AN EXPERIMENTAL INVESTIGATION OF A SHORT BACKFIRE ANTENNA WITH ELECTROMAGNETIC COUPLED PATCH AS FEED ELEMENT

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SUMMARY: In this paper a short backfire antenna fed by an electromagnetic coupled patch (EMCP) operating at X-band is constructed and its performance is experimentally investigated and reported. The antenna is excited in the TM_{10} -mode. The resonant frequency is also measured and its value is compared with the predicted values as a mutual check of the experimental data. The experimental results indicate a remarkable improvement in the radiation pattern as well as in the gain and a noticeable increment in the bandwidth of the backfire antenna as compared with those of a single patch microstrip radiator.

Key Words: Backfire antenna, electromagnetic coupled patch feed element.

INTRODUCTION

Over the past twenty five years microstrip resonators have been widely used in the range of microwave frequencies. In general these structures are poor radiators, but by proper design the radiation performance can be improved and these structures can be used as antenna elements (1-6). In recent years microstrip patch antennas became one of the most popular antenna types for use in aerospace vehicles, telemetry and satellite communication, since they are light weight, inexpensive, easily manufactured and have simple geometry, flat profile. They can be simply integrated with solid state devices.

A basic microstrip patch antenna is a thin conducting strip radiator of different shapes separated from its grounded plane by a thin layer of dielectric substrate. There are two main restriction of use of a single patch microstrip antenna, namely, its intrinsic narrow bandwidth and its limited gain. The bandwidth of a single patch microstrip antenna does not exceed 2% and its gain is limited to (5-8) dB. In recent years, several techniques have been attempted to increase the bandwidth of the antenna or to boost its gain. One effective method to overcome these two problems is to add a second patch in front of the initial one resulting in a so called *dual-patch microstrip antenna*. The concept of stacking patches in a backfire form, to enhance the gain or in an *electromagnetic*-coupling form to increase the bandwidth have been treated by several authors (7-14).

This paper represents an experimental study of the performance of the two types of dual patch microstrip antennas. These are an electromagnetically coupled patch (EMCP) antenna with a single square patch-feed excited in the TM_{10}-mode, operating in the X-band region and a backfire antenna with the EMCP as feed element. The experimental results obtained indicate a significant improvement in the radiation characteristics as well as in the gain and a noticeable increment in the bandwidth of the backfire antenna as compared to those of a single patch microstrip antenna.

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ANTENNA DESIGN

a) The single patch microstrip antenna:

The design of a single square microstrip antenna operating in the TM_{10}-mode implies that the patch side taking into account the fringing effect, should be chosen slightly less than $\lambda_d/2$ where λ_d is the wave-length in the substrate. The single patch microstrip antenna investigated is designed to operate at a resonant frequency of about 9 GHz. Accordingly the antenna consists of a square patch of a side a=8.8 mm. The patch is fabricated on a dielectric substrate of thickness h=1.6 mm and of relative permittivity of ε_r=2.5. The patch was fed an SMA-coaxial feed located at the midpoint of the edge of the patch. The patch and the substrate are supported on a 9 cm x 9 cm grounded copper plate.

b) The electromagnetic-coupled patch (EMCP) antenna:

A second patch is added and the two patches were photo-etched on separate substrates and aligned so that their centers are long the common axis. The size of the second patch and the separation between the two patches were adjusted to obtain maximum bandwidth. The first patch is referred to as feeding patch (P_f) and the second patch is the radiating patch (P_r).

c) The backfire antenna with the EMCP as feed element:

The EMCP with optimum dimensions is used as feed element to excite the backfire antenna. A small square reflector is placed at a distance d' from the second patch with its center a long the common axis of the antenna. The ground plane serves as large back reflector for the backfire antenna. Different sizes of small front reflectors were tried. The one with optimum size was used in the final design of the antenna. The spacing between the small reflector and the radiating patch is provided with a facility for optimum adjustment. The final shape of the backfire antenna with its optimum dimensions is illustrated in Figure 1.

