Mansoura Engineering Journal

Volume 27 | Issue 1 Article 3

1-23-2021

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Recommended Citation

Mahmoud, Ahmed; Abd Elrazzak, Maher; Mitkees, Abd Elaziz; and Elmikati, Hamdi (2021) "Study of the Characteristics of a Line-Fed Two-Layers Coupled Rectangular Patch Antenna Using FDTD Method.," *Mansoura Engineering Journal*: Vol. 27 : Iss. 1 , Article 3.
Available at: https://doi.org/10.21608/bfemu.2021.142447

STUDY OF THE CHARACTERISTICS OF A LINE-FED TWO-LAYERS COUPLED RECTANGULAR PATCH ANTENNA USING FDTD METHOD

دراسة خواص الهوائى المستطيل المكون من طبقتين متعانقتين والمغذى
بواسطة خط شريطى دقيق باستخدام طريقة الفروق المحدودة فى الحيز الزمنى

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خلاصة:-

فى هذا البحث: تم تقديم تحليل وتصميم الهوائى المستطيل المكون من طبقتين متعانقتين والمغذى بواسطة خط شريطى دقيق. ولهذا الهوائى تم حساب الفقد الناتج عن الانعكاس (return loss) والمعاوقة الداخلية (input impedance) و مجسم الاشعاع (radiation pattern) باستخدام طريقة الفروق المحدودة فى الحيز الزمنى(FDTD) و كذلك تم دراسة تأثير تغيير سمك فجوة طبقة الهواء بين الطبقتين على خصائصه.

وقد وجد أن النتائج التى تم الحصول عليها بطريقة الفروق المحدودة فى الحيز الزمنى متوافقة مع النتائج المنشورة وكذلك وجد أنه كلما زاد سمك فجوة طبقة الهواء بين الطبقتين قل الحيز الترددى للهوائى(bandwidth) وزاد حيز الاشعاع(beamwidth) له.

ABSTRACT- In the present work, the analysis and design of a line fed two- layers coupled rectangular patch antenna is presented. The return loss, the input impedance, and the radiation pattern of the proposed structure are determined using the finite-difference time-domain (FDTD) method. The effect of changing the air gap layer thickness between the two layers of that antenna is studied. The results obtained by the FDTD method are found to be in good agreement with the published data. Also it is found that as the air gap layer thickness is increased the 10-dB return loss bandwidth is decreased while the 3-dB beamwidth of that antenna is increased.

Key-words:- FDTD. patch antenna.

I-INTRODUCTION

In recent years, microstrip antennas have been widely used in a variety of applications due to their many natural advantages. Probably the most serious limitation of those antennas are their narrow bandwidth [1]. So it is not surprising that bandwidth improvement techniques are so prevalent in the literature. One of these techniques is to use the stacked patch antenna configurations [2-4].

In this paper, the analysis and design of a line fed two- layers coupled rectangular patch antenna on isotropic substrates are carried out using the FDTD method. This method is characterized by its capability, flexibility, and accuracy in modeling complex geometries [5-6]. The method was applied successfully for a variety of antenna configurations [5,7-9]. For antenna problems. the use of absorbing

Accepted January 20, 2002

boundary conditions (ABCs) is necessary to accurately terminate the computational domain, and reduce the reflection. Mur's ABCs is used in the present work [10]. In the next sections, a brief outline of FDTD method based on the E- and H-fields, and ABCs, the analysis of patch antenna under consideration with its numerical results, and concluding remarks are given.

II. BASIC FORMULATION

This section presents the basic formulation of FDTD method. Maxwell's equations for patch antenna shown in Fig. 1, can be written as [5],

$$\frac{\partial H}{\partial t} = -\frac{1}{\mu}\nabla x E - \frac{\rho'}{\mu} H \tag{1.1}$$

$$\frac{\partial E}{\partial t} = \frac{1}{\varepsilon}\nabla x H - \frac{\sigma}{\varepsilon} E \tag{1.2}$$

where,

ρ' is the magnetic resisitivity of the medium in (Ω/m)

σ is the electric conductivity of the medium in (S/m)

$\frac{\partial}{\partial t}[\bullet]$ is the partial derivative with respect to time

