Deign of Broad Band Gap-Coupled Microstrip Antenna Using Microwave Office 7.5

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Abstract

The objective of this paper is to design a compact and broadband microstrip patch antenna which operates at 2.9 GHz center frequency with parasitically coupling rectangular microstrip antenna RMSA. Several parasitically coupled geometries are studied here.Thes are: radiating edge and non radiating edge gap-coupled RMSA with parasitic patches, one, two and four parasitic patches are being presented. The antenna has been analyzed using Microwave Office package software 7.5 in 2007. This proposed structure can have an operating bandwidth more than six times than that of the conventional rectangular patch antenna.

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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 e_r. However, there is a practical limit on increasing the thickness, and increased beyond $0.1l$, surface-waves propagation take place resulting in degradation in the antenna performance[1,2]. To overcome its inherent limitation of narrow impedance bandwidth, many techniques have been suggested such as probe fed stacked antenna[3], microstrip patch antennas on electrically thick substrate[4], slotted patch antenna[5], stacked shorted patches[6] and multi resonator patches or as known microstrip antenna with parasitic patches, when the patches have a planar form or in stacked geometry[7-9]. The planar coupled multiple resonators yield wide bandwidth in the same way as in the case of multistage tuned circuits[8]. Several configurations of coupled multiple resonators are available yielding wide bandwidth in the range of 5%~25%[4]. Various parasitic patches like narrow strips, shorted quarter-wavelength rectangular patches, and rectangular resonator patches have been gap-coupled to the central-fed rectangular patch.Wan K., was designed and fabricated a proto type sandwich rectangular patch antenna covers the 2.4 GHz band for WLAN with 7.8% bandwidth[7]. Sumana K., was designed a multilayer patch antenna with total bandwidth of 8.5%[8]. Selman H., and Michael N., was used the idea of four edges parasitic patches with triangular patches for WLAN system resulting in 8.4% bandwidth [9].

This paper describes the planar multi-resonator technique using rectangular patches RMSA for broadband operation. Only a single patch is fed, and the other patches are electromagnetic coupled EMC. The antenna analyzed using Microwave office package software virgin 7.5 in 2007.

1- Mechanisms of Parasitic Coupling

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 can be 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-b). If the bandwidth of the individual patch is large, then the difference in the two frequencies should be large to yield an overall wide band width. Also dual band can be obtained, by increasing the difference

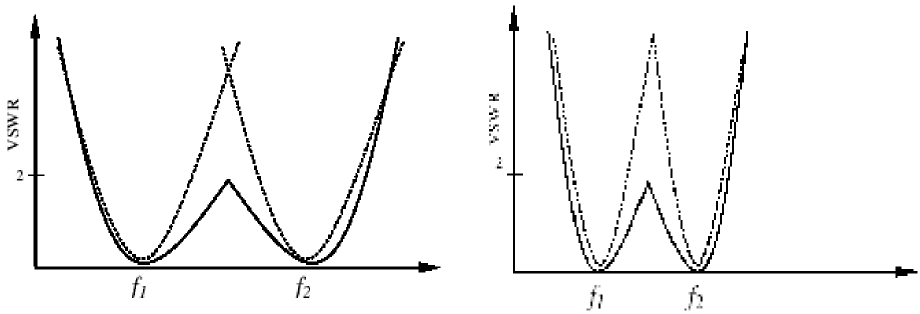


Figure (1) VSWR Plot of Two Coupled Resonators Having
(a) Broad Bandwidth

(b) Narrow Bandwidth.

2- Rectangular Microstrip Antenna

One of the simplest and widely used of the microstrip antenna configurations is the rectangular microstrip antenna RMSA. A rectangular patch is defined by its length L and width W. For the fundamental TM_{10} , the resonance frequency is given by [1]:

$$f_o = \frac{c}{2L_e\sqrt{e_e}} \qquad \text{...(1}$$

Where:

***c* is the light velocity equals to 3 10^8 m/sec.**

e_e is the effective dielectric constant given by:

$$e_e = \frac{e_r+1}{2} + \frac{e_r-1}{2}\left[1+\frac{10h}{W}\right]^{-\frac{1}{2}} \qquad \text{..... (2)}$$

L_e is the effective patch length due to the effect of the fringing field given by: $L_e = L + 2\Delta L$

$$\Delta L = 0.421h\frac{(e_e+0.3)\left(\frac{W}{h}+0.264\right)}{(e_e-0.258)\left(\frac{W}{h}+0.8\right)} \qquad \text{.. ...(3)}$$

3.Gap-Coupled Rectangular Microstrip Antennas

Either one or two parasitic rectangular patches can be placed along one or both of the radiating edges of the fed rectangular patch with a small gap between them. All cases of parasitic patches performance will be discussed in the next sub sections.

3.1- One Parasitic Patch

An rectangular microstrip antenna with one parasitic rectangular patch placed along one of its radiating edges is shown in figure (2). The dimensions of the fed patch (exited patch) are taken *L=3 cm* and *W=4 cm*, with $e_r = 2.55$, $h = 0.159\,cm$. **The antenna has been analyzed using Microwave Office 7.5 package software. Figures (3,4) show the input impedance and *VSWR* of the antenna without parasitic patch (only fed patch). The computed resonance frequency is 2.9 GHz and the bandwidth BW equals to 1.6% for** $VSWR \le 2$.

