Design of Microstrip Antenna Array for Improvement of FBR Using Partial Ground Plane Technique

V.N. Lakshmana Kumar, M. Satyanarayana, S.P. Singh

Abstract:: ***In this paper, improvement of front to back ratio (FBR) for rectangular microstrip array antenna is discussed by using the partial ground plane technique. A four-element rectangular microstrip antenna array is designed for X-band frequency of 9.1GHz, with a peak gain of 10.09dBi and front to back ratio of 13.72dB. By optimizing the ground plane, the FBR has improved to 38.42dB at 9.1GHz for 75% of the full ground plane. The FBR has also improved to 42.58dB, 46.57dB at 9GHz, 8.9 GHz respectively. The Peak gains have improved by 0.28dB compared to the peak gains with full ground plane. The 3dB gain bandwidth has also improved by 114 MHz compared to bandwidth with full ground plane. The simulations are carried using HFSS software. A good agreement between simulated and measured results is observed.***

Keywords: ***Front to back ratio, Microstrip antenna, Radiation efficiency, Sidelobe level, Surface waves.***

I. INTRODUCTION

challenging in the antenna network. Especially, between closely placed antennas, high sidelobe levels and low FBRs will create interference problems and lower the performance of the antenna system. GPS synchronization and frequency reuse demand the antennas with high FBR. Not only in mobile network, even in satellites, missiles, aircraft, and Radars etc., there is a need for design of on-board antennas with high front to back ratio. To lower the interference problems, antennas with FBR greater than 20dB is very much essential [1]. Some applications even demand FBR to be between 30dB and 35dB.

In literature, several techniques are proposed to improve the FBR. The concept of artificial dielectric layers is used to enhance the FBR in printed and planar antennas [2]. In paper [3], the technique of strapline aperture coupling is mentioned to improve FBR over C band frequencies. In paper [4], printed directors are used increase the FBR for Ku band frequencies. Using circular aperture slot on ground plane the FBR is enhanced in [5], [6]. In [7]- [9], the back lobe reduction technique using multilayer frequency selective surface reflector is mentioned. But it has the negative impact on VSWR. The technique of cavity reflector is used to improve the front to back ratio in [10], [11]. The concept of magneto-electricdipole is discussed for increasing FBR for wire antennas [12], [13]. Using the Co-planar rod parasitic elements, the back lobe reduction is explained in [14], for microstrip patch antenna over L band. In [15], the method of SIW cavity- backed slot is discussed to achieve FBR greater than 19dB. More or less, these all techniques are complex in implementation. In this paper a simple and effective method of improving FBR is mentioned for microstrip antenna arrays, using the partial ground plane technique. Section 2 discusses the design of single patch and four-element rectangular microstrip antenna array. In Section 3, the concept of partial ground plane technique is discussed. In Section 4, the results and discussions are presented. Section 5 gives the conclusion.

II. DESIGN OF 4-ELEMENT RECTANGULAR MICROSTRIP ARRAY ANTENNA

The design of 4-element rectangular microstrip array starts with the basic design of single patch antenna at x-band frequency of 9.1GHz. The antenna is designed on FR4 substrate with dielectric constant εr= 4.4, with a thickness of h = 1.6mm. The dimensions of single edge fed rectangular patch are calculated as follows [16], [17].

The width of the patch antenna is calculated as

$$W = \frac{c}{2 f_0 \sqrt{\frac{(\varepsilon_r + 1)}{2}}} \tag{1}$$

Where f_0 is the resonant frequency 9.1GHz and c= 3 X 10^8 m/s. Calculation of Actual Length (L):The effective length of patch antenna (L_{eff}) depends on the resonant frequency (f_0) and is given by

$$L_{eff} = \frac{c}{2 f_0 \sqrt{\varepsilon_{reff}}} \tag{2}$$

Where $$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + \frac{12h}{w}\right]^{-\frac{1}{2}} \tag{3}$$

The E-fields at the edges of the patch undergo fringing effects. Because of these effects, the effective length of the patch antenna appears to be greater than its actual length. So, actual length and the effective length of a patch antenna can be related as

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$$L = L_{eff} - 2\Delta L \quad (4)$$

Where ΔL is a function of effective dielectric constantε_{reff} and the width to height ratio (w/h).