By applying conventional FDTD method, the difference equation: for the six field components in Cartesian cordinates of equations (1) can be obtained [5-6]. For example, the discretized equations for H_x and E_x field components are,

$$H_x\Big|_{i,j,k}^{n+1/2} = D_a\Big|_{i,j,k} H_x\Big|_{i,j,k}^{n-1/2} + D_b\Big|_{i,j,k}\left\{\frac{E_y\Big|_{i,j,k+1/2}^{n} - E_y\Big|_{i,j,k-1/2}^{n}}{\Delta z} - \frac{E_z\Big|_{i,j+1/2,k}^{n} - E_z\Big|_{i,j-1/2,k}^{n}}{\Delta y}\right\} \tag{2.1}$$

$$E_x\Big|_{i,j,k}^{n+1} = C_a\Big|_{i,j,k} E_x\Big|_{i,j,k}^{n} + C_b\Big|_{i,j,k}\left\{\frac{H_z\Big|_{i,j+1/2,k}^{n+1/2} - H_z\Big|_{i,j-1/2,k}^{n+1/2}}{\Delta y} - \frac{H_y\Big|_{i,j,k+1/2}^{n+1/2} - H_y\Big|_{i,j,k-1/2}^{n+1/2}}{\Delta z}\right\} \tag{2.2}$$

where Δx, Δy, and Δz are the space increments in the x, y, and z directions respectively. The D's, and the C's are the updating magnetic and electric field components coefficients, respectively [5]. To ensure that the numerical error generated in one step does not accumulate and grow, a stability condition is usually applied [5,6].

III. ANALYSIS OF TWO- LAYERS COUPLED RECTANGULAR PATCH ANTENNA

III.A Frequency dependent characteristics

In this section, the return loss, the input impedance, and the bandwidth of a line fed two- layers coupled rectangular patch antenna shown in Fig. 1, are presented. This configuration consists of a driven patch on the bottom and a parasitic patch on the top. The two layers of rectangular patch elements are separated by an air gap layer of thickness S. The driven patch is fed by a microstrip line feeder. The ground plane and the two thin patches are assumed to be perfect electric conductor (PEC). Each rectangular patch has dimensions of $16\text{mm} \times 12.45\text{mm}$ which is fabricated on substrate with ε_r=2.2 and thickness of 0.795 mm. The FDTD mesh used in computation is different according to the type of patch configuration. For example.

the total number of nodes for stacked rectangular patch antenna without air gap layer are 62×101×22 in the x, y, and z directions, respectively. The total number of nodes for each rectangular patch are: 32Δx 40Δy, while the free space above the substrate of upper parasitic patch is taken as 13 Δz. The length of the microstrip line feeder from the source plane to the edge of the driven antenna is 50Δy. The reference plane is 10Δy from the edge of the driven patch. The width of microstrip feeder line w is 6Δx, the displacement w1 is 5Δx. The spatial steps used for this structure are Δx =0.389 mm, Δy =0.400 mm, and Δz =0.265 mm. The microstrip line is excited by a Gaussian pulse with unit amplitude at the edge of the computation domain i.e. at port 1 (source plane) as shown in Fig. 1. This pulse is given by:

$$E_z(t) = e^{-\frac{(t-t_o)^2}{T^2}} \tag{3}$$

where,

T: Gaussian half width = 15.01 ps,

t_o = 3T

The time step Δt is computed from the stability condition according to the Cournt condition [5,6] as;

$$\Delta t \le \frac{1}{v_{max}}\left(\frac{1}{\Delta x^2}+\frac{1}{\Delta y^2}+\frac{1}{\Delta z^2}\right)^{-\frac{1}{2}} \tag{4}$$

where,

v_{max} is the phase velocity in the computational domain

Δt=0.4416 ps

The value of Δt is constant for both air and substrate in all the computational domain. The values of T and t_o are chosen to cover the entire frequency range of operation and to ensure that the Gaussian pulse start approximately at time 0, respectively.

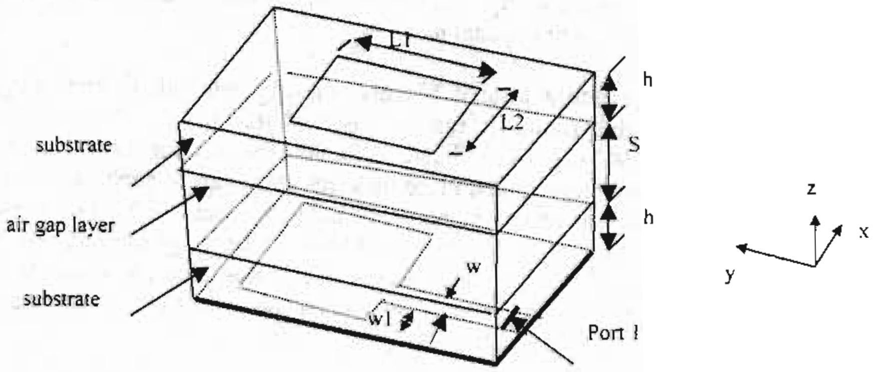

Fig. 1. Line-fed two- layers coupled rectangular patch antenna. The parameters of dielectric substrate are: ε_r=2.2 and h=0.795 mm. L1=16mm and L2=12.45mm, w=2.334 mm and w1=1.946 mm.