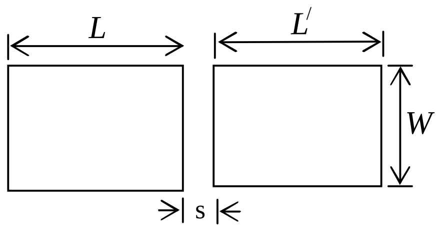


Figure (2) Two Radiating Patches with Gap-Coupled

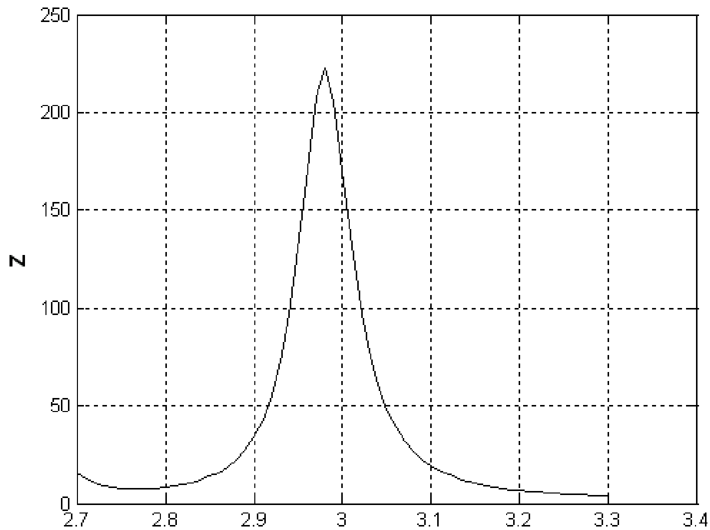


Figure (3) Input Impedance Variation w.r.t Frequency for RMSA

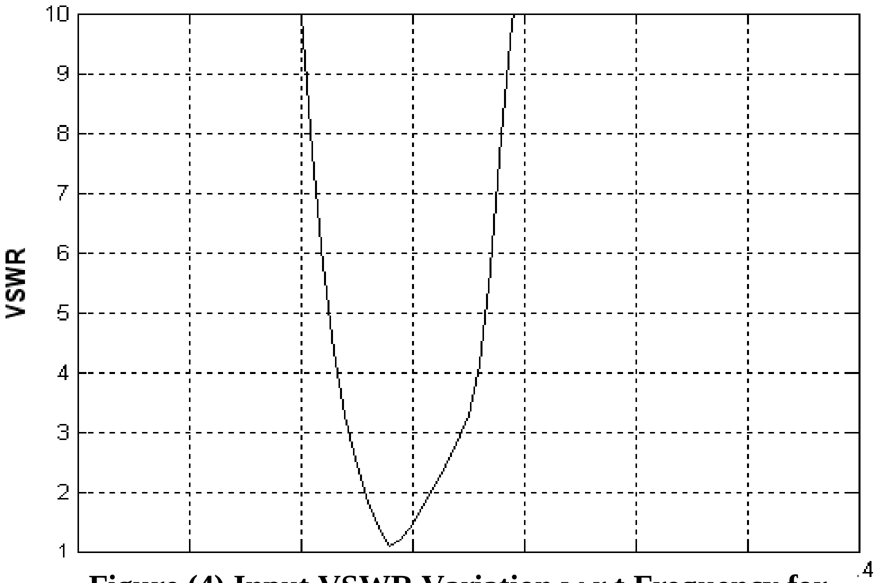


Figure (4) Input VSWR Variation w.r.t Frequency for RMSA

A parasitic patch with resonance frequency slightly above the resonance frequency of the fed patch is placed next to the fed patch as shown in figure (2), it gets exited due to coupling with fringing fields along the width of the patch. The antenna analyzed for gap spacing range from $0.1l$ **to** $0.4l$ **with three values of parasitic patch length** $\left(L' = 2.9\ cm, L' = 2.8\ cm\ and\ L' = 2.7\ cm\right)$**.**

The input impedance and VSWR plots of a single RMSA with one parasitic patch are shown in figures (5,6). The length of the parasitic patch is 2.9 cm. The input impedance will be reduced from its value without parasitic patch. When the gap increases, the input impedance increases.

At s=0.4 the parasitic patch has no effect on the overall input impedance, which can easily seen with simple comparison from a single RMSA without parasitically coupled (figure (3)). Maximum bandwidth is obtained when the two resonances is completely inside the VSWR=2 line and is as large as possible. For s=0.2 cm, broader bandwidth is obtained which equals to 4.77% (figurer(6)). For s=0.25 the bandwidth is 3.3%, while for s=0.1, 0.15 and 0.3 cm the VSWR configuration has dual-band characteristics. For s=0.4 cm, the VSWR plot match with that of RMSA (see figure (3)).

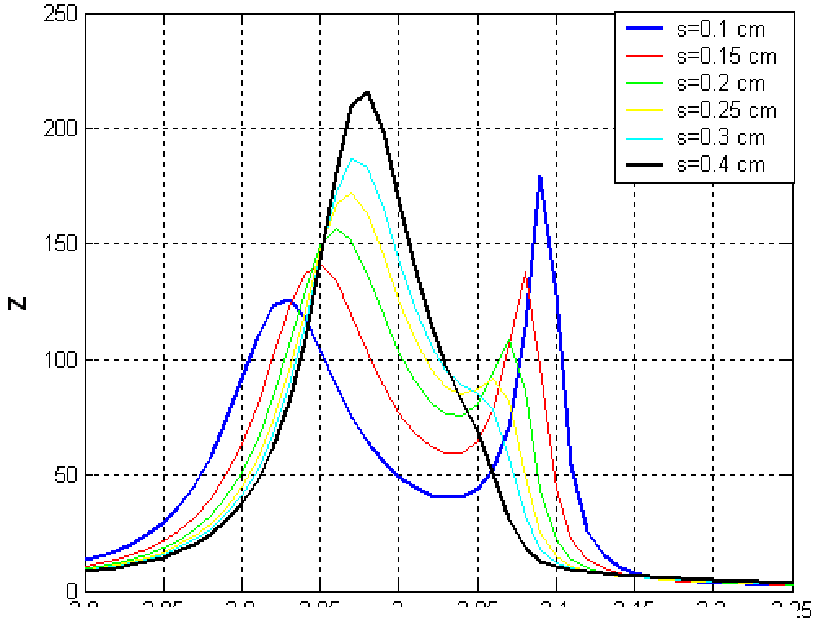


Figure (5) Input Impedance Variation w.r.t Frequency for $L' = 2.9\ cm$ **.**

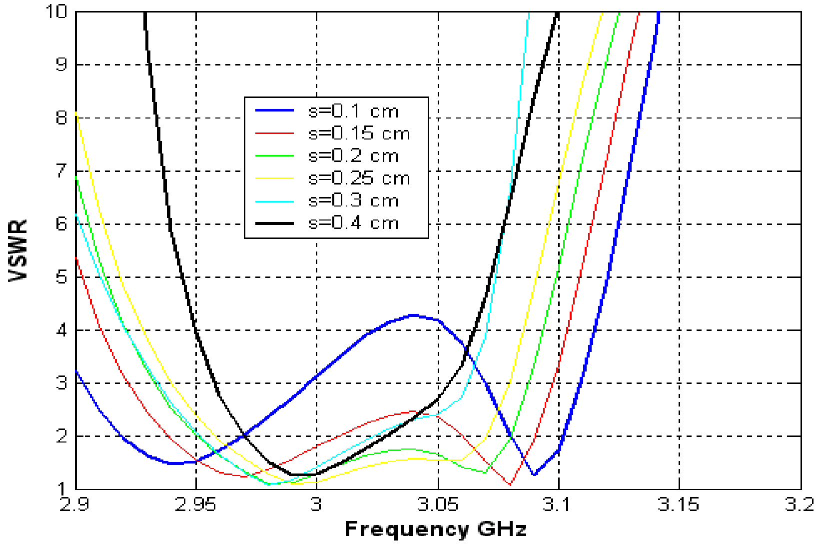


Figure (6) Input VSWR Variation w.r.t Frequency

The length of the parasitic patch determines the position of the resonance frequency. For $L^{/} = 2.8\ cm\ and\ L^{/} = 2.7\ cm$ **the input impedance and VSWR plots are shown in figures (7,8) respectively. As** $L^{/}$ **decreases, the resonance frequency of the parasitic patch will increased, then the total VSWR plots shift to the right. For** $L^{/} = 2.8\ cm$**, maximum bandwidth occurs at s=0.1 cm which equals to 2.4% for VSWR≤2. The effect of the parasitic patch is reduced with reducing the parasitic patch length. For** $L^{/} = 2.7\ cm$**, no effect can be observed on the total bandwidth and the VSWR plot approximately matches with the VSWR of RMSA (figure (3)).**

