Journal of Engineering and Development, Vol. 13, No. 4, Des (2009) **ISSN 1813-7822**

Bandwidth Improvement of Microstrip Antenna Using Multi-Resonator Elements with Stacked Geometry

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Abstract:

This paper introduces some studies on microstrip antenna (MSA) which can be used for wide or dual band communication systems. The antenna geometry presented in this paper consists of multi-resonators with stacked geometry. The antenna is characterized and designed using Microwave Office 7.5 package software produced in 2007. Some results regarding the input impedance, *VSWR*, bandwidth and radiation power pattern are presented in this paper.

الخلاصة:

أن هذا البحث يقدم بعض الدراسات بخصوص الهوائيات الشريطية الدقيقة و التي من الممكن ان تعمل ضمن انضمة الاتصالات التي تتطلب حزم ترددية عريضة أو ثنائية.ان الشكل الهندسي للهوائي المقدم في هذا البحث يتكون من عدد من الرقع المستطيلة ذات الشكل الهندسي المكدس. تم دراسة وتحليل الهوائي بأستخدام حقيبة برامجيات المايكروويف نسخة 7.5 الصادرة في ٢٠٠٧ .وتم حساب بعض النتائج والمتعلقة بالممانعة الداخلية للهوائي ، نسبة فولتية الموجة الواقفة، عرض الحزمة الترددية و شكل الاشعاع.

1. Introduction

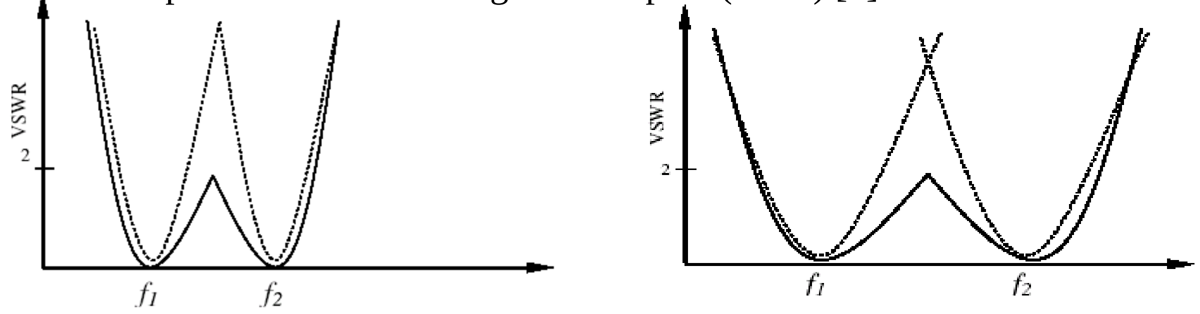
The narrow bandwidth available from microstrip patch radiator is recognized as the most significant factor that limits the applications of this class of antennas. The bandwidth of the microstrip antenna increases with an increase in the substrate thickness H or with a decrease in the dielectric constant ε_r. However, there is a practical limit on increasing the thickness, and increased beyond 0.1λ, surface-waves propagation take place resulting in degradation in the antenna performance[1,2]. To overcome its inherent limitation of narrow impedance bandwidth, multiple radiating elements with planar configuration or multi-layer stacked patch antennas using circular, annular, rectangular and triangular patches can be used [3-5]. Long S., and Walton M., designed two circular stacked patch antenna operate at 3.3 GHz. The bandwidth achieved from this structure is 5% for $VSWR \leq 2$[٣]. Later, Chen C., Tulintseff A., & Sorbello R., modified the previous antenna structure by using a relatively thick and low permittivity. They obtained 20% bandwidth for $VSWR \leq 2$ and 10% bandwidth for $VSWR \leq 1.22$[4]. Prior J., and Hall P., designed a microstrip antenna structure consist of driven disc element with a parasitic short-circuited annular ring on the substrate surface. They obtained a 9% bandwidth for $VSWR \leq 2$ [5]. Sharma M., Swati G., Deepak B., and Yadav R., designed a single radiating patch on a thick substrate with a single parasitic patch placed beside the radiating patch. By changing the substrate, separation between the parasitic patch and radiating patch. The obtained bandwidth from this structure is 22% [6]. James A., Afrozee Z., and Richard Q., designed a microstrip antenna similar to Yagi antenna by implementing a vertically stacked structure with three parasitic directors above the driven patch and a single reflector underneath the driven patch. The bandwidth obtained from this design is 20% for $VSWR \leq 2$[7].

All the above works divided into two categories, namely multi-resonator planar configuration or stacked geometry. This paper describes the planar multi-resonator with stacked geometry technique (without changing the substrate thickness or permittivity) using rectangular patches RMSA for broadband or dual-band operation. Only a single patch is fed, and the other patches are electromagnetic coupled EMC. The antenna analyzed using Microwave office 7.5 package software produced in 2007.

2-Effect of Parasitic Patches

A patch placed close to the fed patch gets excited through the coupling between the two patches. Such patch is known as a parasitic patch. If the resonance frequencies f_1 and f_2 of these two patches are close to each other, then broad bandwidth is obtained as shown in figure (1-a). The overall input VSWR will be superposition of the responses of the two resonators resulting in a wide bandwidth. If the bandwidth is narrow for the individual patch, then the difference between f_1 and f_2 should be small as shown in figure (1-a). If the bandwidth of the individual patch is large, then the difference in the two frequencies should be large to yield an overall wide bandwidth as shown in figure (1-b). Also dual-band can be obtained, by increasing the difference between f_1 and f_2.

Planar and stacked multi-resonators techniques are combined to yield a wide bandwidth or dual-band operation. In this paper it is used a configuration with two dielectric layers and placed three patches on the top layer and one patch at the bottom of the top layer. Only the patch on the bottom layer fed while, the three other patches are electromagnetic coupled (EMC) [8].



(a) (b)

Figure (1) VSWR Plot of Two Coupled Resonators Having
(a) Narrow Bandwidth

3-Antenna Design

In this antenna three patches are stacked on a fourth patch to improve the bandwidth. Only the bottom patch is fed and the top patches are electromagnetically coupled as shown in figure (2). The patch on the bottom layer is shown in dotted lines and the patches on the top layer are shown in solid lines. The dimensions of the fed patch (exited patch) are taken as: *L=3 cm* and *W=4 cm*, with $\varepsilon_r = 2.55$. Three parasitic patches with resonance frequency slightly above the resonance frequency of the fed patch $(L_1 = 2.9\ cm)$ are placed above the fed patch as shown in figure (2). They get exited due to coupling with fringing fields along the width of the patch. The antenna analyzed for gap spacing (s) range from 0.1λ to 0.4λ with substrate thickness $(H = 0.159\ cm)$and five sets of exited patch substrate thickness (h_1) and parasitic patches substrate thickness (h_2) . The antenna has been analyzed using Microwave Office 7.5 package software.

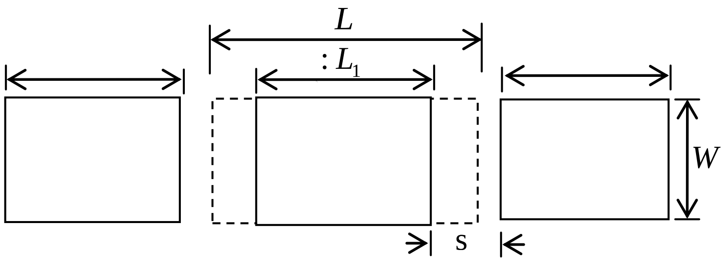


Figure (2) Antenna Configuration Consisting of One Exited Patch Stacked by Three Other Patches

4- Simulation and Results

Three patches are stacked on the other patch. The antenna is constructed using Microwave Office software for five values of driven substrate thickness ($h_1=0.07\ cm$, $h_1=0.08\ cm$, $h_1=0.09\ cm$, $h_1=0.1\ cm$ & $h_1=0.12\ cm$) with constant antenna substrate thickness (H=0.159 cm).

4.1- Simulation for $h_1=0.07\ cm$

The antenna structure has been constructed using microwave office package software for $h_1 = 0.07\ cm$. Then: $h_2 = H - h_1 = 0.089\ cm$. The antenna has been analyzed for five values of parasitic gap spacing (s). Table (1) shows the resonance frequencies (f_1 and f_2) and bandwidths (BW_1 and BW_2) for different values of (s). The input impedance and the voltage standing wave ratio *VSWR* have been plotted in figures (3) and (4) respectively.