$$\frac{\Delta L}{h} = 0.412\frac{(\varepsilon_{reff}+0.3)}{(\varepsilon_{reff}-0.258)}\frac{\left(\frac{w}{h}+0.264\right)}{\left(\frac{w}{h}+0.8\right)} \quad (5)$$

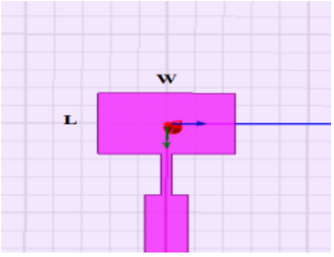

Figure 1.Edge fed rectangular patch antenna

The designed values of patch antenna are W=10.03mm, L=7. 17mm.The patch antenna shown in Figure 1 is in turn optimized for best return loss by varying L value. At L=6.8082mm, S_{11} of -35.6dB was achieved using HFSS software. The optimized dimensions of single rectangular patch antenna are W=10.03mm and L=6.8082mm. Using the same dimensions, four-element array is designed using corporate feed technique as shown in Figure 2.

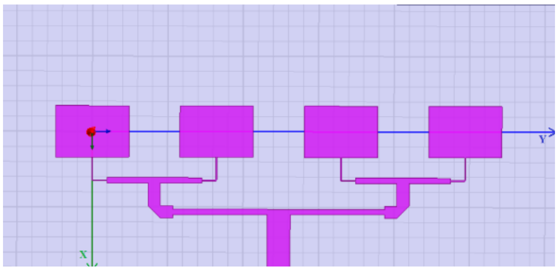

Figure 2.Four-element microstrip array with the corporate feed network

The Input power will be given to 50Ω line, which is equally dived using 100Ω lines. The 100Ω lines are connected to 50Ω junction points of next stage by using quarter wave transformer of 70.7Ω lines [18]. Each patch impedance is 251Ω. The patch and 100Ω lines are connected using quarter wave transformer of 158.7Ω. The strip line dimensions of the feed network as shown in table 1.

Table 1.Strip line dimensions of the feed network

S.N0	Impedance in Ω	Width in mm	Length in mm
1	50.0	3.058	7.527
2	70.7	1.621	4.625
3	100.0	0.709	Variable
4	158.7	0.141	4.886

III. DESIGN OF 4-ELEMENT MICROSTRIP ARRAY WITH PARTIAL GROUND PLANE TECHNIQUE

In rectangular microstrip patch antennas, the electromagnetic waves travel in the dielectric substrate as guided waves, space waves, leaky waves, and surface waves. Guided waves are those waves which are confined to the dielectric substrate between the ground plane and patch surface. The substrate supports like a waveguide. Space waves are those waves, which are radiated into space in upward direction at the edges of the patch. Due to the small thickness of the substrate, some waves undergo substantial reflections before arriving at the edges of patch and will be radiated as space waves. When some of the electromagnetic waves inside the cavity, incident on the ground plane at angles less than the critical angle of the substrate material, few waves will get refracted at the interface of air and substrate. Those waves are called leaky waves. While other waves, totally get reflected by the air-dielectric interface and will be trapped in the substrate. These are called surface waves. These surface waves will be diffracted and reflected at the edges of the dielectric substrate and can degrade the antenna radiation pattern.

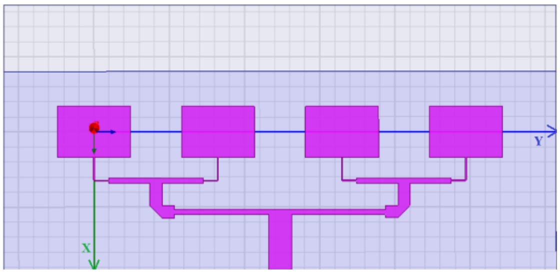

Figure 3.Four-element array antenna with the partial ground plane

Surface waves and space waves are the major concern in microstrip antennas and back radiation occurs due to the surface waves.The ground plane or substrate can diffract the surface waves and leads to more back radiation. Especially when the substrate with more thickness and dielectric constant are taken, the surface wave power will be more scattered in back ward direction and lead to more back lobe level. The E-plane edge diffraction effects are more dominant than the H-plane edge diffraction effects [19] and its influence will decrease if the ground plane is reduced from one edge, which is opposite to feed network as shown in Figure 3. Figures 4 and 5 show the E-field distribution of 4-element array with full ground and partial ground respectively. From these figures it is very clear that downward diffraction effects are less prominent in case of the array with partial ground. This is due to the absense of ground plane from one edge. So it is very clear that back radiation is less in case of an array with partial ground compared to full ground and this is the main reason for improvement of front to back ratio with partial ground. Ofcourse, if the ground plane is reduced drastically the patch action fails. The ground plane has to be minimally

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maintained upto fringing field extension i.e up to $h/\sqrt{\varepsilon_{eff}}$ distance from the patch edge. In turn , the back radiation with partial ground plane can be optimized by varying the ground plane dimension and high FBR can be achieved.