(a) (b)

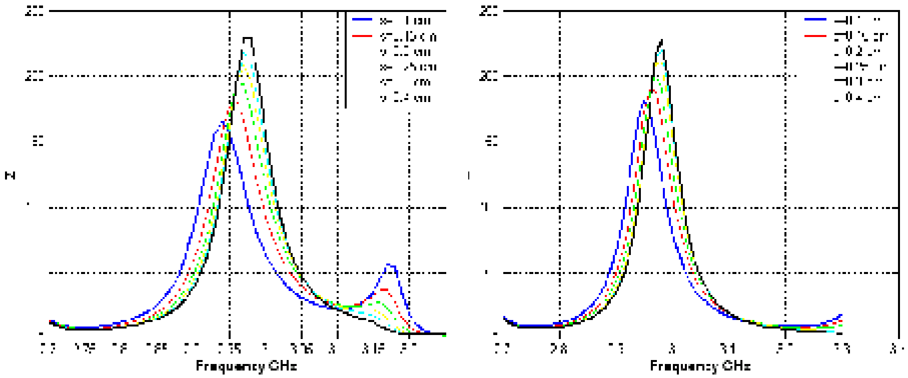


Figure (7) Input Impedance Variation w.r.t Frequency for

(a) $L^{/} = 2.8\ cm$ **, (b)** $L^{/} = 2.7 cm$ **.**

(a) (b)

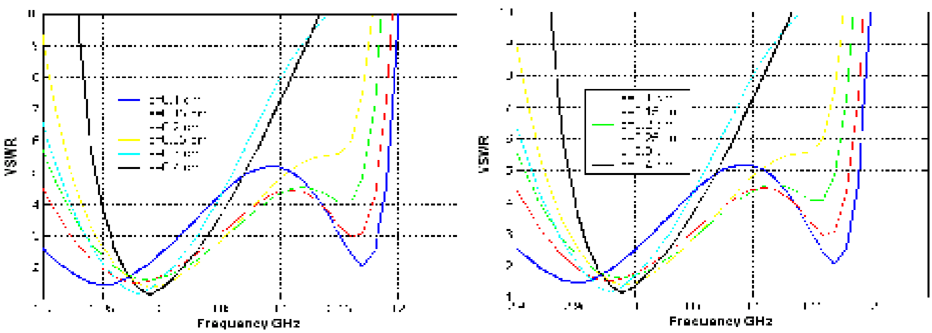
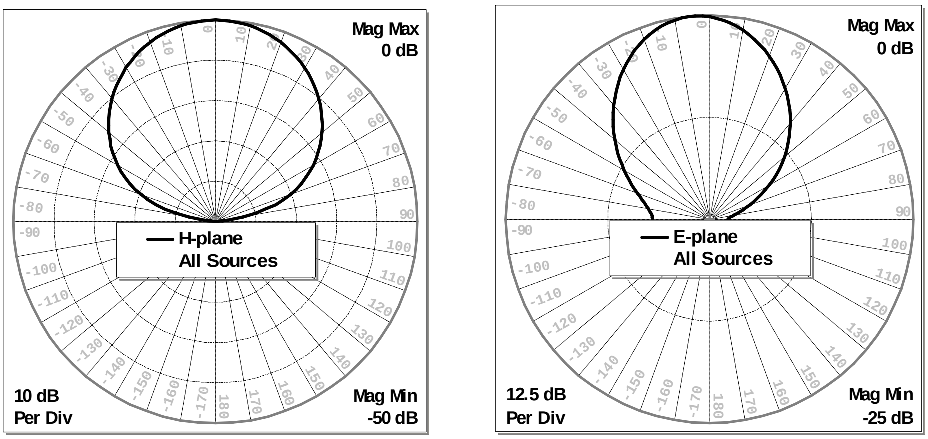


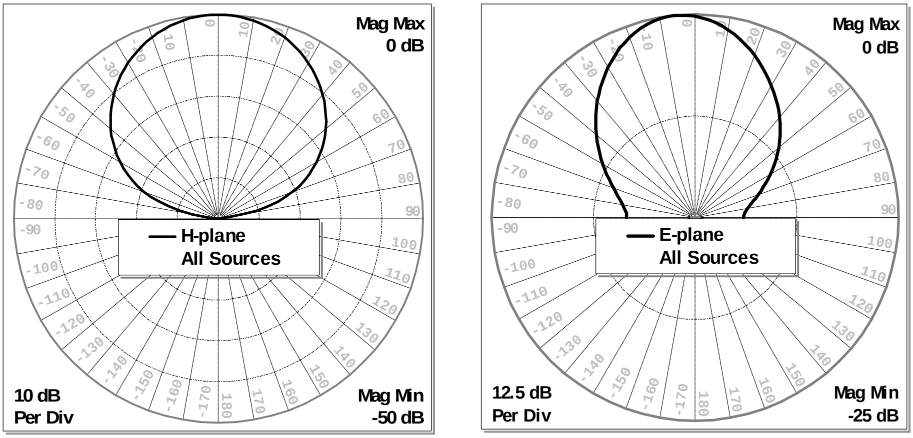
Figure (8) Input VSWR Variation w.r.t Frequency for