Initially all the fields on the whole computation domain are set to be zero. The transient response is recorded at the reference plane until all the fields in the computation domain decay to a negligible steady-state value. Then the Fourier transformation is used to obtain the return loss, and the input impedance of the patch antenna according to [8]. The Mur's first order absorbing boundary conditions is used to terminate the unbounded computational domain [10].

To determine the return loss of the patch antenna, one must calculate the refelected wave at the reference plane. The numerical FDTD simulations is carried out twice. First, is in the absence of the patches. This is required in order to establish a reference incident waveform propagating along the feeder. A second simulation is repeated in the presence of the patches and the total incident and reflected voltages at the reference plane is obtained. Then the reflected wave is computed as the difference between the second and the first results. Using the incident and reflected time domain waveforms the return loss can be evaluated [8].

Fig. 2 shows the return loss of both single patch and the 2-stacked patches without air gap layer. This figure shows a very good agreement between the results of the FDTD and that published in [8] for the case of a single patch antenna of the same parameters. Also, it can be seen that 10-dB return loss bandwidth for single patch and for the 2-stacked patches without air gap layer are about 3.079%, and 8.5561 %, respectively (stacked patch leads to increase the bandwidth by 2.8 times of the case the single patch). Figures 3 and 4 show the imaginary and real part of the input impedance of those antennas. From these figures, one can observe that the value of the input impedance of 2-stacked patches without air gap layer is slightly greater than single patch.

Now, an air gap layer is introduced between the substrate of the upper patch and the lower patch to study its effect on the bandwidth of the proposed structure. Fig. 5 shows the return loss of 2-layers coupled patch with different air gap layer thickness. From this figure, It can be observed that the 10-dB return loss bandwidth are about: 9.79%, 7.535%, and 3.07% for air gap layer thickness: 0.265 mm, 0.53mm,and 0.795 mm, respectively. Figures 6 and 7 show the imaginary and real part of the input impedance of those antennas.

Fig. 8 shows the return loss of 2-layers coupled patch with different air gap layer thickness. From this figure, it can be observed that the 10-dB return loss bandwidth are about : 2.95%, 2.8 %, and 2.45 % for air gap layer thickness: 1.06 mm, 1.325 mm, and 3.18 mm, respectively. From these results, it can be concluded that as the air gap layer thickness is increased the 10-dB return loss bandwidth is decreased, as given in table-1, pp.181 in [4]. Figures 9 and 10 show the imaginary and real part of the input impedance of that antenna. From these figures, it can be shown that at resonant frequencies the input impedance is pure real and their locations correspond to the location of peaks of the return loss in Fig. 8.

III.B Radiation patterns

In this section, the radiation pattern of the antenna under consideration is presented. To calculate the far-fields of that antenna, the equivalent sources on the virtual surface that encloses the antenna are calculated at the same time with the FDTD simulation through the near -to far-field zone transformation principle given in

[5]. After the equivalent sources are known, the far-fields originated by these equivalent sources can be calculated [1]. In the present work, a Gaussian pulse modulated by sinusoidal wave excitation near resonant frequency is used. As soon as the steady state conditions are reached, the normalized E-plane and H-plane field patterns at each far zone angle can be obtained. The E-plane and H-plane radiation patterns for both single patch and the 2-stacked patches without air gap layer are shown in Fig. 11. For the single case, the radiation pattern is calculated by using both the FDTD and the cavity model technique[1]. Very good agreement between the results FDTD and the cavity model is achieved. Also, one can see that 3-dB beamwidth of E-plane patterns of a single patch is greater than the other stacked patch, while the H-plane patterns of the two antennas remain similar as expected.

Focusing on introducing an air gap layer in the proposed antenna, the effect of changing the air gap layer thickness on the radiation pattern is studied. Fig. 12 and Fig. 13 show the E-plane and H-plane field patterns for the antenna shown in Fig. 1 at resonant frequencies. As shown from the figures, a significant improvement in the beamwidth of the E-plane pattern occurs as the thickness of air gap layer increases.

IV. CONCULSION

In this paper, the performance of a line fed two- layers coupled rectangular patch antenna is presented. The finite-difference time-domain (FDTD) method is applied to determine the return loss, the input impedance, and the radiation pattern of the proposed structure. The effect of changing the air gap layer thickness between the two layers of that antenna is investigated. The results obtained by the FDTD method are found to be in good agreement with the published data.