For h_1=0.007 cm, and s=0.2 cm, and s=0.25 cm the radiation power patterns in E- and H-planes at the first and second Resonances are plotted in Figure (5). In the H-plane, there is no much change in the radiation patterns at the two frequencies. However in the E-plane the beam maxima shifts 22^o (for s=0.2 cm) and 10^o (s=0.25 cm) away from the broadside direction.

Table (1) Variation of the resonance frequencies and bandwidths w.r.t gap spacing (s) for h_1=0.07 cm.

Gap Spacing (s) in cm	F_1 in GHz	f_2 in GHz	BW_1	BW_2
0.1	2.875	3.14	0%	0.52%
0.15	2.92	3.12	0%	0.68%
0.2	2.95	3.11	2.5%	3.1%
0.25	2.97	3.09	2.6%	2.4%
0.3	2.99	3.08	4.11%	0%
0.4	3	3.17	2.87%	0%

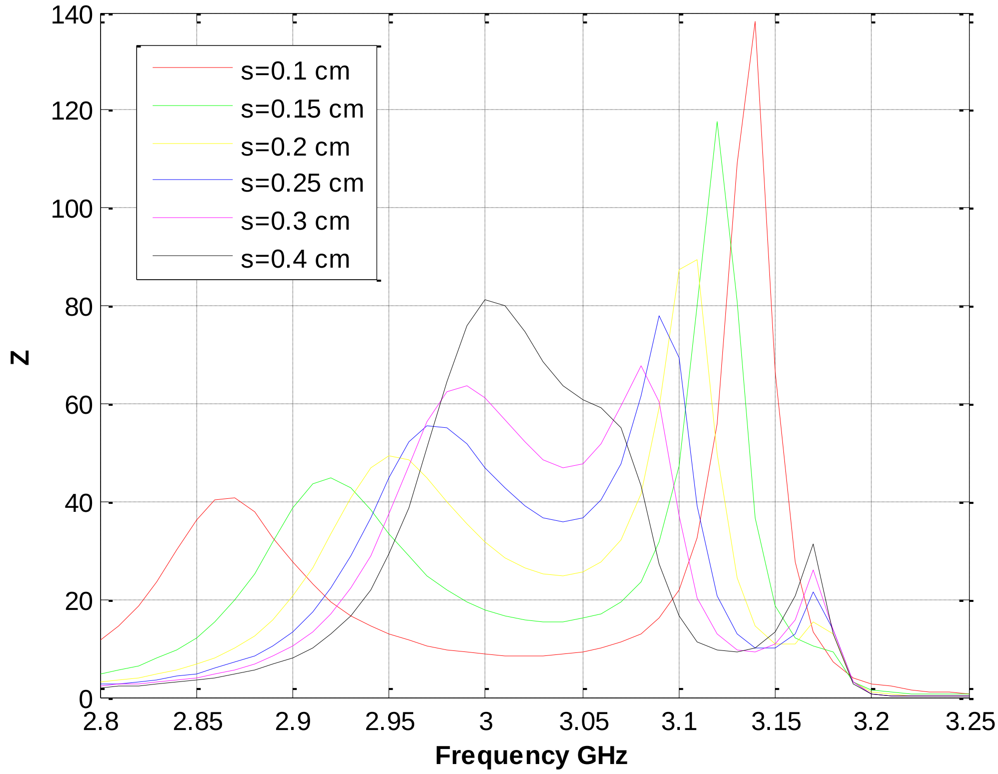


Figure (3) Input Impedance Variation w.r.t Frequency for $h_1 = 0.07\ cm$**.**

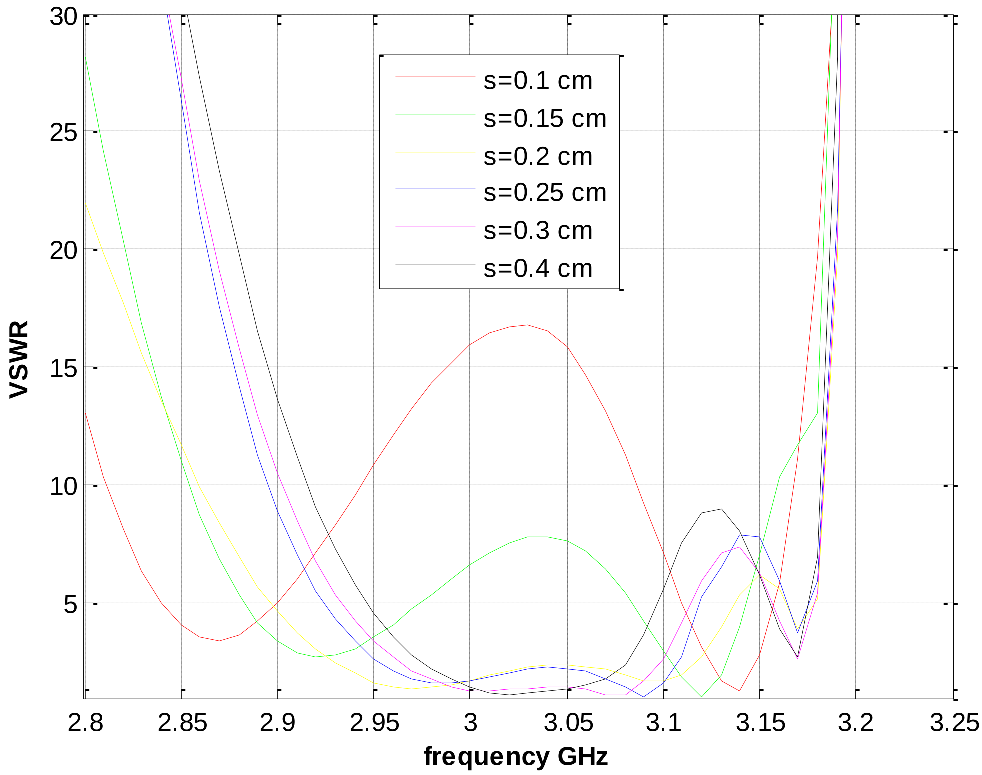
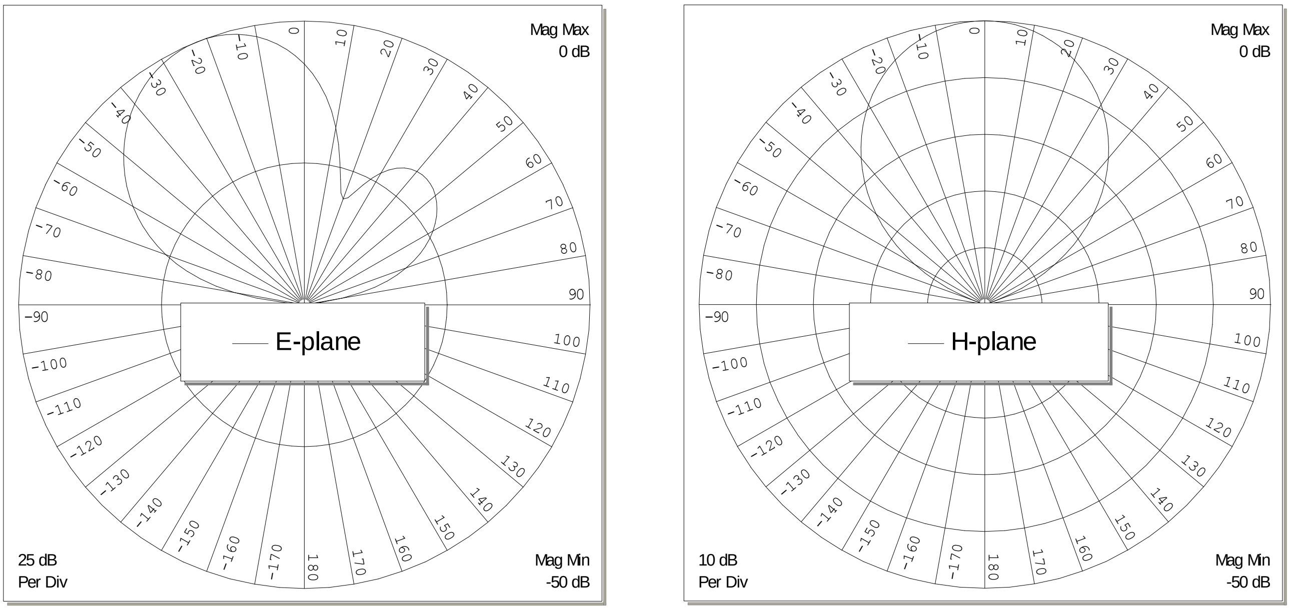
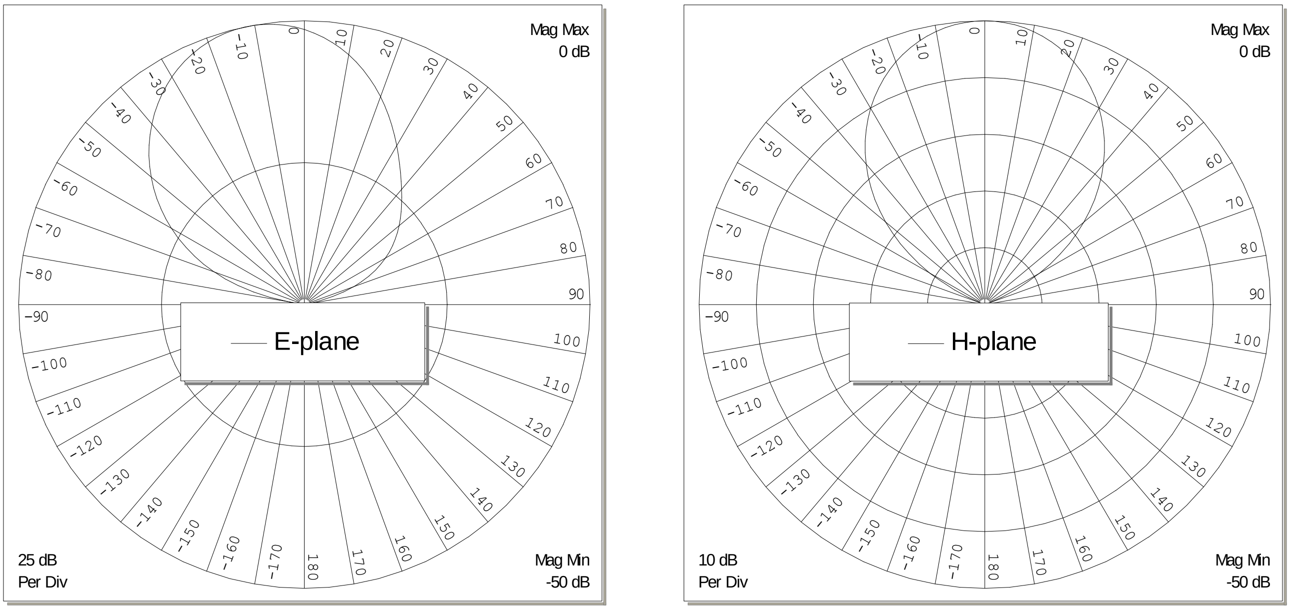


