its (analysis is reduced to the analysis of the repeated structure and the unit cell. The periodic walls are represented by dashed lines in Fig. 1

We consider a periodic arbitrary one-layer structure. Fig. 2 represents the unit cell of periodic circuit. This interface can support the circuit and includes three sub-domains metal Mi, dielectric Di, and switch Swi. We suppose that the electromagnetic field is identified on all points of the plane interface.

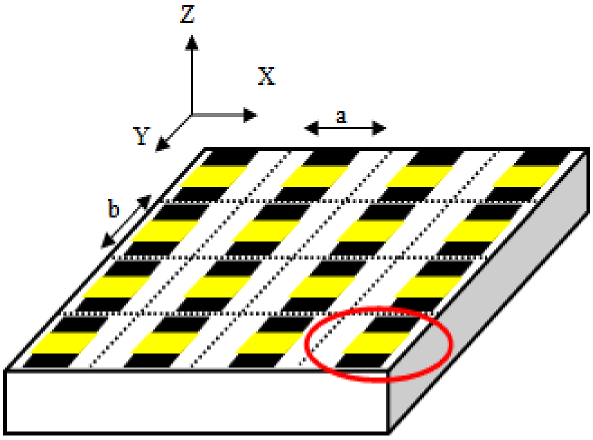

Figure. 1. Geometry of arbitrarily shaped FSS.

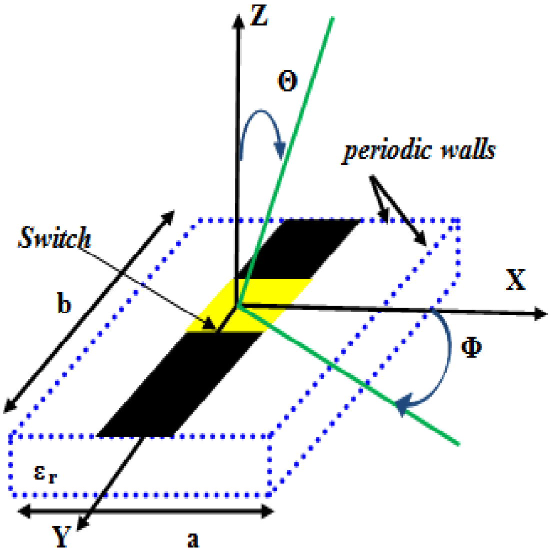

Figure.2. Unit cell of the periodic structure with arbitrary incidence A00.

The answer of the problem has to satisfy the following boundary conditions:

$$\begin{cases} E_{T1} = E_{T2} = 0 & Metal(M) \\ J_T = J_{T1} + J_{T2} & Dielectric(D) \\ J_{sw} = y_{sw} E_{sw} & Switch(SW) \end{cases} \quad (1)$$

In the first equation, ET1 and ET2 are the tangential components of the electric field of media (1) and (2), respectively, and J_{T1} and J_{T2} are the corresponding current density. E_{SW}, J_{SW}, and y_{SW} are the electric field, the current density, and the admittance equivalent circuit of the switch domain respectively.

In the switch domain, the electric field and the current density are related to the potential and electric current as follows:

$E_{sw} = \frac{V_1}{G}$; $J_{sw} = \frac{I}{W}$ (2); This *enables us to write*

$$\frac{J_{sw}}{E_{sw}} = \frac{I}{V_1}\left(\frac{G}{W}\right) = Y_{sw}\left(\frac{G}{W}\right) = y_{sw} \quad (3)$$

As present on Fig.3, the incident waves A_i and the scattering waves B_i are given in the terms of the transverse electric E_{Ti} and magnetic fields H_{Ti} at the circuit interface (Ω). This leads to the following set of equations:

$$\begin{cases} A_i = \frac{\sqrt{y_{0i}}}{2}\left(E_{Ti} + \frac{1}{y_{0i}}(H_{Ti} \times n)\right) \\ B_i = \frac{\sqrt{y_{0i}}}{2}\left(E_{Ti} - \frac{1}{y_{0i}}(H_{Ti} \times n)\right) \end{cases} \quad (4)$$

On the switch:

y_{0i} is an intrinsic admittance characterizing the medium, i denotes the two media biased Ω (i=1 and 2), which can be defined as: $y_{0i} = \sqrt{\frac{\varepsilon_0 \varepsilon_{ri}}{\mu}}$ with ε_0, μ_0, and ε_{ri} are the permittivity and permeability of the vacuum and the relative permittivity of the medium 'i' respectively. n is the outward vector normal to the interface.