(a) $L^{/} = 2.8\ cm$ **, (b)** $L^{/} = 2.7\ cm$ **.**

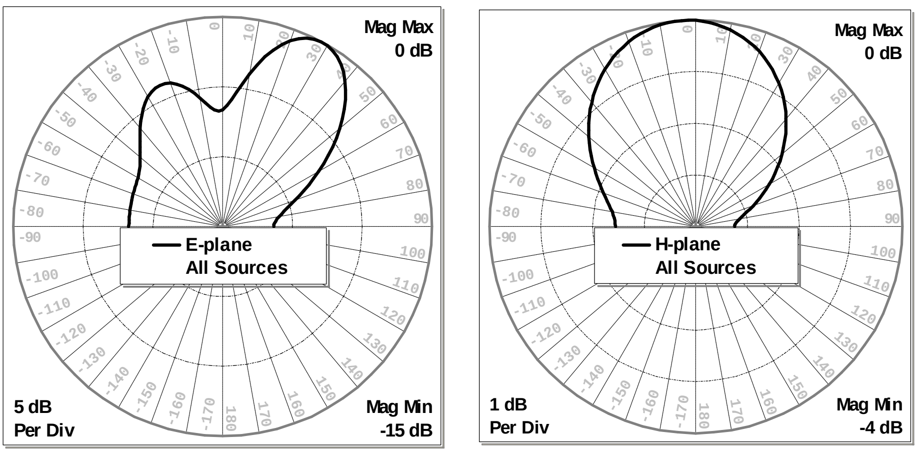
For the one parasitic RMSA with s=0.1 cm, the radiation power patterns in the E- and H-planes at the lower, center and upper frequency $\left(f = 2.871, 3.015\ and\ 3.159\ GHz\right)$ **are plotted in Figure (9). In the H-plane, there is no much change in the radiation patterns at the three frequencies. However in the E-plane, as the frequency increases, the beam maxima shifts away from the broadside. At the highest frequency, the beam maxima shifts away from the broadside to** $q = 45^o$**. Figure (10) shows the directivity variation with respect to frequency. The change in the directivity reaches 1.8 dB in the antenna impedance bandwidth which is not acceptable for many applications.**



a) ***f=2.871 GHz (Lower band).***

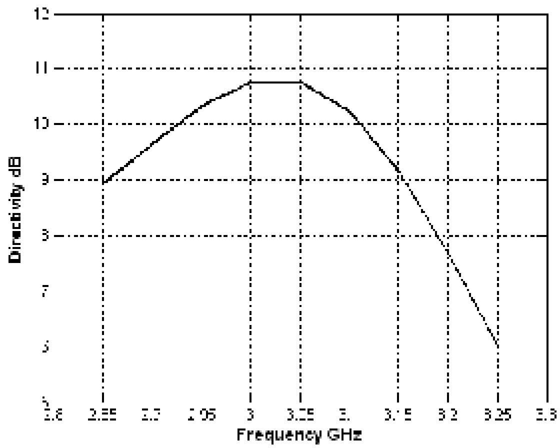


b) ***f=3.015 GHz (center frequency).***



c) ***f=3.205 GHz (upper band).***

Figure(9) Radiation Power Pattern of One Parasitic Patch RMSA with $L^{/} = 2.9\ cm$ and s=0.1 cm for the Center and the Two Band-edges Frequencies.



Figure(10) Directivity Variation w.r.t Frequency for One parasitic Patch RMSA.

3.2- Two Parasitic Patches

As seen in the previous section, when a parasitic patch is placed along one of the radiating edges of the RMSA, the beam maxima shifts away from the broadside direction and the pattern is not symmetrical with respect to the broadside direction. To obtain a symmetrical pattern with the broadside, identical parasitic patches are gap-coupled to both the radiating edges of the fed patches as shown in figure (11).

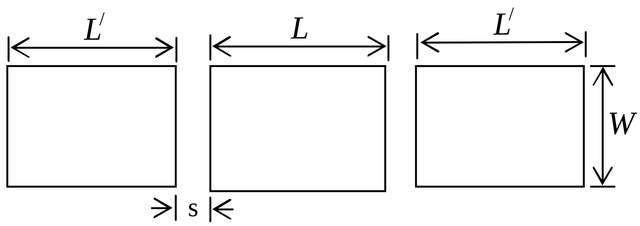


Figure (11) Two Identical Parasitic patches with RMSA.

A two identical parasitic patches with resonance frequency slightly above the resonance frequency of the fed patch is placed in both sides of the fed patch, it gets exited due to the coupling with fringing fields along the width of the patch (radiating edges). The antenna analyzed for gap spacing range from $0.1l$ to $0.4l$ with three values of parasitic patch length $\left(L' = 2.9\ cm, L' = 2.8\ cm\ and\ L' = 2.7\ cm\right)$.

The input impedance and VSWR plots of a single RMSA with two parasitic patches are shown in figures (12) and (13) respectively. The length of the parasitic patch is 2.9 cm. The plots is wider compared to the one parasitic patch RMSA because the two coupled patches are resonant at the same frequency and hence the coupling is greater. The plot width is reduced by increasing the gap (s). Maximum bandwidth is obtained when the two resonances is completely inside the VSWR=2 line and is as large as possible. For s=0.25 cm, broader bandwidth is obtained which equals to 6% for VSWR < 2. While, dual band operation is achieved for s=0.1 and 0.15 cm,(all these cases are illustrated in the table (1)).

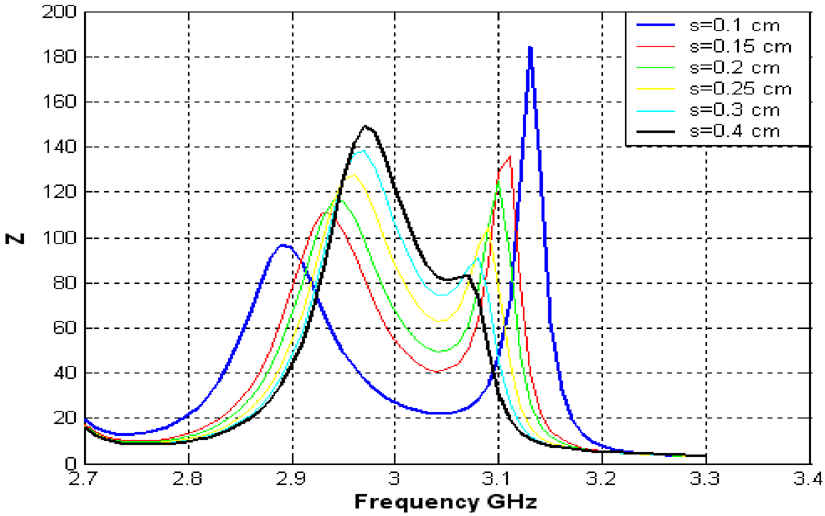


Figure (12) Input Impedance Variation w.r.t Frequency for Two Parasitic Patches RMSA with $L^{/} = 2.9\ cm$.