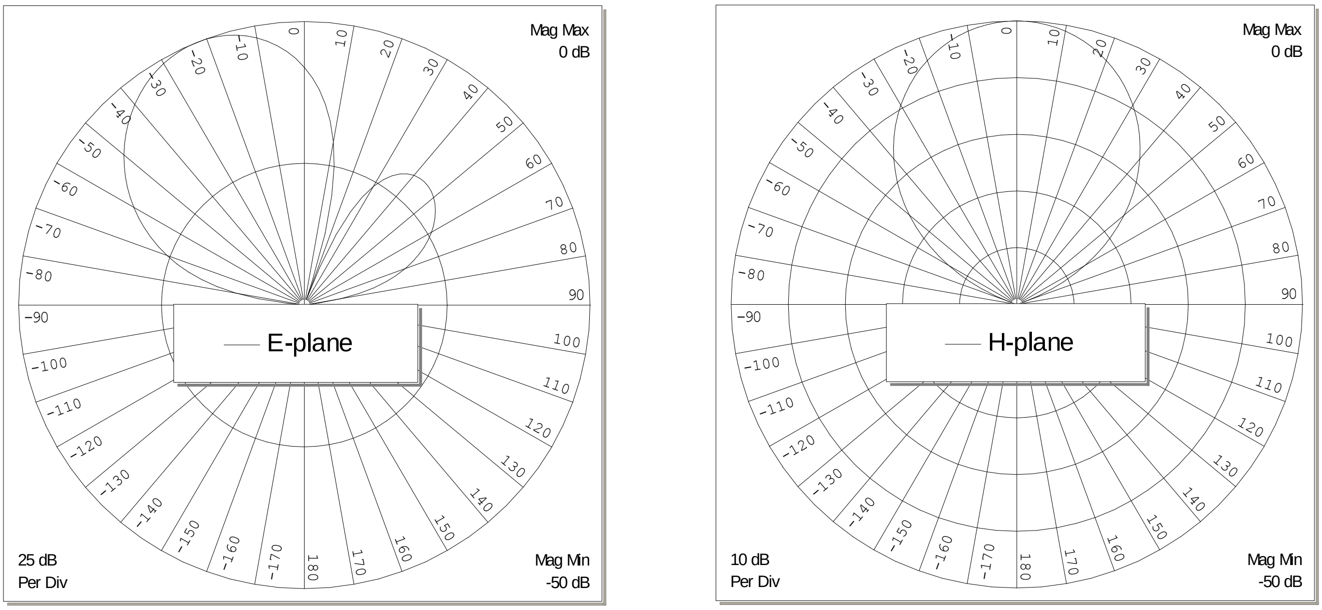
Figure (4) Input ***VSWR*** **Variation w.r.t Frequency for** $h_1 = 0.07\ cm$**.**



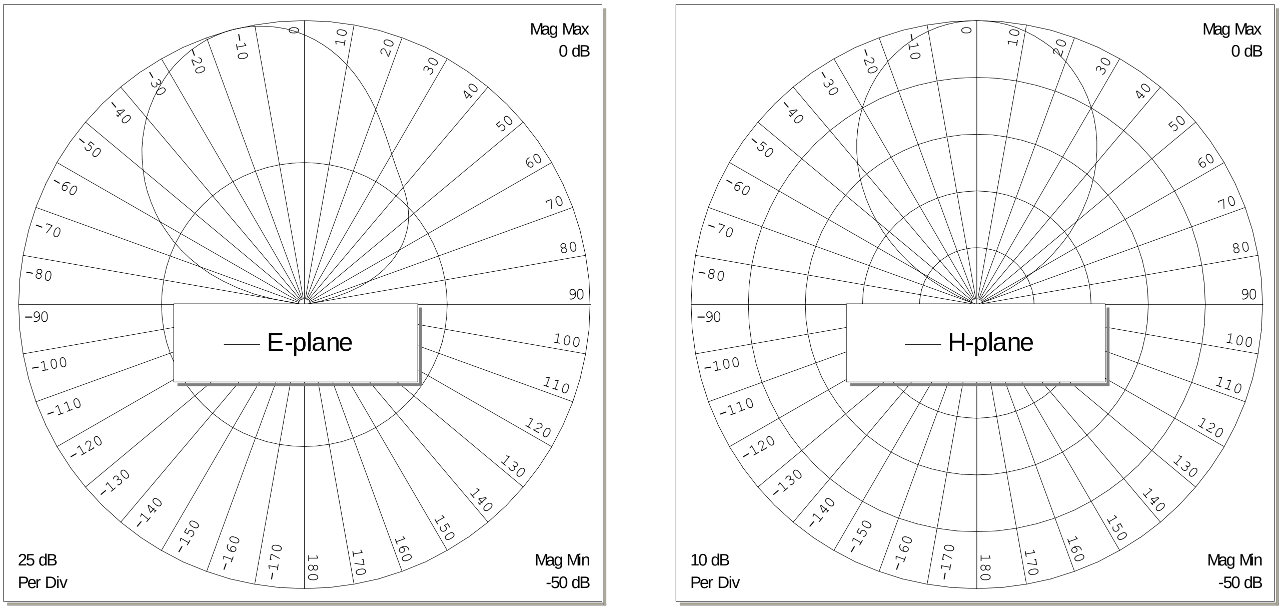
a) f=2.95 GH (First Resonance)



b) f=3.11 GH (Second Resonance)



c) f=2.97 GH(First Resonance)



d) f=3.09 GH (Second Resonance).