The surface current density is introduced as being $J_{Ti} = H_{Ti} \times n$.

On the metal:

$$\left\{ \begin{vmatrix} B_i \\ B_i' \end{vmatrix} = [S_{M\,i}] \begin{vmatrix} A_i \\ A_i' \end{vmatrix} \right\}_{x,y}, [S_{M\,i}] = \begin{vmatrix} -1 & 0 \\ 0 & -1 \end{vmatrix} \quad (5)$$

On the dielectric:

$$\left\{ \begin{vmatrix} B_1 \\ B_2 \end{vmatrix} = [S_D] \begin{vmatrix} A_1 \\ A_2 \end{vmatrix} \right\}_{x,y}, \quad (6)$$

$$[S_D] = \begin{bmatrix} \frac{1-n_{12}}{1+n_{12}} & \frac{2n_{12}}{1+n_{12}} \\ \frac{2n_{12}}{1+n_{12}} & -\frac{1-n_{12}}{1+n_{12}} \end{bmatrix}, \quad (6)$$

Where:

$$n_{12} = \frac{y_{01}}{y_{02}}.$$

$$\left\{\begin{vmatrix} B_1 \\ B_2 \end{vmatrix} = \left[S_{SW}\right] \begin{vmatrix} A_1 \\ A_2 \end{vmatrix}\right\}_{x,y}, \quad (7) \quad \left[S_{SW}\right] = \begin{bmatrix} \dfrac{-1-n_{s1}+n_{s2}}{1+n_{s1}+n_{s2}} & \dfrac{2n_s}{1+n_{s1}+n_{s2}} \\ \dfrac{2n_s}{1+n_{s1}+n_{s2}} & -\dfrac{1+n_{s1}-n_{s2}}{1+n_{s1}+n_{s2}} \end{bmatrix}, \quad n_{s1} = \frac{y_{sw}}{y_{01}}, n_{s2} = \frac{y_{sw}}{y_{02}} \text{ and } n_s = \frac{\sqrt{y_{01}y_{02}}}{y_{sw}}$$

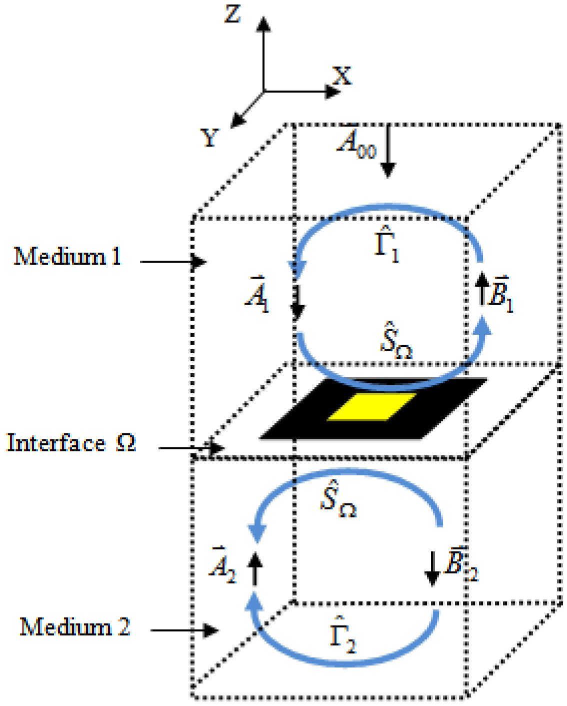

Figure. 3. Definition of waves for the single-layer structure.

With equations (6), (7), and (8), we can assume the global spatial equation that relates the incident waves on all the interfaces.

$$\left\{\begin{vmatrix} B_1 \\ B_1^{'} \end{vmatrix} = [S] \begin{vmatrix} A_1 \\ A_1^{'} \end{vmatrix}\right\}_{x,y}, \tag{9}$$

Thus: $[S] = \hat{H}_M [S_M] + \hat{H}_D [S_D] + \hat{H}_{SW} [S_{SW}] + A_{00}$, And: $\hat{H}_\pi = \begin{cases} 1 & if \quad \pi = M_i, D_i \text{ or } SW_i \\ 0 & else\ where \end{cases}$.