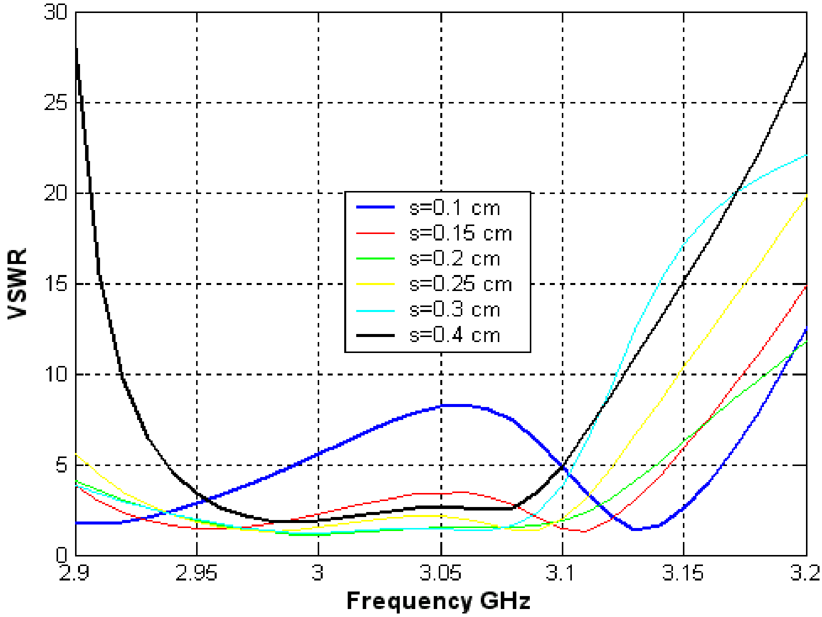


Figure (13) Input VSWR Variation w.r.t Frequency for Two Parasitic Patches RMSA with $L^{/} = 2.9\ cm$.

Table (1) Two Parasitic Patches Operation w.r.t Gap (s) for $L^{/} = 2.9\ cm$

Gap Space (s) in cm	**First Resonance f_1**	**Second Resonance f_2**	**B.W$_1$ %**	**B.W$_1$ %**
0.1	2.89 GHz	3.13 GHz	1.7%	0.78%
0.15	2.91 GHz	3.11 GHz	2.2%	0.985%
0.2	2.94 GHz	3.1 GHz	2.7%	1.12%
0.25	2.96 GHz	3.09 GHz	6% **(The Two Resonances below VSWR=2)**	
0.3	2.97 GHz	3.08 GHz	4% **(The Two Resonances below VSWR=2)**	
0.4	2.94 GHz	3.1 GHz	2.7%	1.12%

For $L^{/} = 2.8\ cm$ and $L^{/} = 2.7\ cm$ the difference in resonance frequency is greater than that for $L^{/} = 2.9\ cm$. The input impedance and VSWR plots are shown in figures (14, 15) respectively. For $L^{/}=2.8\ cm$ dual band operation can be observed. While, for $L^{/}=2.7\ cm$ the effect of the parasitic patch is reduced. For gap space s>0.2 cm no effect can be observed on the total bandwidth and the VSWR plot approximately matches with the VSWR plot of RMSA.

The radiation patterns of the antenna in the E and H-planes at center and two band-edge frequencies are shown in figure (16). The E-plane the beam maxima is symmetrical in the broadside direction. However, as the frequency increases, the side lobes begin to appear which is equals to -12dB at the *f*=3.205 *GHz* (upper band).

As in the one parasitic patch RMSA, no effective change in the H-plane radiation patterns. The gain is computed and is equal to 11.3566 dB.

(a) (b)

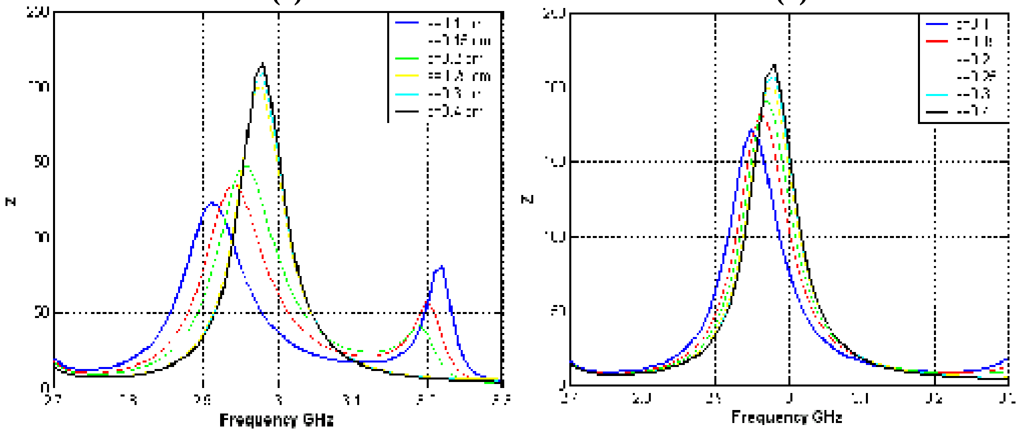


Figure (14) Input Impedance Variation w.r.t Frequency for Two Parasitic Patches RMSA with

(a) $L' = 2.8\ cm$ **(b)** $L' = 2.7cm$.

(a) (b)

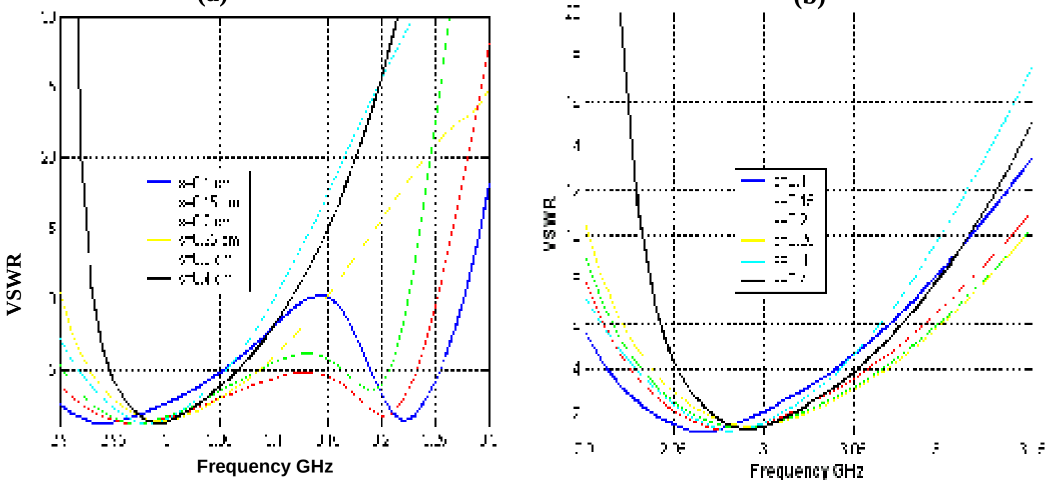
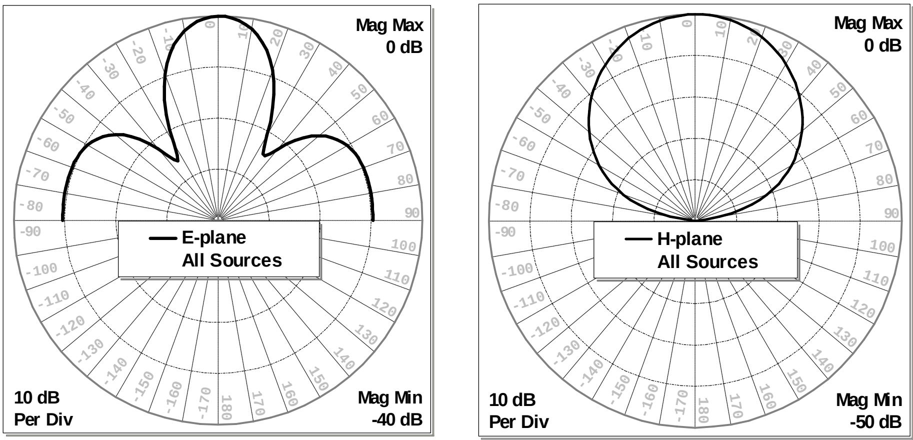
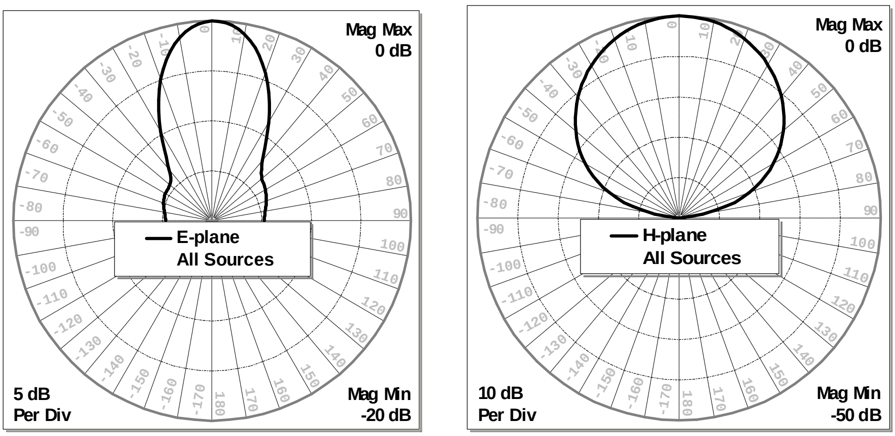