Figure (5) Radiation Power Pattern for *h_1=0.07 cm* with:

(a) and (b) s=0.2 cm

(c) and (d) s=0.25 cm

4.2- Simulation for h_1=*0.0٨ cm*

For $h_1 = 0.08\ cm$. Then: $h_2 = H - h_1 = 0.079\ cm$. The antenna has been constructed and analyzed in Microwave Office software for five values of parasitic gap spacing (s). Table (2) shows the resonance frequencies (f_1 and f_2) and bandwidths (BW_1 and BW_2) variation for different values of (s). The input impedance and the voltage standing wave ratio *VSWR* have been plotted in figures (6) and (7) respectively. For s=0.2 cm, dual characteristics can be observed while, dual characteristics with higher bandwidth can be obtained. For s=0.25 cm the radiation power patterns in E- and H-planes at the first and second resonances are plotted in Figure (8). In the H-plane, there is no much change in the radiation patterns at the two frequencies. However in the E-plane the beam maximum shifts 22.5^o (at the first resonance) and 18^o (at the second resonance) away from the broadside direction.

Table (2) Variation of the resonance frequencies and bandwidths w.r.t gap spacing (s) for h_1=0.08 cm.

Gap Spacing (s) in cm	f_1 in GHz	f_2 in GHz	BW_1	BW_2
0.1	2.85	3.14	0%	0.58%
0.15	2.91	3.12	0%	0.7%
0.2	2.95	3	0.77%	1.1%
0.25	2.96	3.09	3%	2%
0.3	2.98	3.08	4.3%	0%
0.4	2.99	3.18	3.11%	0%

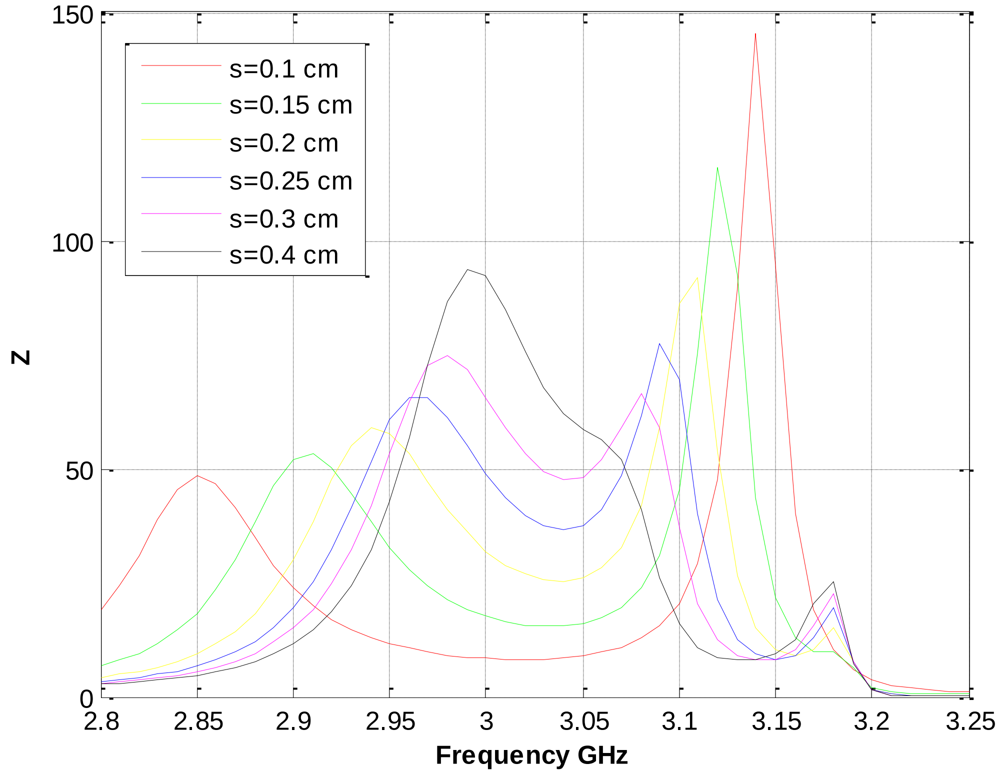


Figure (6) Input Impedance Variation w.r.t Frequency for $h_1 = 0.08\ cm$.

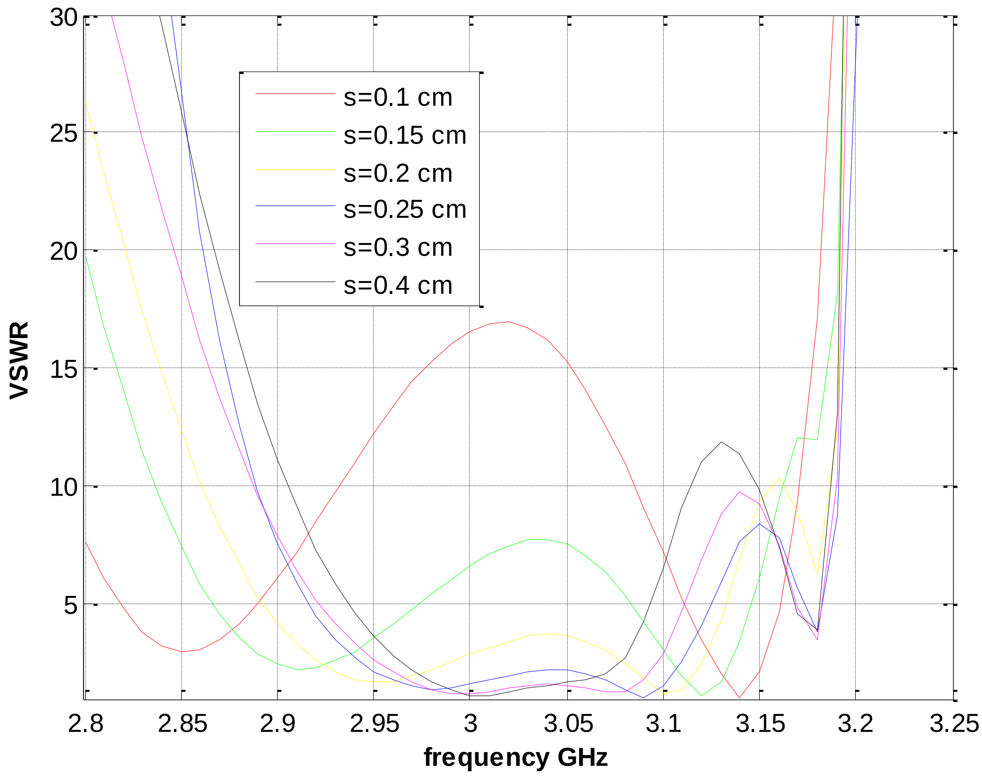
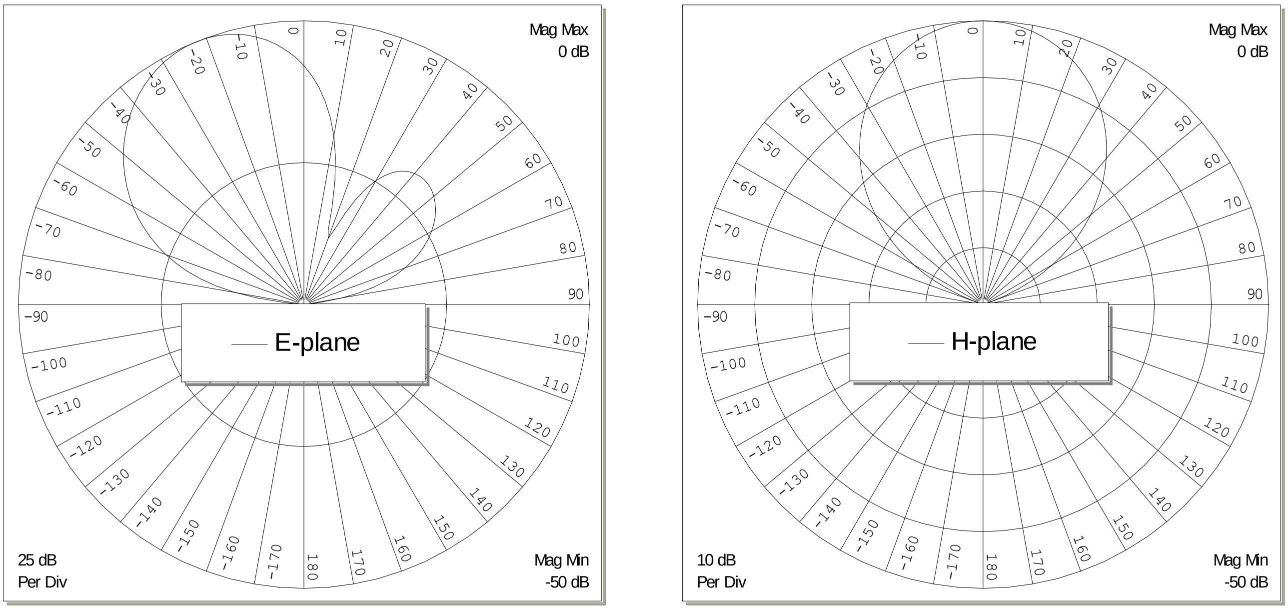
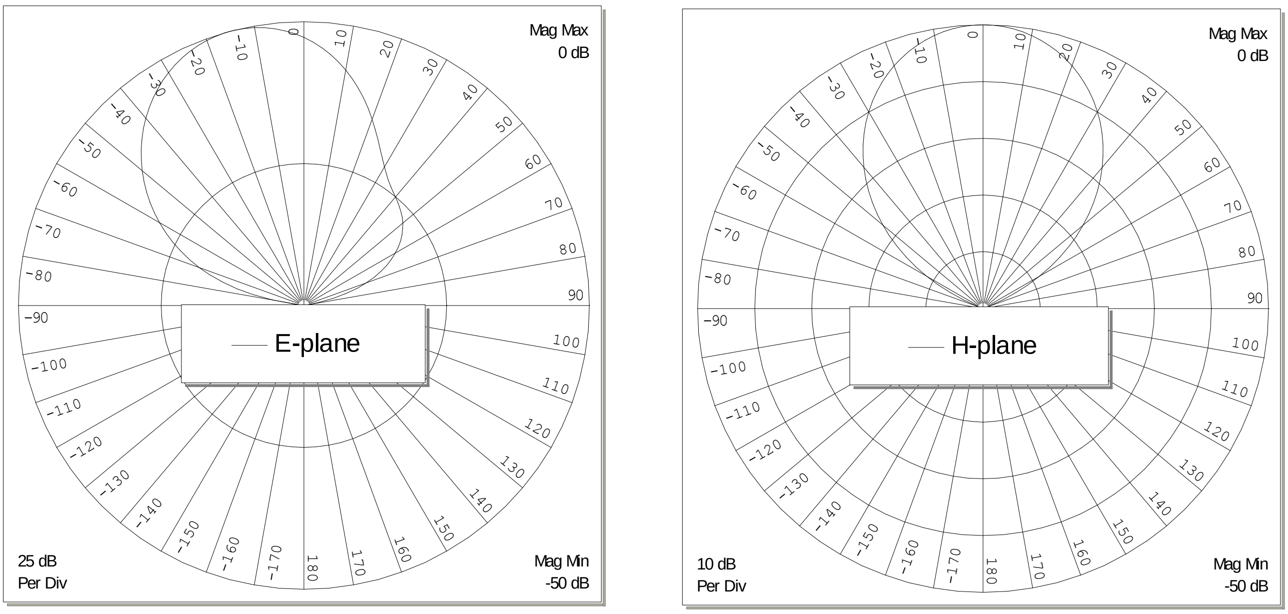