Figure 1: The configuration of the microstrip backfire antenna with the EMCP as feed element.

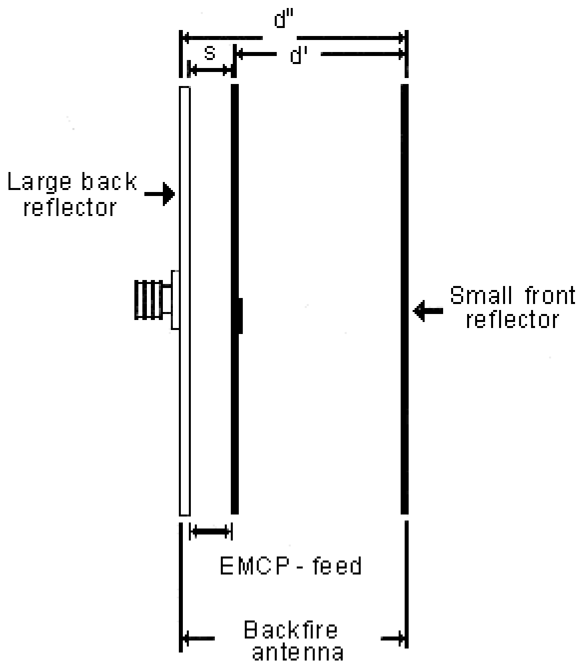
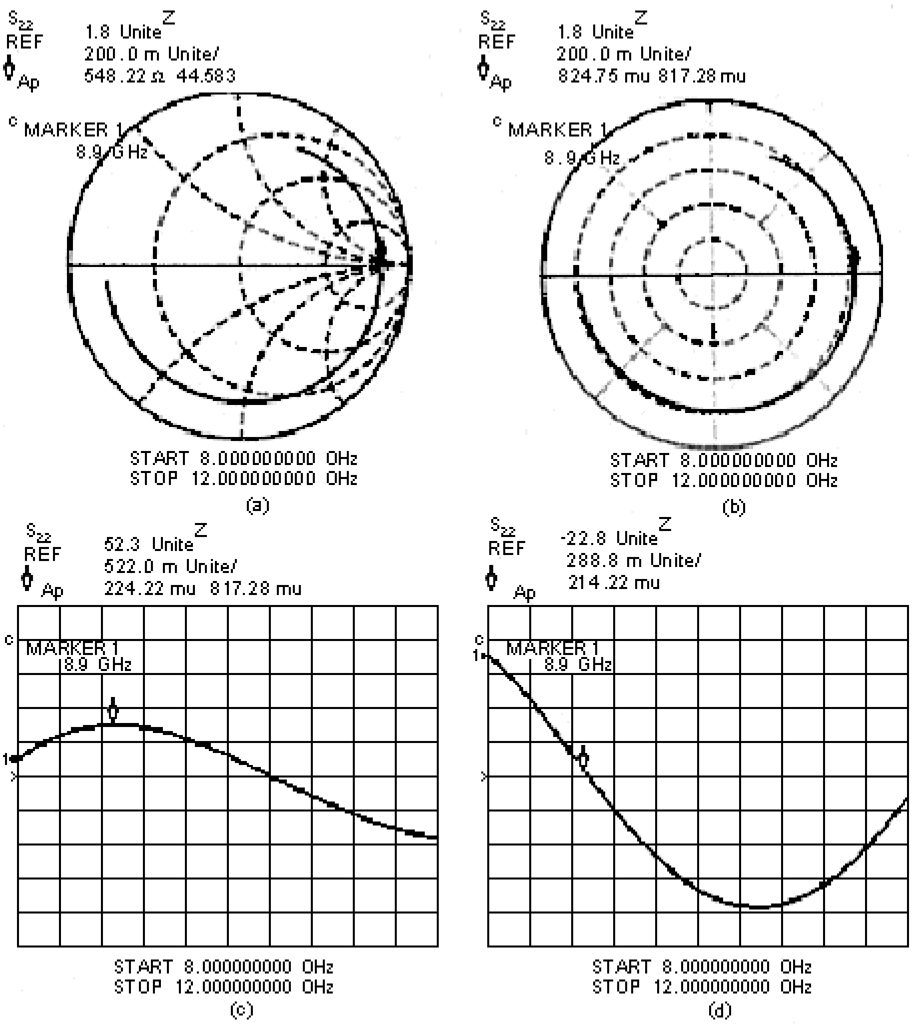


Table 1: Resonant frequency, input impedance and bandwidth for the EMCP antenna for different values of radiating patch size and s.