Figure (15) Input VSWR Variation w.r.t Frequency for Two Parasitic Patches RMSA with

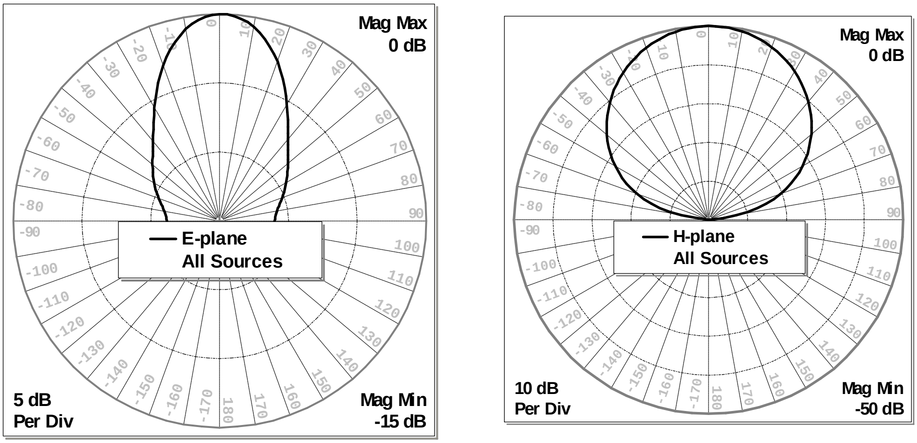
(a) $L' = 2.8\ cm$ **(b)** $L' = 2.7cm$.



a) *f=3.205 GHz (upper band).*



b) *f=3.025 GHz (center frequency*



c) *f=2.845 GHz (lower frequency).*

Figure(16) Radiation Power Pattern of Two Identical Parasitic Patch RMSA with $L^{/} = 2.9\ cm$ and s=0.1 cm for the Center and the Two Band-edges Frequencies.

3.3- Four Parasitic Patches

In this case four patches are parasitically gap coupled with the fed patch to increase the bandwidth. The patch along the non-radiating edge separated by s_1 from the fed patch, while the patch along the radiating edge separated by s_2 as shown in figure (17).

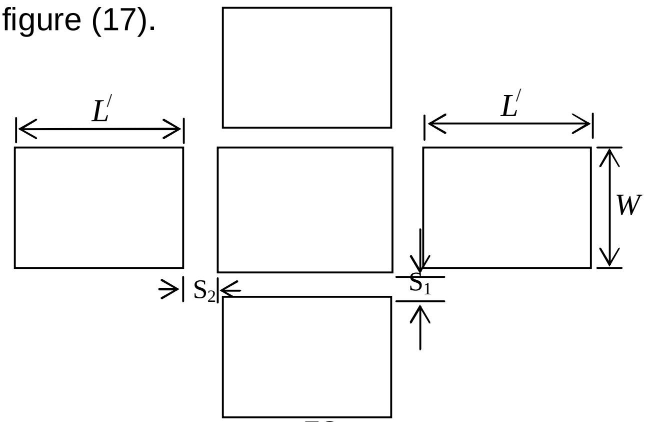
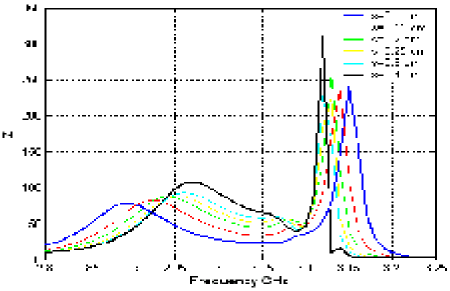


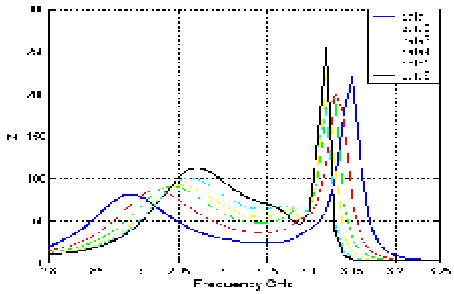
Figure (17) Four Identical Parasitic patches with RMSA.

A four identical parasitic patches with resonance frequency slightly above the resonance frequency of the fed patch is placed in both edges (radiating and non-radiating edge) of the fed patch, it gets exited due to the coupling with fringing fields along the width and length of the patch. The antenna is analyzed for gap spacing range (s_1, s_2) from $0.1l$ to $0.4l$ with parasitic patch length $\left(L' = 2.9\,cm\right)$.