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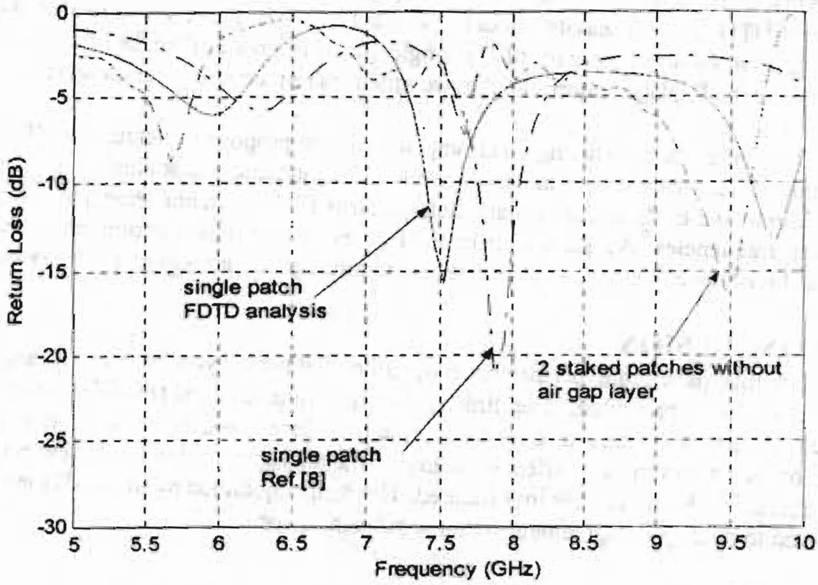


Fig. 2. Return loss of both single rectangular patch and 2- stacked rectangular patches on isotropic substrates without intermediate air gap layer.

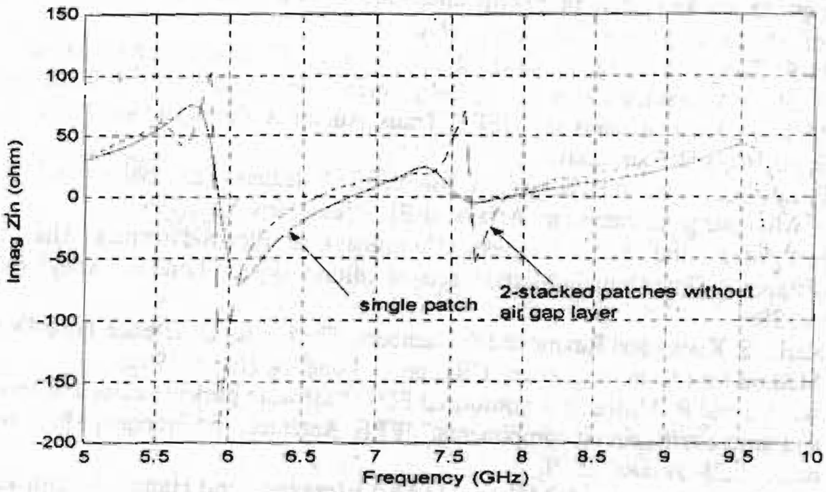


Fig. 3. Imaginary part of input impedance of both single rectangular patch and 2 - stacked rectangular patches on isotropic substrates without intermediate air gap layer.

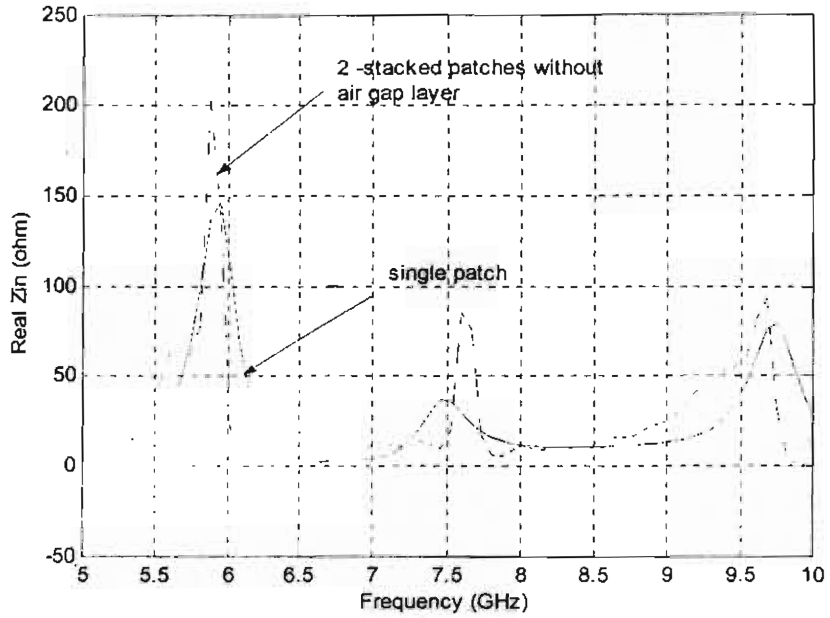


Fig. 4. Real part of input of both single rectangular patch and 2- stacked rectangular patches on isotropic substrates without intermediate air gap layer.