	Radiating Patch Size								
	7.5 mm			8.8 mm			10.5 mm		
s (mm)	f_r (GHz)	B.W (%)	R_{rex} (1/2)	f_r (GHz)	B.W (%)	R_{rex} (1/2)	f_r (GHz)	B.W (%)	R_{rex} (1/2)
0.84	8.68	0.92	1111	8.50	0.92	5.72	8.86	1.13	469
1.68	8.88	1.59	753	8.66	2.31	488	9.36	2.27	416
2.52	8.90	2.24	547	8.74	4.80	288	9.42	2.33	325
3.36	8.94	2.68	484	8.98	11.13	232	9.38	1.70	422
4.20	9.04	2.87	446	9.26	3.02	391	9.28	1.50	600
5.04	9.08	2.40	470	9.26	1.71	585	9.28	1.40	750

Figure 2: The square microstrip antenna (single patch): a=8.8 mm:
(a) The input impedance locus (b) Re (Z_{in}) and Im (Z_{in}) in polar (c) Re (Z_{in}) (d) Im (Z_{in}).



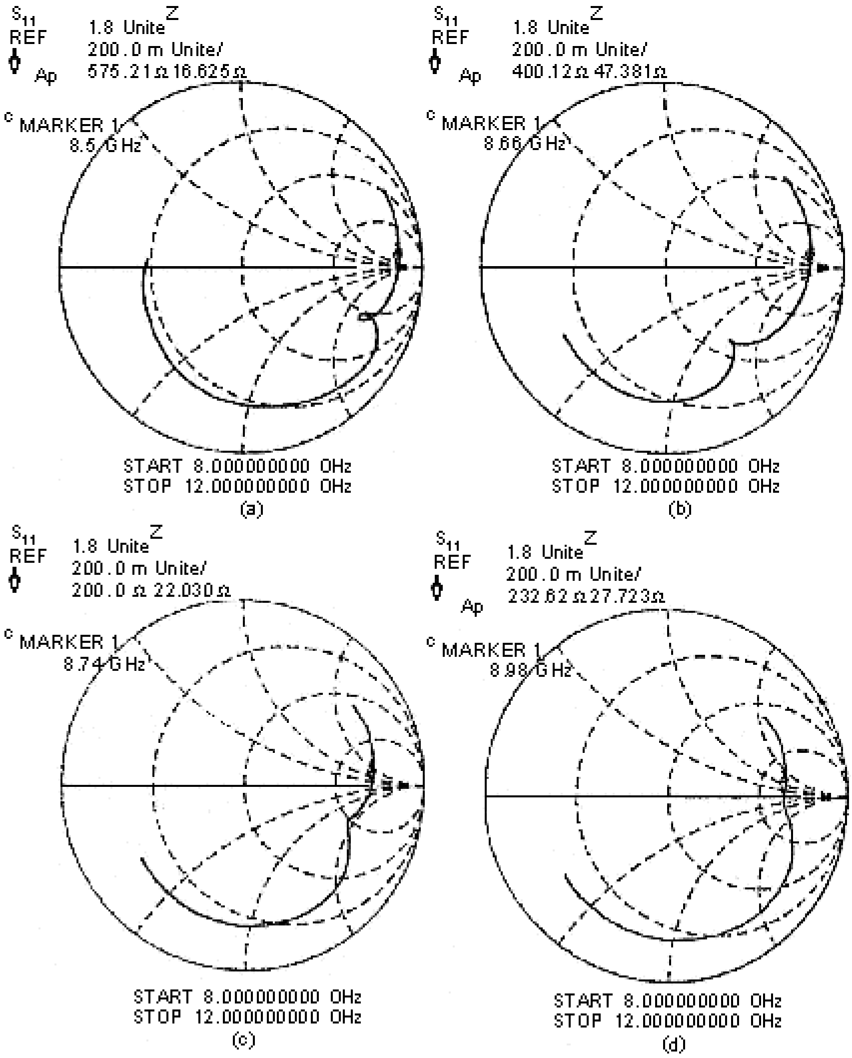
RESULTS

Resonant Frequency and Input Impedance

The resonant frequency of an electrically thin microstrip antenna is defined as the frequency at which the imaginary part of the input impedance is equal to zero. But for electrically thick microstrip antennas, which is the case in this investigation, the reactance curve never passes through zero, because of the inductive shift of the coaxial feed, and for this reason the resonant frequency is defined as that frequency at which the input resistance reaches its maximum value (15). Using an HP 8510 automatic network analyzer the measured resonant frequency of the single patch antenna was found to be 8.9 GHz and the measured input resistance at resonance was 548 Ω. The input impedance locus and the input impedance as a function of frequency for the single patch antenna are shown in the Figure 2. The calculated value of the resonant frequency for the single patch excited with the TM_{10}-mode if there were no fringing effect is given by (6,15)

$$f_r = \frac{c}{2a\sqrt{\varepsilon_r}} \qquad (1)$$

Figure 3: The impedance loci of the EMCP antenna: The dimension of P_r= 8,8 mm: (a) s=0.84 mm (b) s=1.68 mm (c) s=2.52 mm (d) s=3.36 mm.