Between medium 1 and 2, the waves are defined in the spectral domain (TE and TM modes), and they are guided by the following spectral equation, as shown in Fig4.

So, with equation (4), we can identify a reflection operator in modes. Hence, we deduce the reflected spectral wave A_i from the incident spectral B_i as:

$$\left\{A_i = \hat{\Gamma}_i B_i\right\}_\alpha, \quad (10) \qquad \hat{\Gamma}_{i\alpha} = \frac{Z_{mni\,\alpha} - z_{0i}}{Z_{mni\,\alpha} + z_{0i}}, \tag{11}$$

Where, i=1,or 2 and $Z_{mni\,\alpha}$ is the impedance of the mn-TE mode on the medium i and α stands for the modes TE or TM.

Where: $Z_{mni\,TE} = \dfrac{j\omega\mu_0}{\gamma_{mni}}, \ Z_{\text{mni TM}} = \dfrac{\gamma_{\text{mni}}}{j\omega\varepsilon_0\varepsilon_{\text{ri}}}$

γ_{mni} Being the propagation constant of the medium *I* and it is given by $\gamma_{mni}=\sqrt{\beta_{xm}^2+\beta_{yn}^2-k_0^2\varepsilon_{ri}}$,

$k_0=\omega\sqrt{\mu_0\varepsilon_0}$, $\omega=2\pi\frac{c}{\lambda}$, $\beta_{xm}=\beta_x+\frac{2m\pi}{a}$, $\beta_{yn}=\beta_y+\frac{2n\pi}{b}$.

$\beta_x=\omega\sqrt{\varepsilon_{r1}\mu_{r1}}\sqrt{\varepsilon_0\mu_0}\sin\theta\cos\varphi$, $\beta_y=\omega\sqrt{\varepsilon_{r1}\mu_{r1}}\sqrt{\varepsilon_0\mu_0}\sin\phi\cos\theta$.

(a) and (b) are the periodicity along (ox) and (oy), respectively, θ and φ define the angle of incidence.

We conclude that the global spectral equation relates the diffracted wave A_i to incident B_i one in the spectral domain.

$$A_i^{k+1}=\hat{\Gamma}_i B_i^{(k)}+A_0. \tag{12}$$

In the above equation, we have integrated the excitation wave $A_{00}=\begin{vmatrix}A_{ox}\\A_{oy}\end{vmatrix}$. A_{00} is defined in the spectral domain and has the following expression:

For TE polarization:

$$\begin{cases} A_{0x}=\dfrac{1}{2\sqrt{Z_{oi}}}\dfrac{\beta_y}{\sqrt{|\beta_x|^2+|\beta_y|^2}}\dfrac{1}{\sqrt{ab}}e^{-j(\beta_x x+\beta_y y)} \\ A_{0y}=\dfrac{-1}{2\sqrt{Z_{oi}}}\dfrac{\beta_x}{\sqrt{|\beta_x|^2+|\beta_y|^2}}\dfrac{1}{\sqrt{ab}}e^{-j(\beta_x x+\beta_y y)} \end{cases}. \tag{13}$$

For TM polarization:

$$\begin{cases} A_{0x}=\dfrac{-1}{2\sqrt{Z_{oi}}}\dfrac{\beta_x}{\sqrt{|\beta_x|^2+|\beta_y|^2}}\dfrac{1}{\sqrt{ab}}e^{-j(\beta_x x+\beta_y y)} \\ A_{0y}=\dfrac{1}{2\sqrt{Z_{oi}}}\dfrac{\beta_y}{\sqrt{|\beta_x|^2+|\beta_y|^2}}\dfrac{1}{\sqrt{ab}}e^{-j(\beta_x x+\beta_y y)} \end{cases}. \tag{14}$$

Equations (13) and (14) are derived from the characteristic functions of periodic wails

III. APPLICATIONS

The RF MEMS switches are mechanically micro switches. In this application, we consider an FSS circuit as a screen integrating a PIN diode in Fig.4. The structure is excited by a plane wave with normal incidence. The physical parameters are the next: height of the substrate h=2. 6mm its permittivity ε_r=3. 8. The unit cell dimension is a=b=40mm. The microstrip line length L=49mm and its width W=4mm, as shown in Fig. 4.