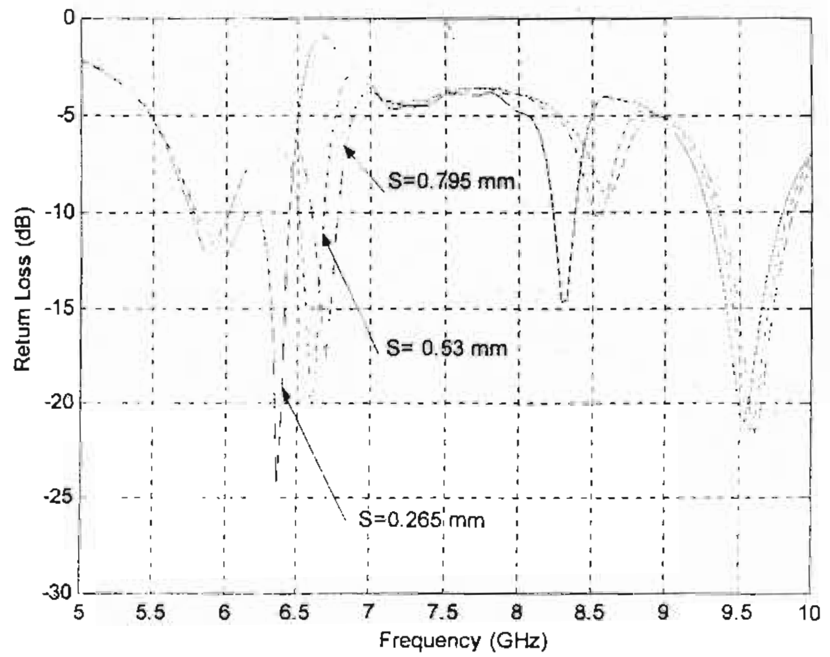


Fig. 5. Return loss of 2- stacked rectangular patches on isotropic substrates with different intermediate air gap layer thickness ; S=0.265mm,0.53mm and 0.795 mm.

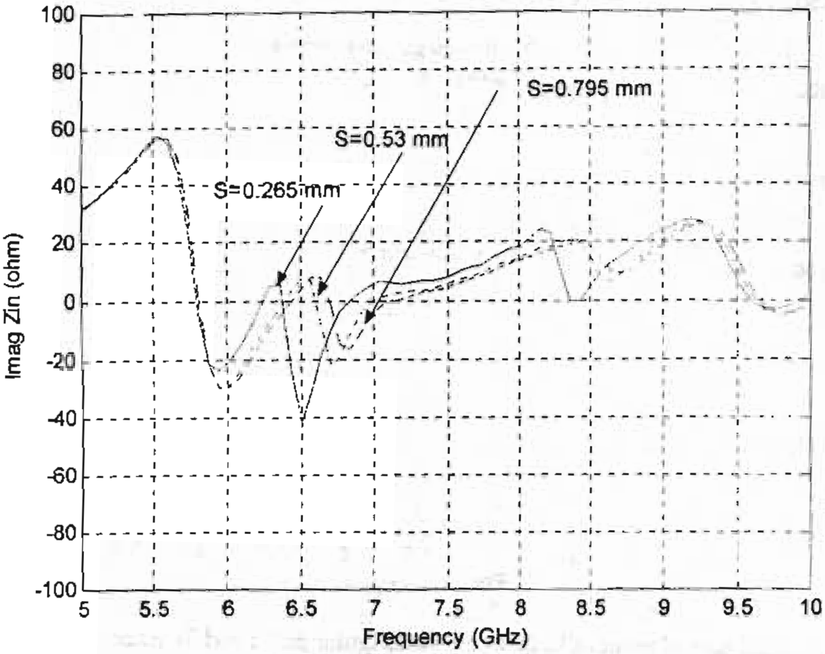


Fig. 6. Imaginary part of input impedance of 2- stacked rectangular patches on isotropic substrates with different intermediate air gap layer thickness ; S=0.265mm,0.53mm and 0.795 mm.