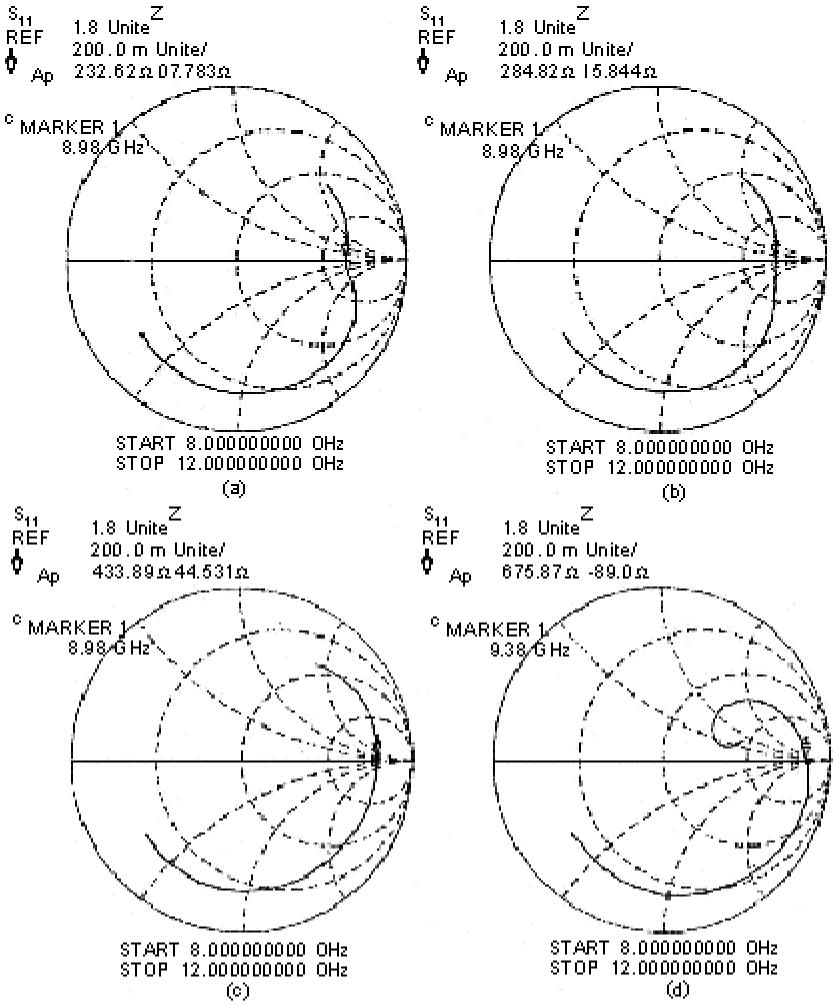


where c is the velocity of light in free space. However, in practice the fringing effect causes the effective distance between the radiating edges of the patch to be slightly greater than a, therefore the actual value of the resonant frequency is slightly less than f_r. Taking into account the effect of the fringing field two predicted formulas proposed by Hammerstadt (15) and by James *et. al.* (16) were used to calculate the resonant frequencies of the single patch antenna. The calculated frequency values using these two methods were 9.17 GHz and 8.78 GHz respectively.

The resonant frequency and the resonant input resistance were measured for the EMCP antenna with different sizes of the radiating patch for different separation between the two patches. The results are illustrated in Table 1. The input impedance loci of the EMCP antenna for different separations between the two patches and for different sizes of the second patch are given in Figure 3 and 4 respectively.

The Gain: The directive gain of the three antenna types were measured using a pyramidal horn of gain 16.7 dB as a standard antenna. The gain of the single patch antenna was found to be 5.3 dB. The gain of the EMCP antenna was measured for patches of equal