Figure (7) Input *VSWR* Variation w.r.t Frequency for $h_1 = 0.08\ cm$.



a) f=2.96 GH (First Resonance)



b) f=3.09 GH (Second Resonance)

Figure (8) Radiation Power Pattern for *h_1=0.08 cm* with s=0.25 cm

4.٣- Simulation for h_1=0.٠٩ cm

For $h_1 = 0.09\ cm$. Then: $h_2 = H - h_1 = 0.069\ cm$. The antenna has been constructed and analyzed in Microwave Office software for five values of parasitic gap spacing (s). Table (٣) shows the resonance frequencies (f_1 and f_2) and bandwidths (BW_1 and BW_2) variation for different values of (s). No effective changes can be observed on the results obtained compared with the results obtained for $h_1 = 0.08\ cm$. The input impedance and the voltage standing wave ratio *VSWR* have been plotted in figures (9) and (١0) respectively. For s=0.2 & cm s=0.25 cm dual characteristics is obtained while, broad bandwidth is obtained for s=0.3. The radiation power patterns in E- and H-planes at the lower, centre and upper frequency band are plotted in figure (11). For E-plane radiation pattern the beam maximum shifts away from the broadside direction by 21^{o}, 22.5^{o} & 22.5^{o} for the lower, centre and upper frequency band respectively.

Table (٣) Variation of the resonance frequencies and bandwidths w.r.t gap spacing (s) for h_1=0.0٩ cm.

Gap Spacing (s) in cm	f_1 in GHz	F_2 in GHz	BW_1	BW_2
0.1	2.89	3.14	0%	0.6%
0.15	2.9	3.12	0.8%	0.7%
0.2	2.93	3.11	2.4%	1%
0.25	2.96	3.09	3.27%	2%
0.3	2.97	3.08	5%	0%
0.4	2.98	3.19	3.14%	0%