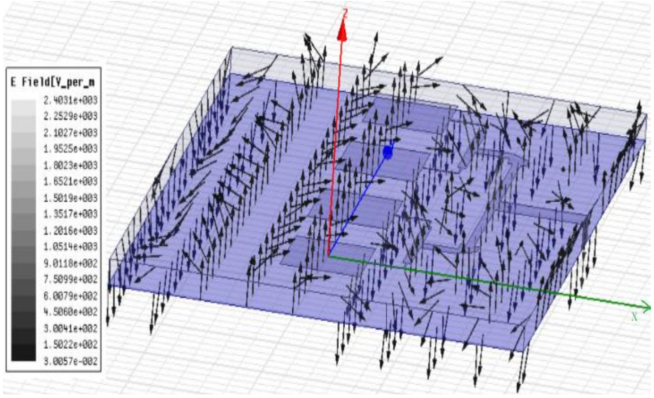

Figure 4.E-field distribution of 4-element array with the full ground plane

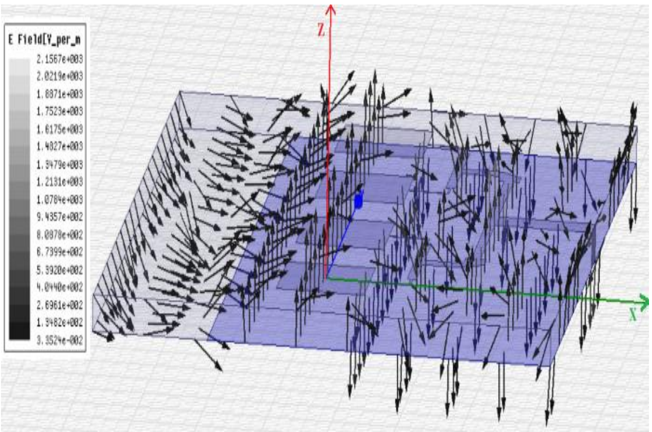

Figure 5.E-field distribution of 4-element array with the partial ground plane

IV. RESULTS AND DISCUSSIONS

As discussed in section 3, the ground plane is varied from one edge and its performance is observed from 100% to 63% of the fullground plane. From tables2, 3 and 4 it is observed that, the front to back ratio gradually increasing by reducing the ground plane and reaching the peak value at 75% of ground plane. Thereafter, it again decreases. Figure 6 shows the front to back ratio (FBR) versus frequency comparison plot with ground plane variation. The ground plane has to be minimally maintained up to fringing field extension from patch edge. For better gains, the ground plane should be extended greater than h (thickness of substrate) distance from patch edge. For 3.2h extension from patch edge (75% ground plane), highest FBR is obtained without losing the gain. At 8.9 GHz frequency, highest FBR of 46.57dB is observed for 75% ground plane. From the figure 6, it is observed that the FBR with 75% ground plane is much improved than FBR with 100% ground plane over 8.4 GHz to 9.3 GHz frequency range. Figure 7 shows the S11 comparison plot with full ground and 75% ground plane.

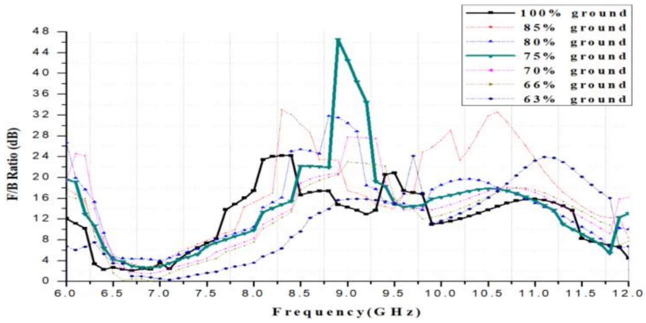

Figure 6. Front to back ratio (FBR) versus frequency plot with ground plane variation