Figure 4: The impedance loci of the EMCP antenna: for the different dimensions of the radiating patch (DP_r): s= 3.36 mm: (a) DP_r= 8.8 mm. (b) DP_r= 9.8 mm. (c) DP_r= 8 mm (d) DP_r= 10.5 mm.



size of 8.8 mm on a side with different positions of the second patch with respect to the basic patch. The results are tabulated in Table 2. Inspection of Table 2, taking into account the best value for the bandwidth, indicate that the maximum value of the directive gain is 8.7 dB. This is an improvement of 3.4 dB above that of a single patch antenna. The gain of the backfire antenna was measured for different sizes of front reflector and different separations d" between front reflector and the ground plane. The best result was for a small reflector of size equal to those for the two patches and with a separation d"=3.33 cm ($\approx\lambda_0$). The maximum gain for the backfire antenna was 12.5 dB with an increment of 7.2 dB above that for the single patch antenna. More increment in the gain can be achieved by adding more front reflectors.

The gain of the backfire antenna was calculated as a mutual check of the experimental results using the following relation (10).

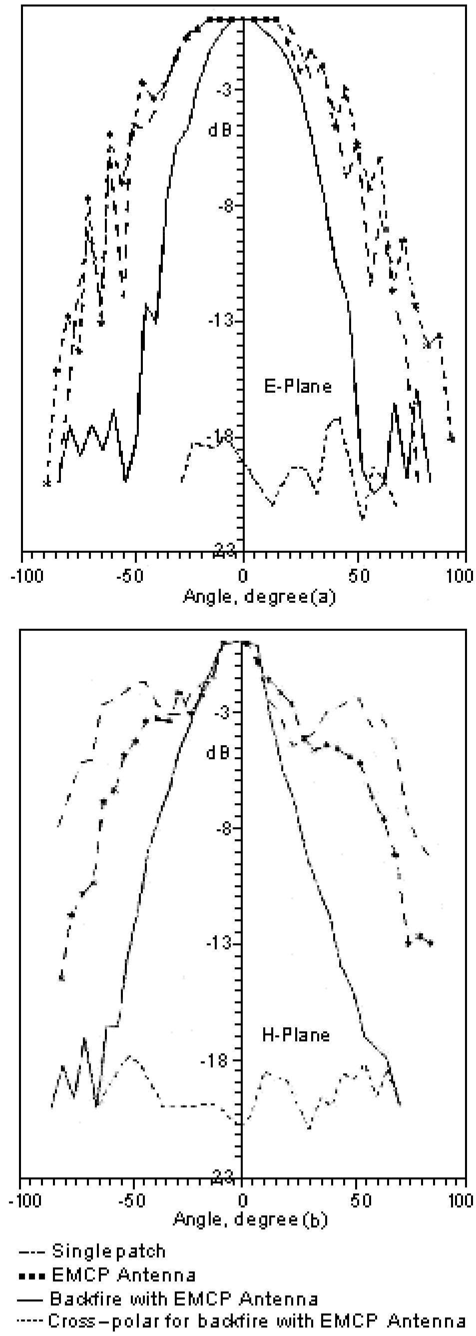
$$G(dB) = 10\log \frac{2600}{\Theta^\circ_E \Theta^\circ_H} \qquad (2)$$