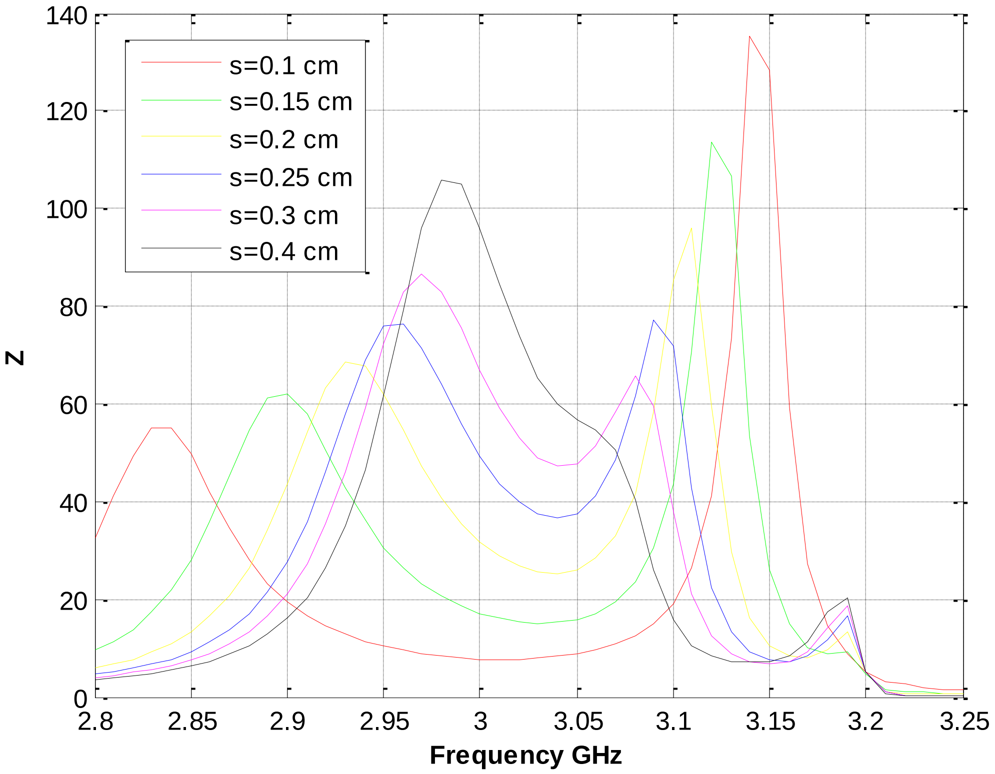


Figure (9) Input impedance Variation w.r.t Frequency for $h_1 = 0.09\ cm$ **.**

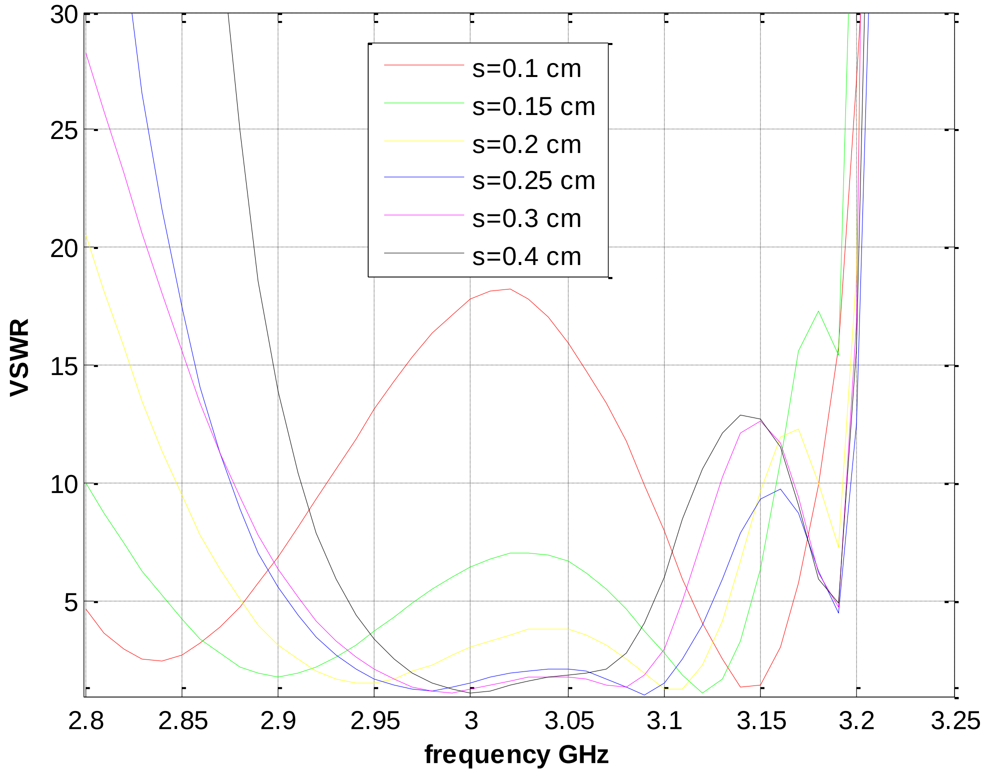
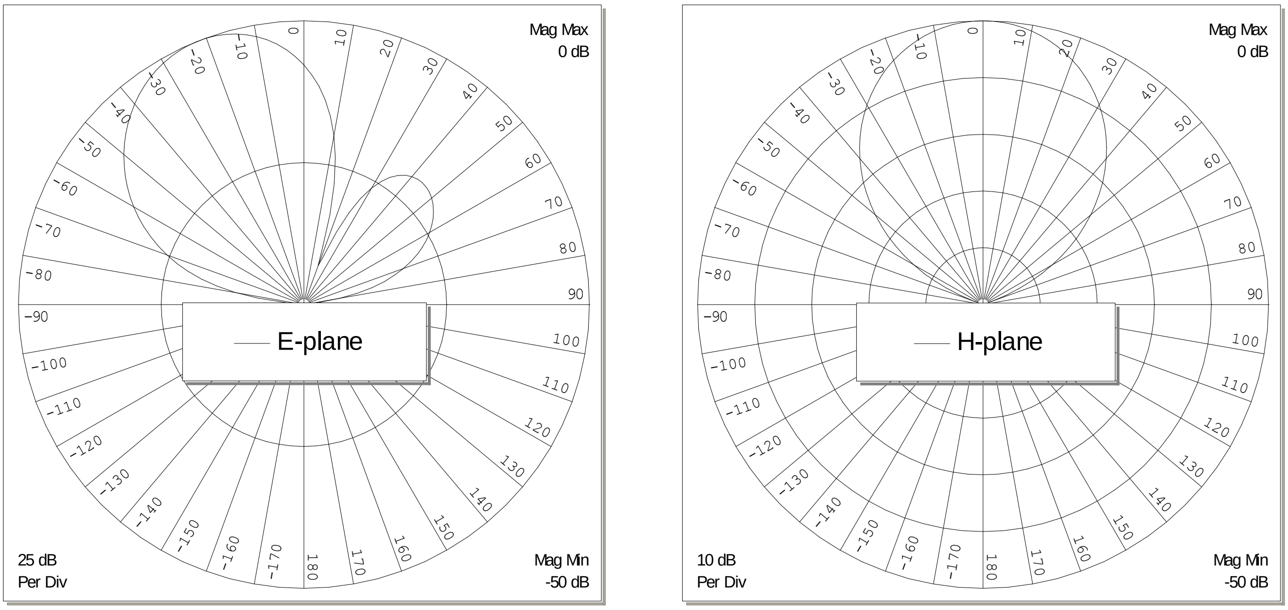
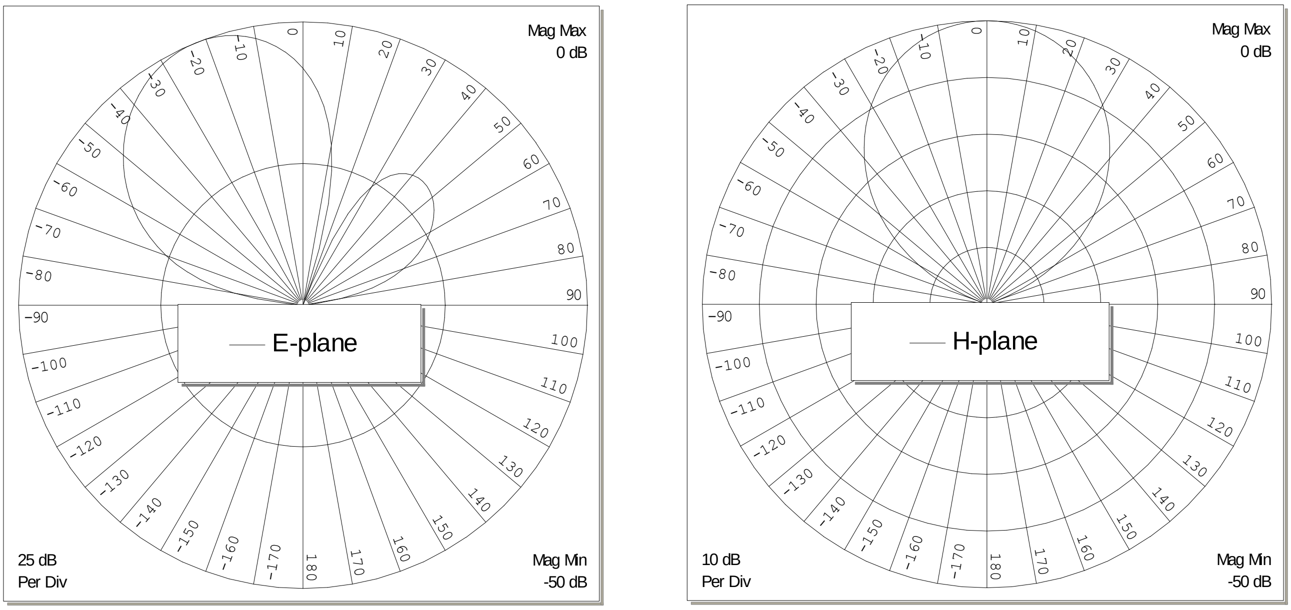


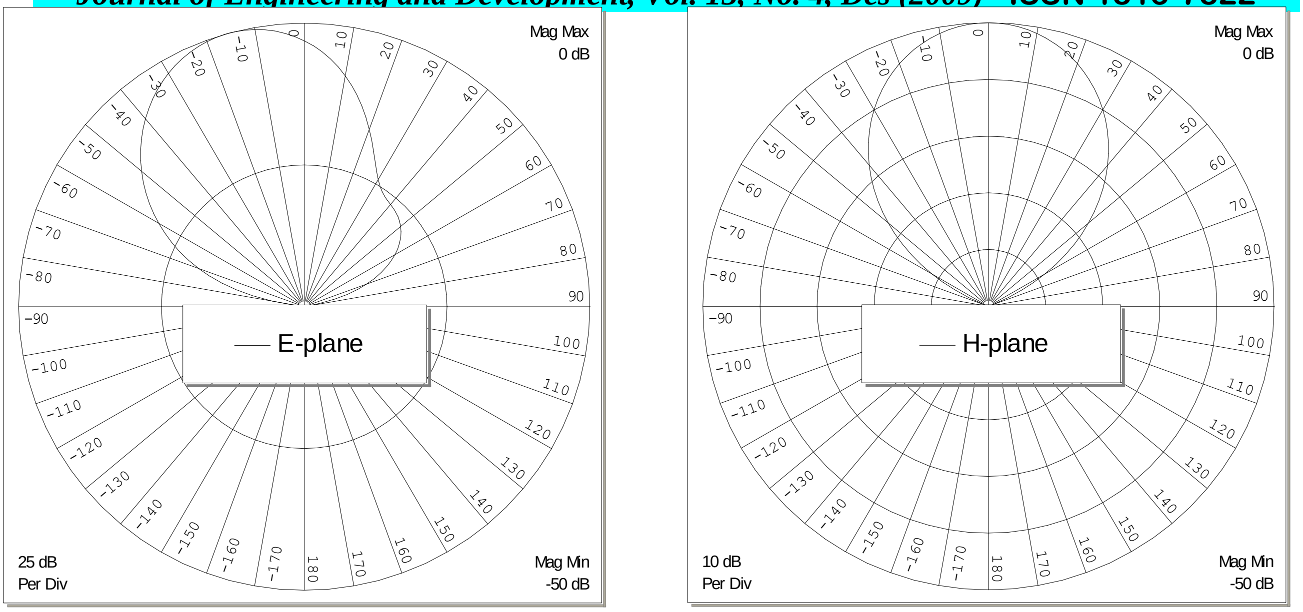
Figure (10) Input ***VSWR*** **Variation w.r.t Frequency for** $h_1 = 0.09\ cm$ **.**



a) f=2.96 GH (Lower Band)



b) f=2.97GH (Centre Frequency)



c) f=3.09 GH (upper band)