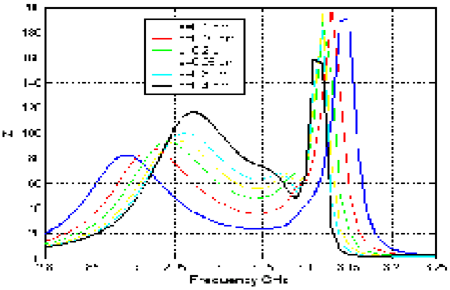
The input impedance and VSWR plots are shown in figures (18) and (19) respectively. The results (bandwidth) obtained from theses plots are listed in the table(2). For s_1=0.25 cm, and s_2=0.2 cm the bandwidth is 11.3%(maximum bandwidth obtained). Figure(20) shows the variation of the power patterns for the center frequency and the two band edges. The E-plane power pattern still broadside direction in the antenna bandwidth range. The antenna directivity equals to 13 dB. The variation of the directivity in the antenna bandwidth range is within 0.5 dB, which means suitable field variation with frequency compared with one or two parasitic patches.



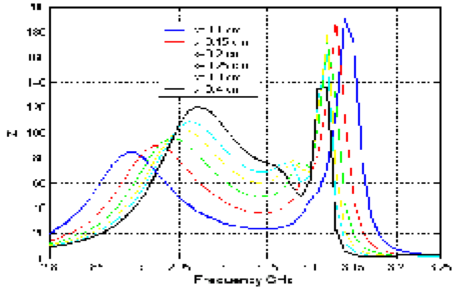
S_1=0.1



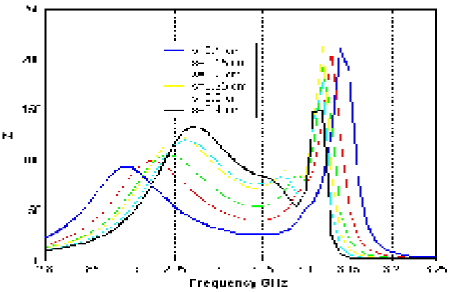
S_1=0.15



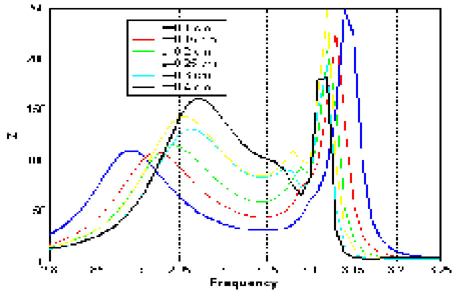
S_1=0.2



S_1=0.25



S_1=0.3



S_1=0.4

Figure (18) Input Impedance Variation w.r.t Frequency for Four Parasitic Patches RMSA with $L' = 2.9\ cm$.

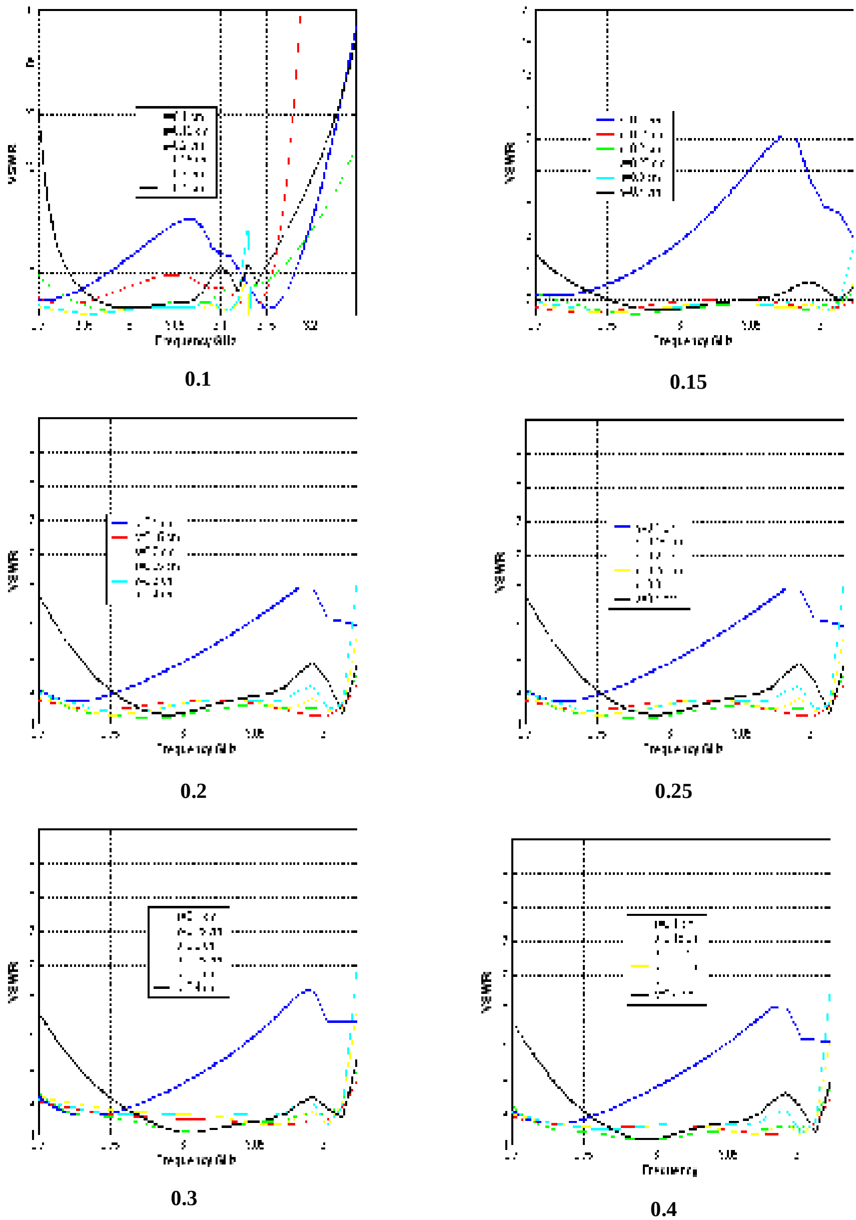
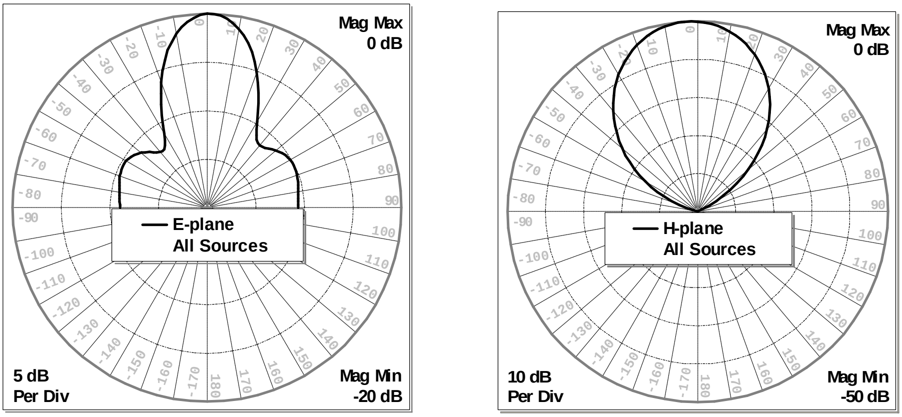