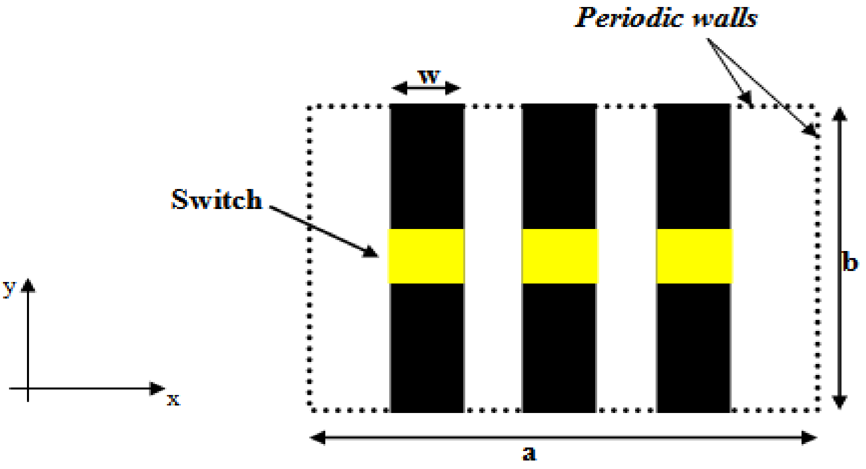

Figure. 4. Switch inserted on a microstrip line.

The convergence, according to the iteration count presented in Fig. 5; is obtained from 200 iterations.

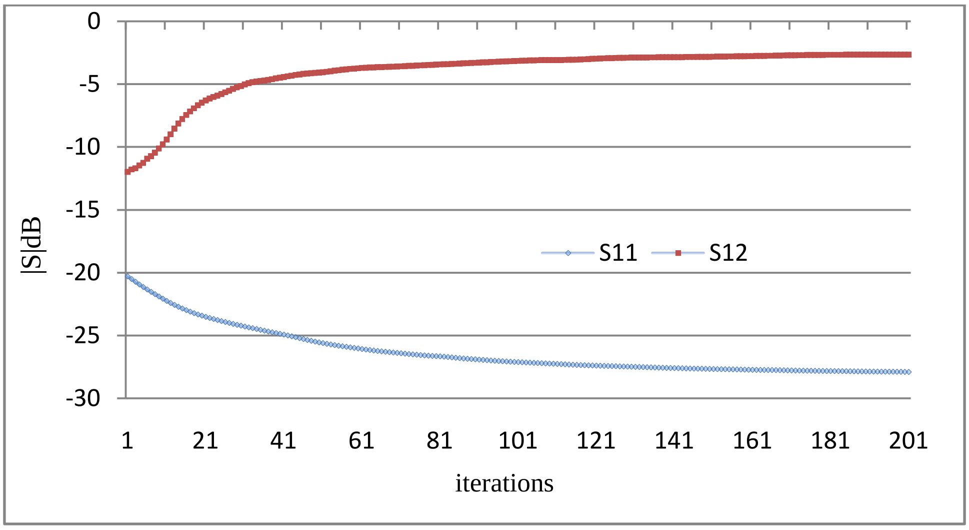

Figure. 5. Convergence of the S parameters as function of iteration number at 4.8 GHz. Off state

In the numerical examination of tunable components of the RF Schottky diode for the ON and OFF states, the values of R_j and C_j, as the effect forward and reverse biases, respectively, at the structure with the equivalent circuit model shown in Fig 6 is simulated with the resistance of R_s is set to be 6Ω and with 0.7 pF of C_j representing the forward bias (ON state) of the diode, then the resistance of R_j is changed from 1Ω to 100 KΩ.