Figure (11) Radiation Power Pattern for h_1=0.09 cm with s=0.3 cm

4.٣- Simulation for h_1=0.1 cm

For $h_1 = 0.1\,cm$. Then: $h_2 = H - h_1 = 0.059\ cm$ brad band characteristics are obtained as shown in table (4), that is because the two resonances are close to each other and below the *VSWR=2* line as shown in figure (12) & (13). That is occurs when the gap spacing (s) equals to *0.3 & 0.4 cm*. Figure (14) shows the radiation power pattern plot for s=0.25 cm at *f=2.95 GHz* (centre frequency). The E-plane beam maximum shifts away from the broadside direction by 21^o.

Table (4) Variation of the resonance frequencies and bandwidths w.r.t gap spacing (s) for h_1=0.1 cm.

Gap Spacing (s) in cm	f_1 in GHz	f_2 in GHz	BW_1	BW_2
0.1	2.82	3.15	0%	0.63%
0.15	2.89	3.13	1.2%	0.73%
0.2	2.93	3.11	2.66%	1.2%
0.25	2.95	3.09	6% *(Brad band characteristics)*	
0.3	2.96	3.08	5.5% *(Brad band characteristics*	
0.4	2.98	3.2	3.5%	0%

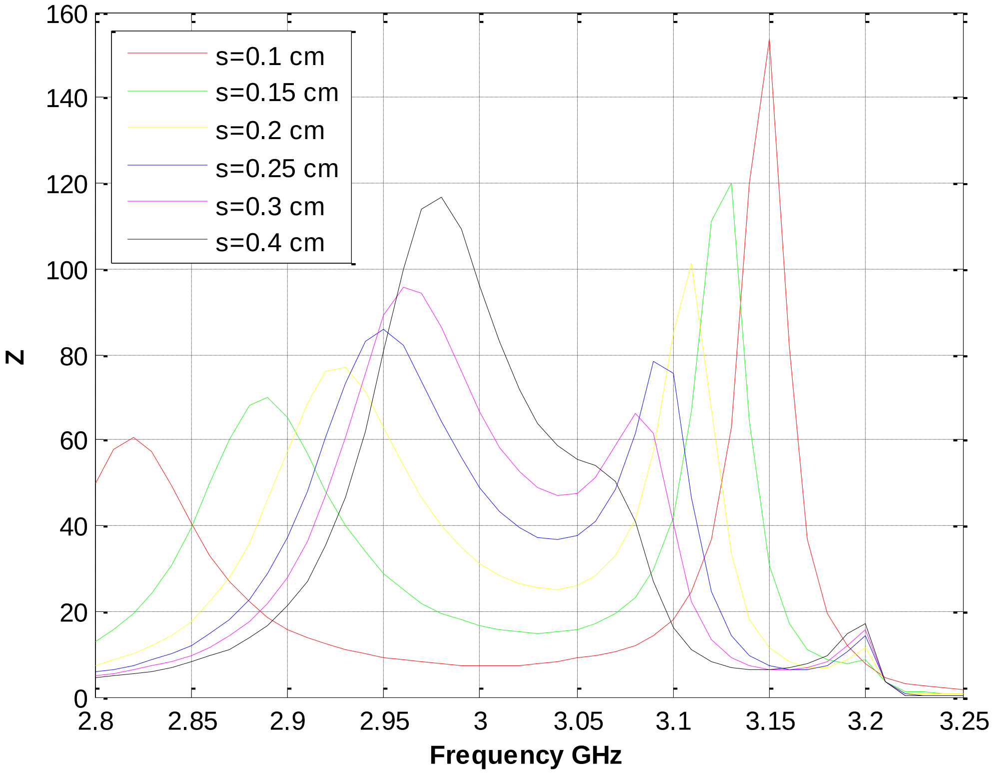


Figure (12) Input impedance Variation w.r.t Frequency for $h_1 = 0.1\,cm$ **.**

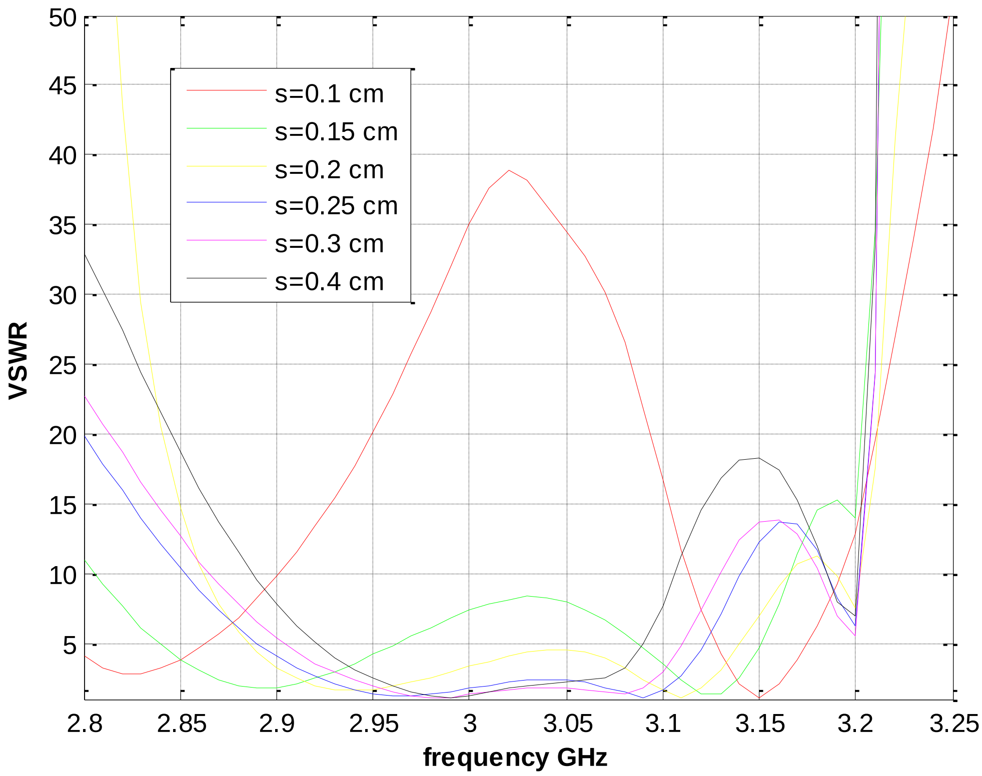


Figure (13) Input *VSWR* Variation w.r.t Frequency for $h_1 = 0.1\,cm$ **.**

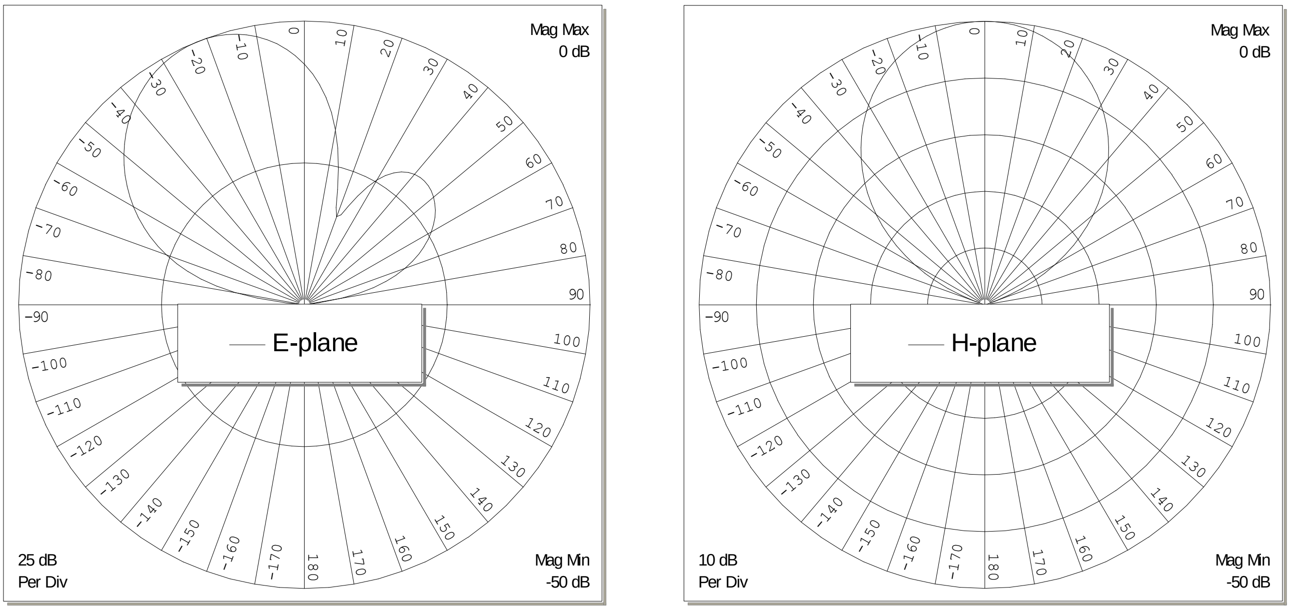


Figure (14) Radiation Power Pattern for h_1=0.1 cm with s=0.25 cm

4.٣- Simulation for h_1=0.12 cm

For $h_1 = 0.12\ cm$. Then: $h_2 = H - h_1 = 0.039\ cm$ dual band characteristics are obtained as shown in table (5). Figure (15) & (16) shows the variation of the input impedance and *VSWR*.

Table (5) Variation of the resonance frequencies and bandwidths w.r.t gap spacing (s) for h_1=0.12 cm.

Gap Spacing (s) in cm	F_1 in GHz	f_2 in GHz	BW_1	BW_2
0.1	2.8	3.15	0.43%	0.63%