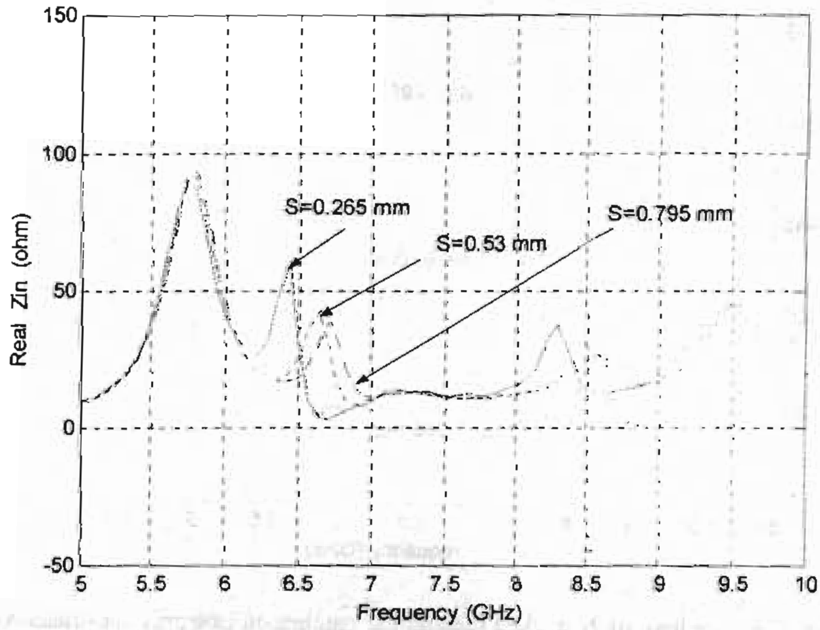


Fig. 7. Real part of input impedance of 2 -stacked rectangular patches on isotropic substrates with different intermediate air gap layer thickness ; S=0.265mm,0.53mm and 0.795 mm.

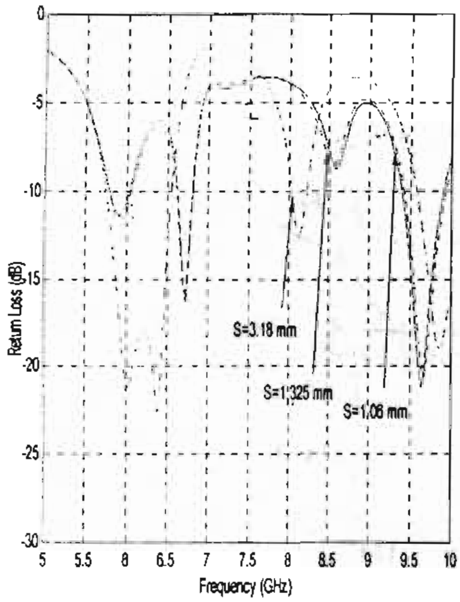


Fig. 8. Return loss of 2- stacked rectangular patches on isotropic substrate with different intermediate air gap layer thickness; S=1.06mm,1.325mm and 3.18 mm.

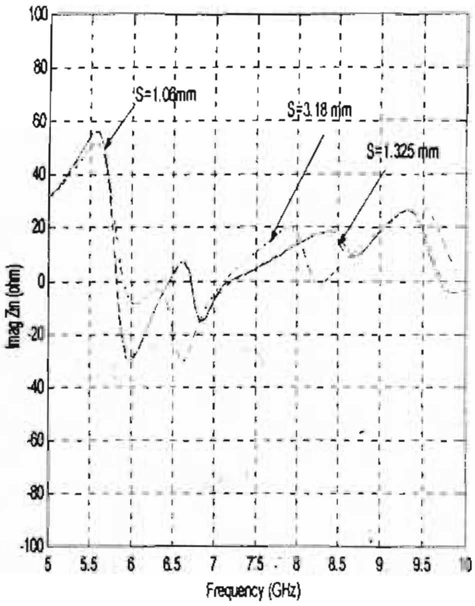


Fig. 9. Imaginary part of input impedance of 2- stacked rectangular patches on isotropic substrate with different intermediate air gap layer thickness; S=1.06mm,1.325mm and 3.1mm