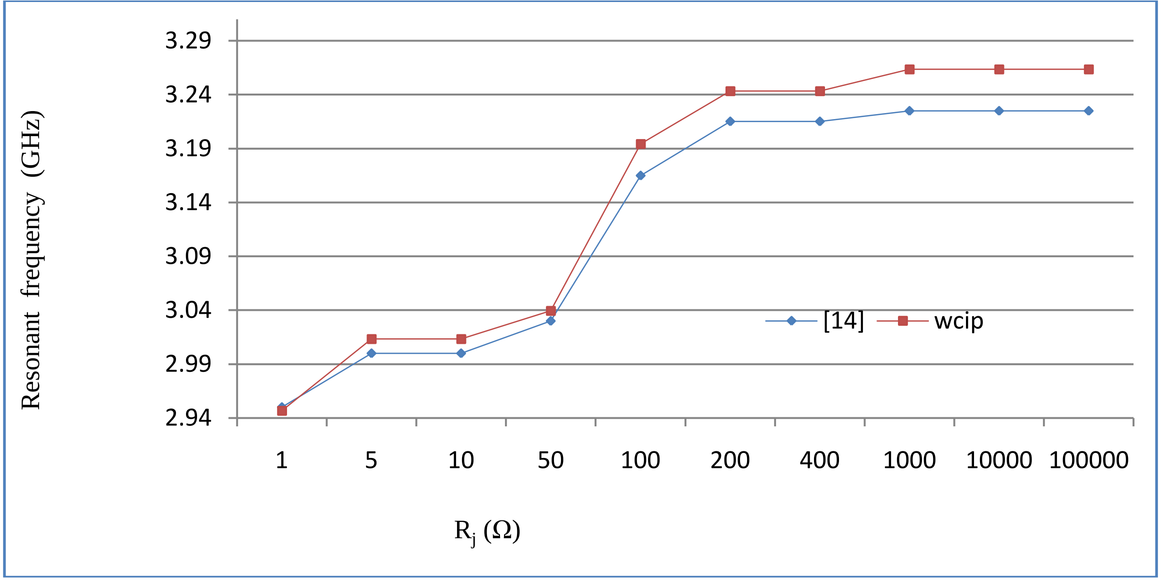

Figure .6. Simulated result of resonant frequency of substrate less FSS structure as function of R_j (ON state)

As shown in Fig 7 the dependence of the resonant frequency of the structure C_j value for the OFF state. We note that when the capacity increases, the resistance of R_s is set to be 6Ω, the resistance of R_j is 1.2MΩ, the capacity of C_j is changed from 0.001 pF to 10 pF.

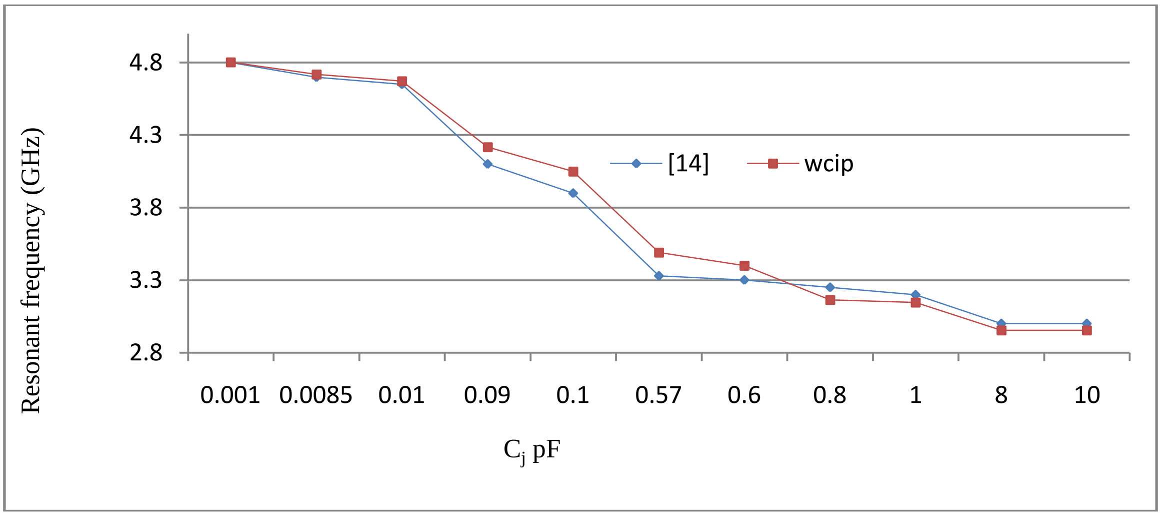

Figure .7. Simulated result of resonant frequency of substrate less FSS structure as function of C_j (OFF state)

In the off state the values of R_j and C_j are chosen 1.2MΩ and 0.01 pF.

As shown in figure (8-9) the simulated results for The coefficient of reflection and transmission in dB. It can be seen from Figure 8 was obtained a total refection at a frequency of 4.8 GHz of about -27.9 dB with a transmission that has led to -2.63 dB as illustrated in Figure 9.