0.15	2.87	3.13	1.4%	0.73%
0.2	2.9	3.11	3.45%	1.2%
0.25	2.93	3.09	3.45%	0.8%
0.3	2.95	3.08	3.1%	1.3%
0.4	2.97	3.22	3.5%	0%

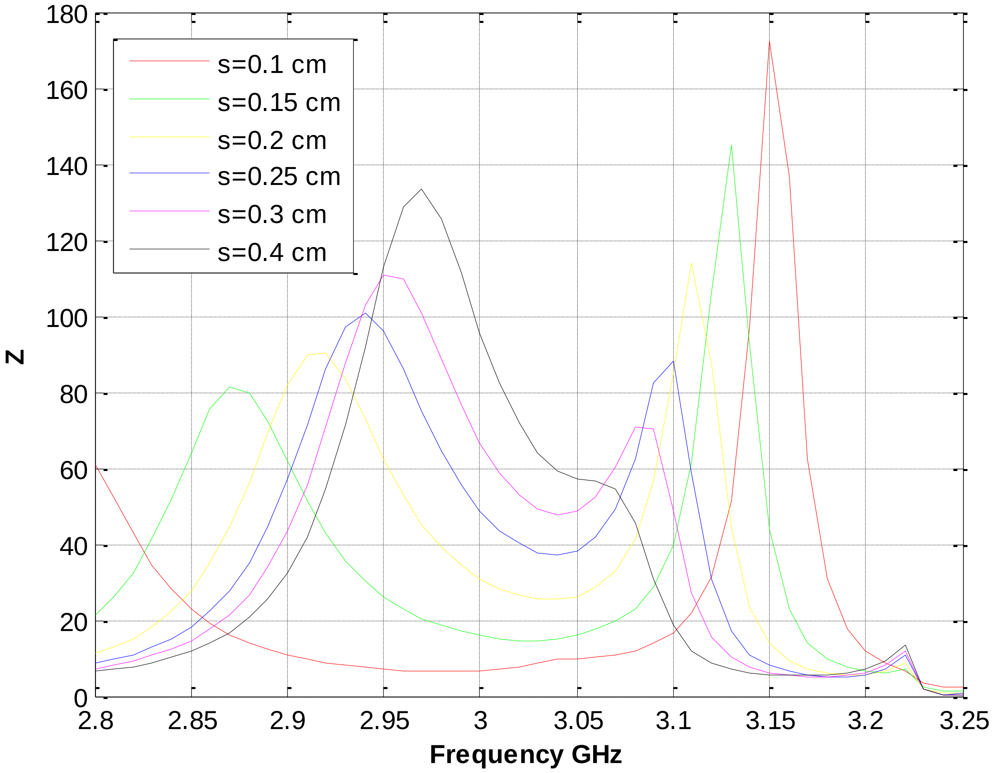


Figure (15) Input *VSWR* Variation w.r.t Frequency for $h_1 = 0.12\ cm$.

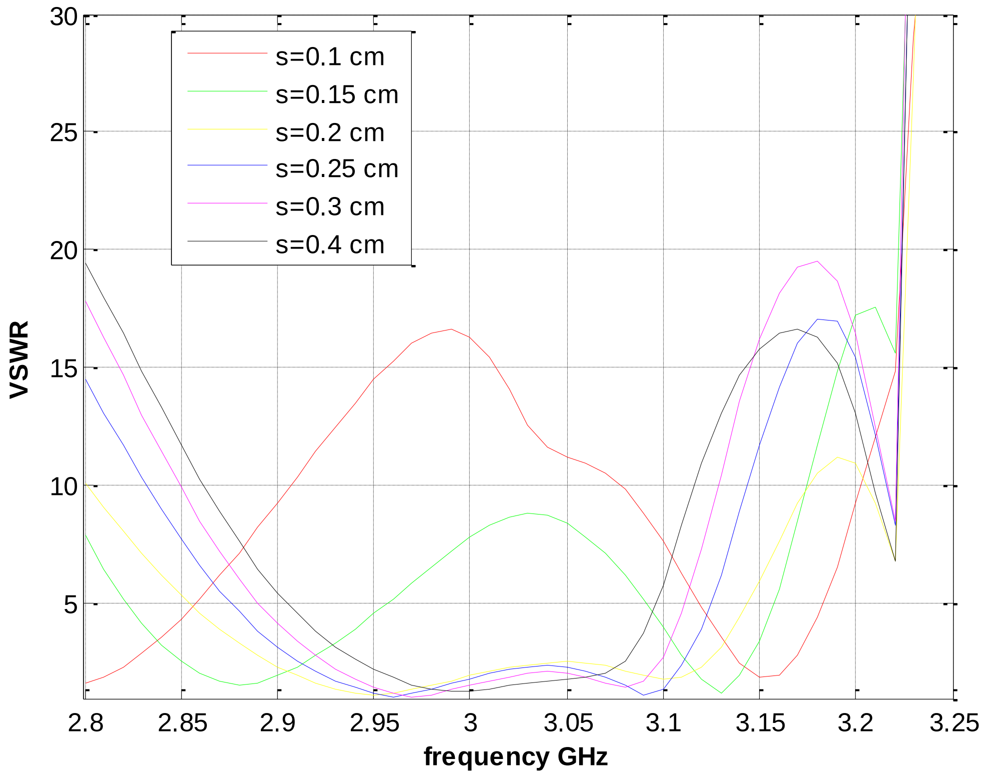


Figure (16) Input *VSWR* Variation w.r.t Frequency for $h_1 = 0.1\,2cm$.

5- Simulation for RMSA

A rectangular microstrip antenna has been constructed and analyzed in Microwave Office in order to show how much the bandwidth is improved. The substrate thickness ε_r and heights (H) are taken as:

$\varepsilon_r=2.45, H=0.159\ cm$

The patch dimensions are taken as derived element dimensions.

The bandwidth computed and is equals to 1.01% for $VSWR \leq 2$.

6- Conclusions

From the investigation done above the following points can conclude:

1. The antenna structure presented in this paper is compact and has dual band as well as broad band characteristics **(without increasing the substrate thickness)** with suitable field variation with respect to frequency. While, the disadvantages of this geometry is the large antenna size which make the possibility of array constriction very difficult and the asymmetry of the E-plane power pattern w.r.t the broadside direction.
2. Maximum bandwidth is 6% obtained for $h_1=0.1\ cm$ and s=0.25 *cm*. which means the bandwidth improved about 6 times compared with the same patch dimensions, substrate thickness & permittivity.
3. The main disadvantage of this design is the asymmetry which obtained from the E-plan power pattern. This is because the different phase between the parasitic patches in top layer due to the geometry.

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