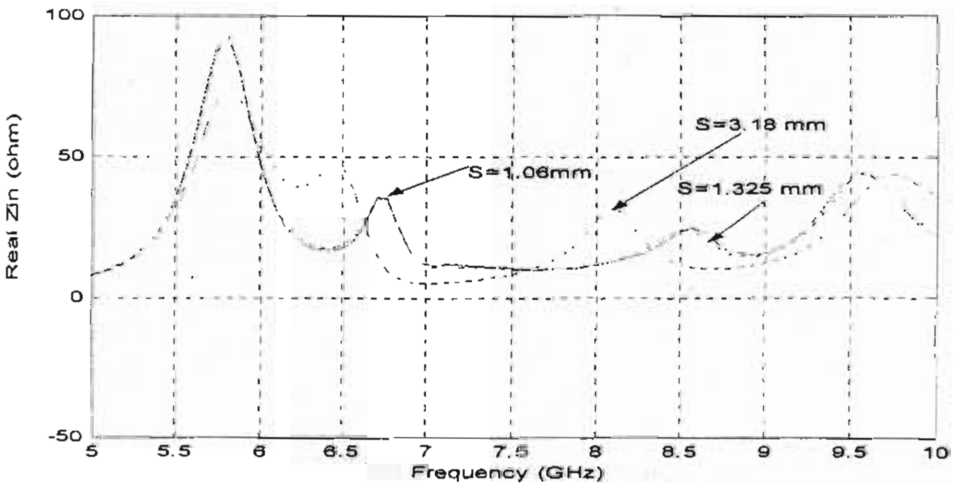
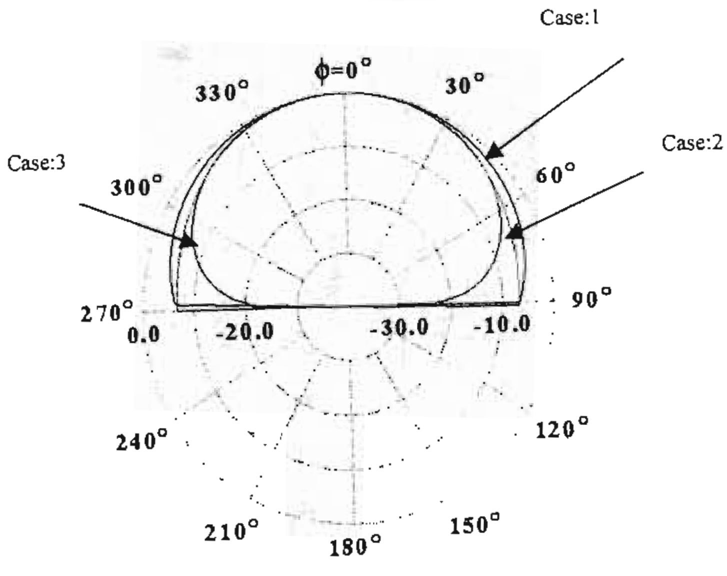
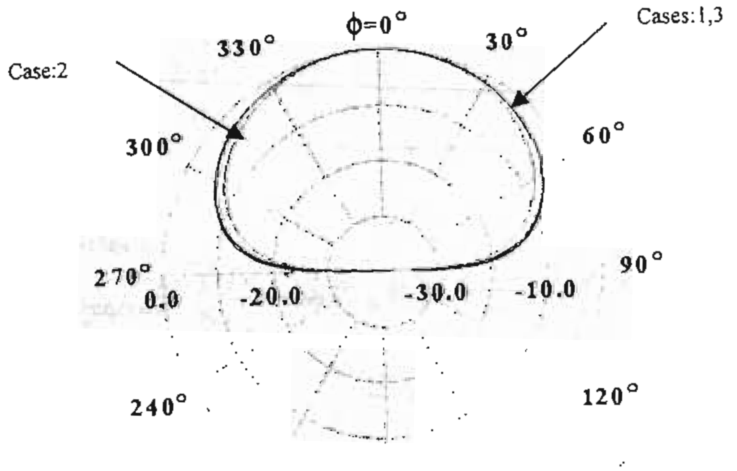


Fig. 10. Real part of input impedance of 2- stacked rectangular patches on isotropic substrate with different intermediate air gap layer thickness ; S=1.06mm,S=1.325mm and S=3.18 mm.

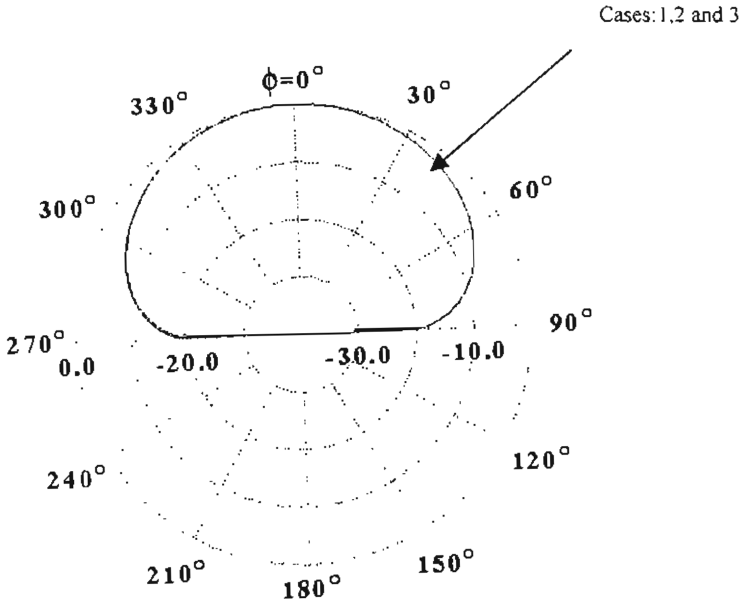


(a)



(b)

Fig. 11. Radiation pattern of both single rectangular patch and 2- stacked rectangular patches on isotropic substrates without intermediate air gap layer. a)-E-plane; b) H-plane. Case:1 FDTD results for single patch, Case:2 Cavity modal for single patch,Case:3 FDTD results for 2-stacked patches.