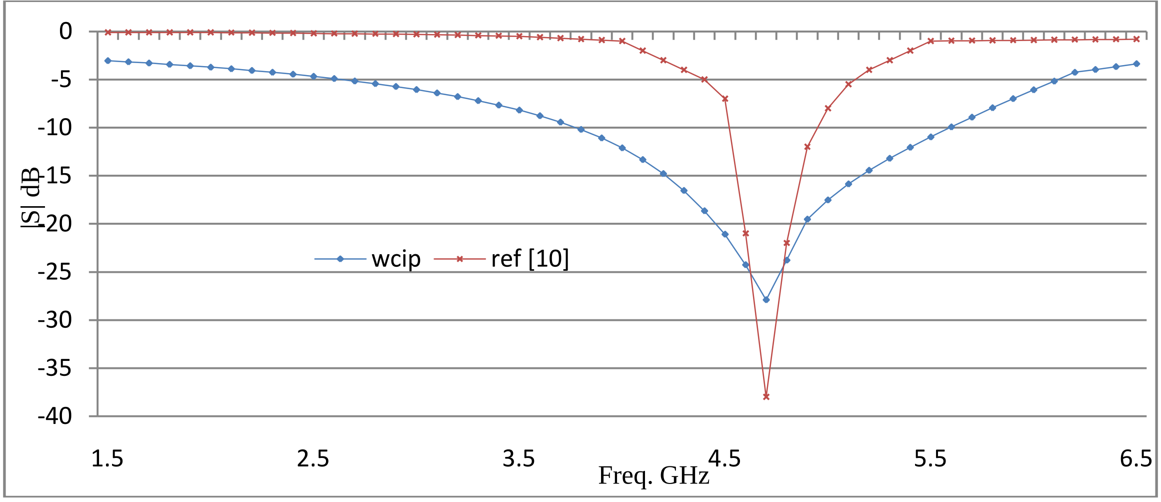

Figure .8. Variation reflection coefficient S11 as a function of frequency of FSS structure in OFF state.

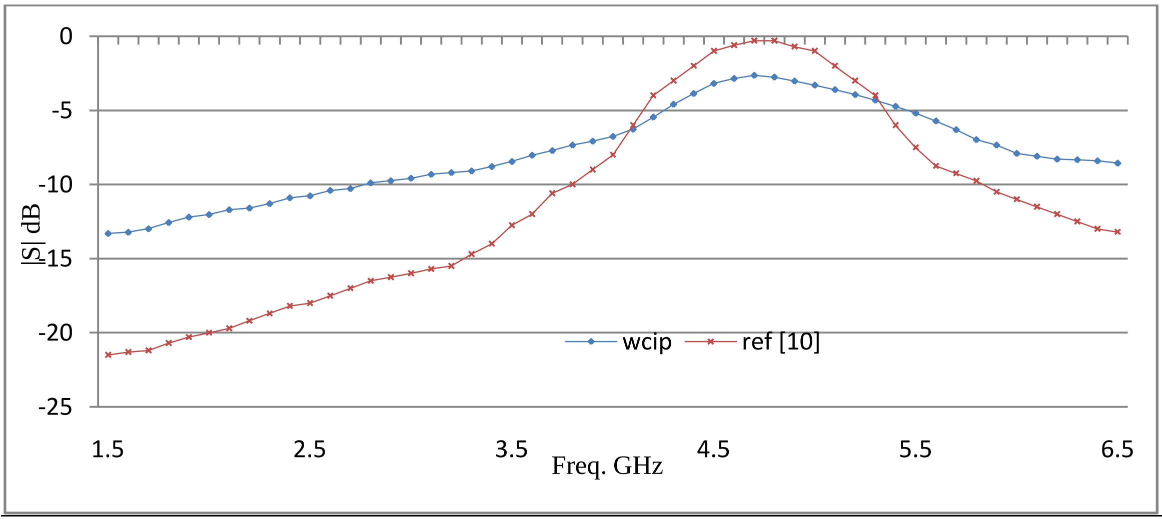

Figure .9. Variation transmission coefficient S11 as a function of frequency of FSS structure in OFF state

In the on state the resistance Rj and the capacity Cj take respectively the following values 2.7Ω and 0.7 Pf.