where θ°_E and θ°_H are the beamwidth of the half power points in the E-plane and H-plane respectively. The

Table 2: Performance of the EMCP antenna for different values of switch patch dimension 8.8 mm.

s (mm)	S/Åo	f_r (GHz)	gain (dB)	B.W (%)	R_{rex} (1/2)
0.84	0.024	8.5	7.02	0.92	576
1.68	0.048	8.66	8.12	2.31	488
2.52	0.073	8.74	8.83	4.8	188
3.36	0.1	8.98	8.72	11.13	232
4.2	0.129	9.26	7.02	3.02	391
5.04	0.155	9.26	6.1	1.7	585

Figure 5: The radiation power pattern of the three antenna types at resonance in both: (a) The E-plane, (b) The H-plane.



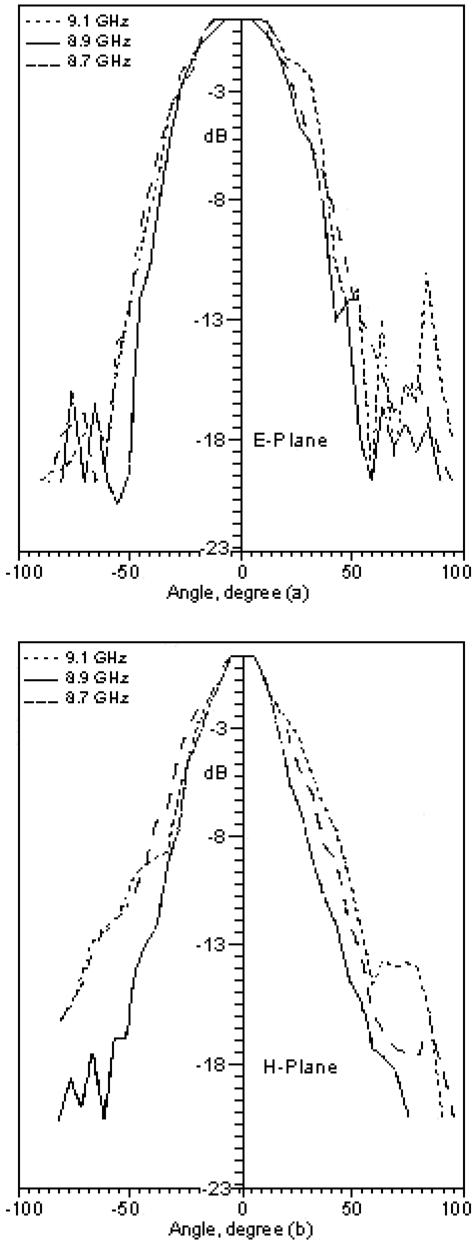
gain was found to be 12.1 dB which is 0.4 dB less than the measured value.

The Power Pattern: The measured radiation pattern of the three antenna types for optimum dimensions at resonant frequency in both E-plane and H-plane are illustrated in Figures 5a and b respectively. Inspection of these two figures shows the effect of applying the backfire principle on the shape of the pattern in both E-plane and H-plane. The shape of the pattern is smooth with narrow beamwidth and very low side lobs and it is symmetrical in both E-plane and H-plane for the backfire antenna, whilst it is rough with broad beamwidth and too many high side lobs and is non-symmetrical in both planes for single patch and EMCP antennas.