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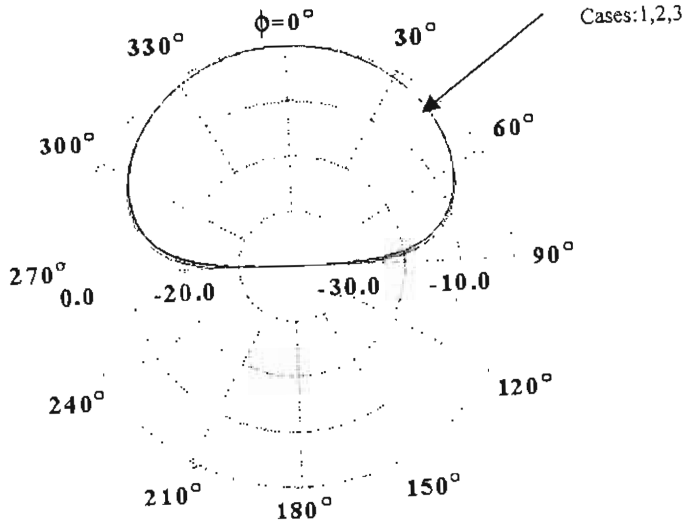
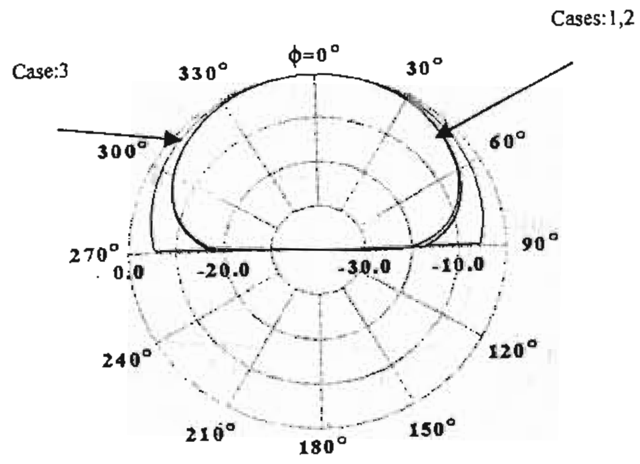
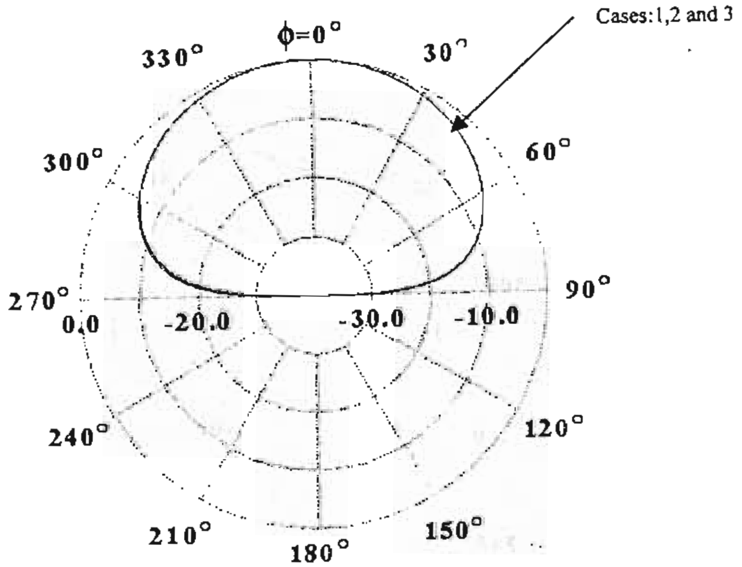


(b)

Fig. 12. Radiation pattern of 2 -stacked rectangular patches on isotropic substrates with different intermediate air gap layer thickness ; Case:1-S=0.265mm.Case:2-S=0.53mm and Case:3-S=0.795 mm. a)-E-plane ; b) H-plane.



(a)



(b)

Fig. 13. Radiation pattern of 2 -stacked rectangular patches on isotropic substrates with different intermediate air gap layer thickness ; Case:1-S=1.06mm,Case:2-S=1.325mm and Case:3- S=3.18 mm. . a)-E-plane ; b) H-plane.