In Figure 10 and 11 is observed simulated results for the coefficient of reflection and transmission in dB. We find a total refection at a frequency of 3.2 GHz of about -17.14 dB we can see it in Figure 10 with a transmission that has led to -4.66 dB as shown in figure 11.

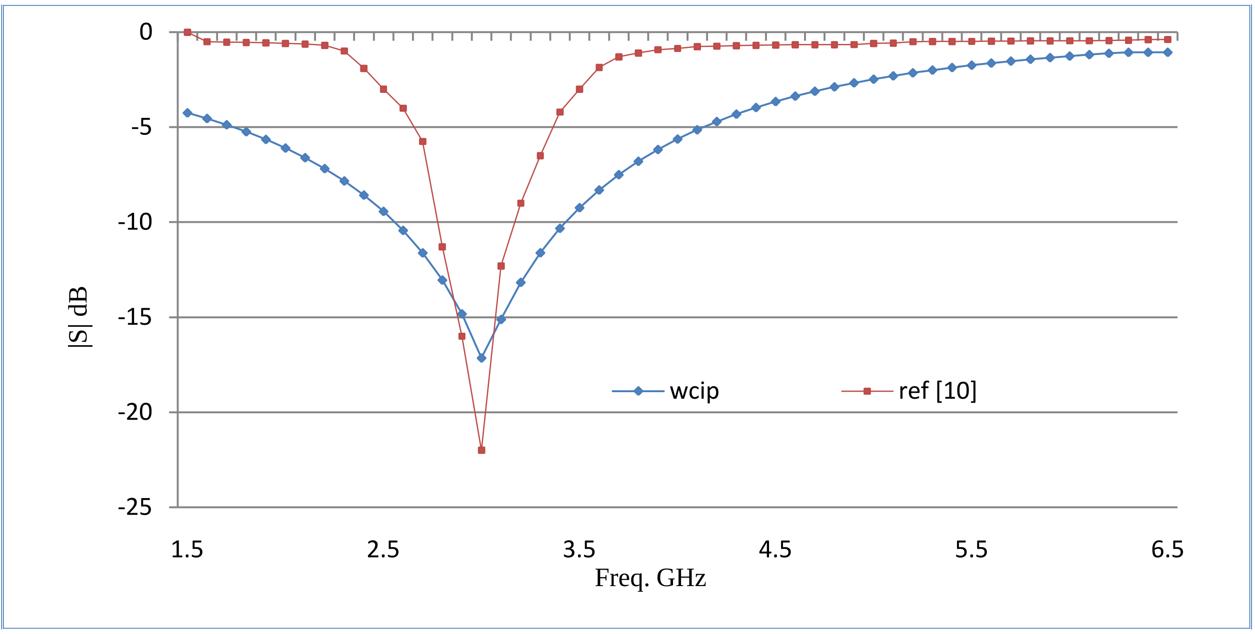

Figure .10. Variation reflection coefficient S11 as a function of frequency of FSS structure in Onstate.