The cross-polar pattern for the backfire antenna was also measured. Its level was better than 15.5 dB in the E-plane and 18 dB in the H-plane, this is also shown in Figure 5. The power radiation patterns of the backfire antenna with the EMCP in E-plane and H-plane at different frequencies are shown in Figures 6a and b respectively. Figure 7 shows the influence of adding a rim of width w=10 mm to the periphery of the ground plane of the backfire antenna on the radiation pattern at resonant frequency in both the E-plane and the H-plane. This figure, indicates some improvement in the beamwidth in the E-plane pattern. This improvement can be seen as an increment in the directive gain. Table 3 gives a comparison summary for the performance of the single patch, the EMCP and for backfire antenna with the EMCP as feed.

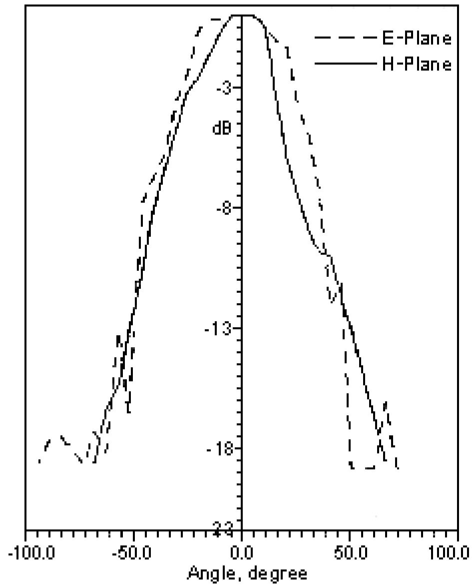
The Bandwidth: The input impedance was calculated as a function of frequency for the single patch as well as for the EMCP antennas. Following the resonant circuit model mentioned in (15) the percentage bandwidth for the single patch antenna was calculated as 1%. The same method was used to calculate the per-

Figure 6: The radiation pattern of the backfire antenna with the EMCP feed for three different frequencies in both.



centage bandwidth for the EMCP antenna for different sizes of the second patch and patch to patch distances. The results are shown in the Table 1 and 2 respectively. The best result was for the EMCP with the second patch of dimensions of 8.8 mm x 8.8 mm and patch to patch separation of s = 3.36 mm. The bandwidth was

Figure 7: The influence of the rim on the radiation pattern of the backfire antenna at resonant frequency in both E-plane and H-plane.



11.1%. It is an excellent improvement in the bandwidth compared with that of a single patch antenna. No more improvement in the bandwidth was noticed by applying the backfire principle.

CONCLUSION

In this study it has been shown that the bandwidth of a conventional square microstrip patch antenna excited in the TM_{10}-mode operating in the X-band region can be improved by applying the electromagnetic coupled principle. The backfire principle was used to improved the electrical characteristics as well as the gain of the antenna. For this purpose the EMCP was used to excite the backfire antenna. The reported results indicate that the backfire antenna has higher directive gain broader bandwidth and symmetrical radiation pattern with narrow beamwidth and lower side lobes level in both the E-plane and the H-plane when compared to those of a single patch antenna. This backfire antenna is compact, light weight, inexpensive and has small size. It can be used as feed element in reflector antennas for communication purposes.

Table 3: A comparison summary for the performance of the single patch, the EMCP and the backfire with the EMCP as feed element.

Type of Antenna	Beamwidth (Degree)		Side lobe to main lobe (dB)				Resonant Frequency (GHz)	Gain (dB)	B.W (%)
			Right		Left				
	E-plane	H-plane	E	H	E	H			
Single Patch	75	43	-4.2	-2.3	-2.2	-3.1	8.90	5.32	1
(EMCP)	72	45	-2.7	-2.2	-1.3	-4.5	8.98	8.72	11.1
Backfire with (EMCP)	44	33	-12	-17	-16	-20	8.98	12.50	7.1

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