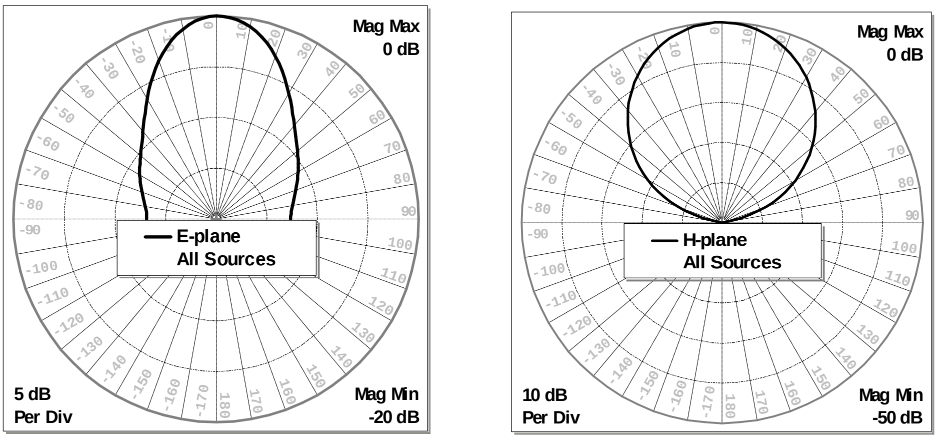
Figure (19) Input VSWR Variation w.r.t Frequency for Four Parasitic Patches RMSA with $L^{/} = 2.9\ cm$.

Table (2) Bandwidth Estimation for Four Parasitic Patches Operation for $L^{/} = 2.9\ cm$.

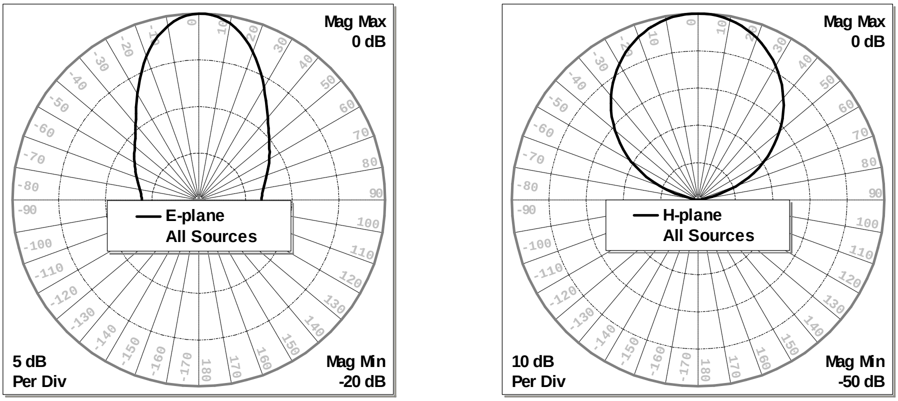
Non-Radiating Gap Space (s_1) in cm	BW% For s_2=0.1 cm	BW% For s_2=0.15 cm	BW% For s_2=0.2 cm	BW% For s_2=0.25 cm	BW% For s_2=0.3 cm	BW% For s_2=0.4 cm
0.1	2%	4%	5.2%	2.5%	1.9%	1.86%
0.15	3.2%	9%	7%	6%	2.6%	1.9%
0.2	6.21%	8%	9.2%	4.5%	2.21%	1.8%
0.25	9%	7.6%	11.3%	3.23%	2%	1.75%
0.3	6.5%	5.5%	7.25%	2.2%	1.88%	1.73%
0.4	3%	3%	5.1%	2%	1.67%	1.71%



a) ***f=3.18 GHz (upper band).***



b) ***f=3.011 GHz (center frequency).***



c) ***f=2.841 GHz (Lower band).***

Figure(20) Radiation Power Pattern of Four Identical Parasitic Patch RMSA with . $L^{/} = 2.9\ cm$ **for the Center and the Two Band-edges with**

4- Conclusion

From the investigation done above one can conclude the following points:

1. **For RMSA the effect of added one parasitic patch will increase the bandwidth to 4.77% (maximum bandwidth obtained) for gap space (s) equals to 0.2 cm, and parasitic patch length (** $L^{/}$ **) equals to 2.9 cm. However, in the E-plane, as the frequency increases, the beam maxima shifts away from the broadside direction toward the parasitic patch , and the directivity will be reduced by 2dB.**

2. **Two identical parasitic patches has the advantages that, the E-plane radiation pattern is symmetrical with respect to the broadside direction. While, side lobes will be appear (which reached to12 dB).**

The maximum bandwidth obtained from two identical patches is 6% at s=0.25 cm, and $L^{/}$=2.9cm and the variation in the directivity does not exceed 1 dB in the antenna range bandwidth.

3. **The addition of four parasitic patches will increase the bandwidth to 11.3%(which is about 7 times the bandwidth of conventional RMSA) for s_1 =0.2 cm, s_2 =0.25 cm and $L^{/}$=2.9cm and the directivity is 13 dB. the E-plane radiation pattern is broad side with low side lobe level over the antenna bandwidth range and the directivity is within 0.5 dB variation.**
4. **The antenna structure presented in this paper is compact and have broad bandwidth operation with suitable field variation with respect to frequency. While, the disadvantages of this geometry is the large antenna size which make the possibility of the array constriction very difficult.**

References

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تصميم هوائي شريطي دقيق عريض الحزمة ذو فجوة رابطة باستخدام حقيبة برمجيات الموجات المايكروية 7.5

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المستخلص

إن هذا البحث يهدف لتصميم هوائي شريطي دقيق عريض الحزمة يعمل بتردد رنيني 2.9 GHz باستخدام هوائي شريطي دقيق ذي رقعة مستطيلة الشكل مربوط بفجوة مع رقع طفيلية. دُرست بضع نماذج هندسية وصُممت مرتكزةً على ربط تلك الرقع الطفيلية بالهوائي الشريطي المستطيل إما من الحافة المشعة للهوائي أو من الحافة الغير مشعة له أو من كلتا الحافتين, تم دراسة تأثير إضافة رقعة واحدة أو اثنين أو أربع رقع. حُلّل هذا الهوائي باستخدام حقيبة برمجيات الموجات المايكروية نسخة 7.5 الصادرة في عام 2007. تم إثبات إن عرض الحزمة يتضاعف بمقدار ستة أضعاف مقارنةً مع هوائي شريطي دقيق مستطيل الرقعة.

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