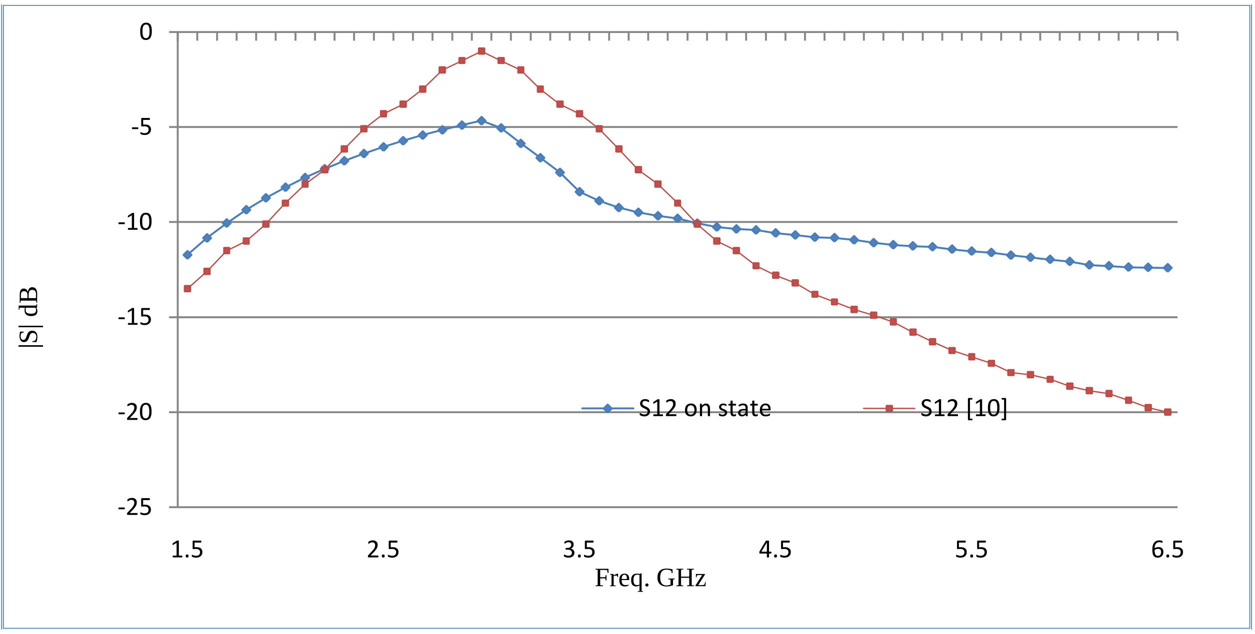

Figure .11. Variation transmission coefficient S11 as a function of frequency of FSS structure in On state.

In the figure below we can observe the effect of the RF MEMS switch for both switching states (off and on states) on the frequencies to a total reflection at a frequency range which varies from 1 to to 7 GHz. The simulation results obtained by the iterative method.

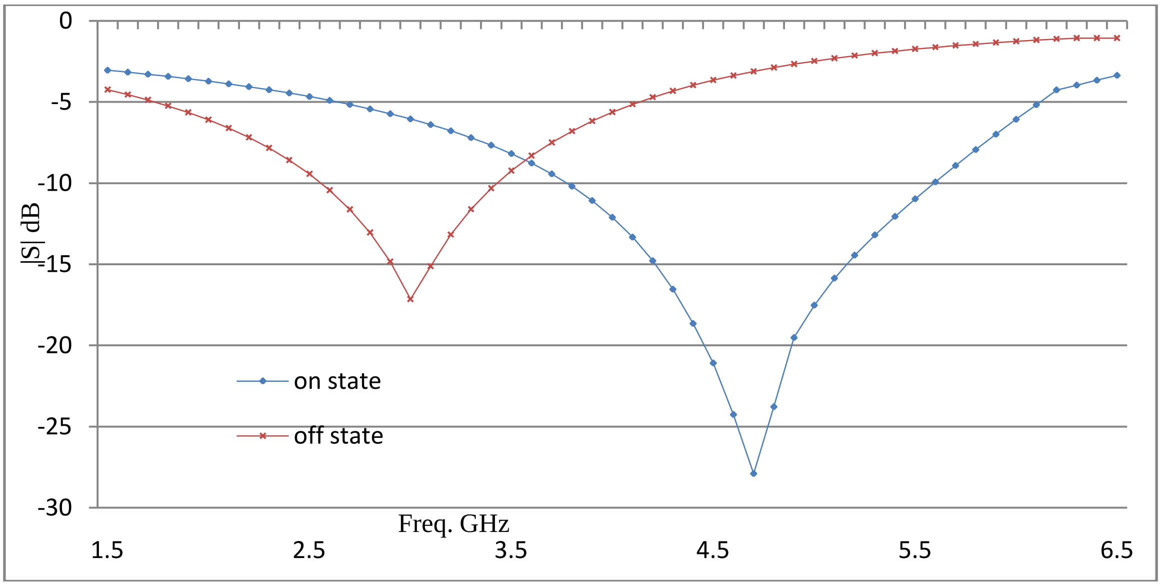

Figure .12. Variation reflection coefficient S11 as a function of frequency of FSS structure in Off and On state.

IV. CONCLUSION

In this paper, a reformulation of the wave concept iterative method is adapted to the integrated RF-MEMS switches. The convergence of the method is about 200 iterations. The comparison of numerical results with the measurement published data ensures the validation of the WCIP method and its ability to integrate the RF Switch. This method has the advantage of simplicity and its conjunction with the 2D-FFT gives a high computational speed and memory consumption.

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