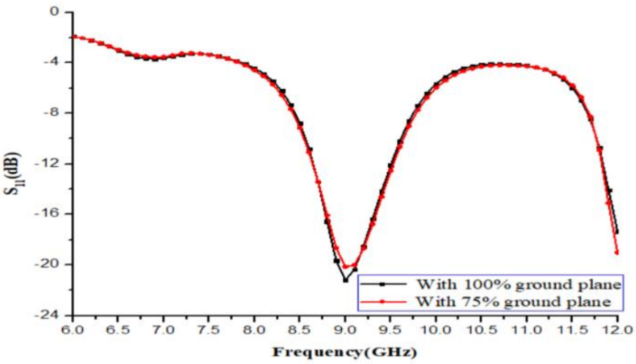

Figure 7. S_{11} comparison plot for 4-element array

Figures 8(a)& 8(b) show the E-plane radiation patterns of the 4-element array with full ground and 75% ground at 9.1GHz and 9.0 GHz respectively. Back lobe level of -28dBi and -32dBi are obtained at 9.1GHz and 9.0 GHz respectively.

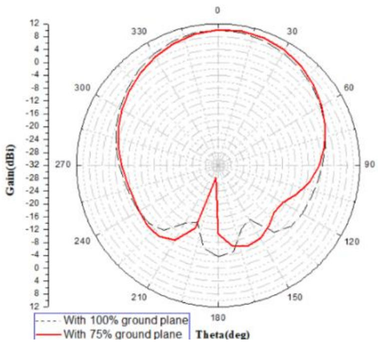

Figure 8(a). E-plane pattern comparison at 9.1GHz

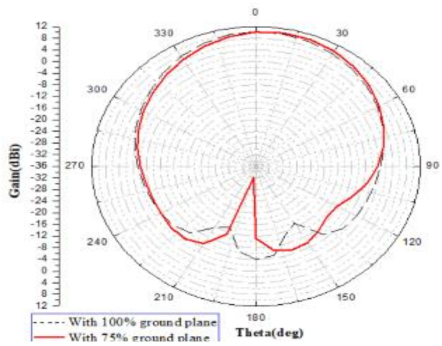

Figure 8(b). E-plane pattern comparison at 9.0 GHz

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Figures 9 and 10 show the Normalized H-pane radiation patterns of the 4-element array with full ground and 75% ground at 9.1GHz and 9.0 GHz respectively. The back lobe level is -13.72dB with full ground and it has reduced to -20.78dB with 75% ground plane at 9.1 GHz. Similarly, the back lobe has reduced at 9.0 GHz.

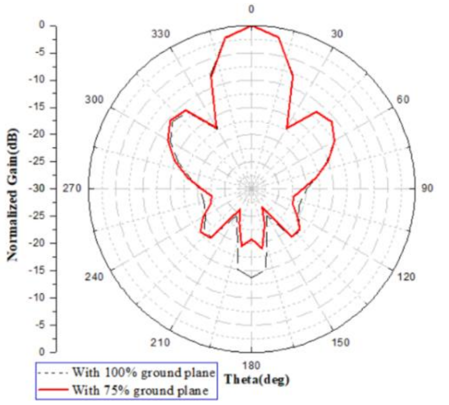

Figure 9. H-plane pattern comparison at 9.1GHz

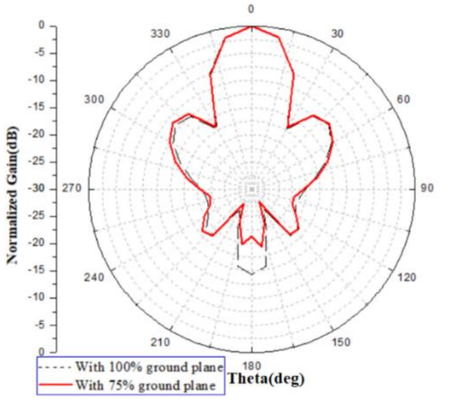

Figure 10. H-plane pattern comparison at 9.0 GHz

Figure 11 shows the Gain versus frequency comparison plot for 4-element array in two cases. The 3dB gain bandwidth is 1.207GHz in case of the array with full ground and it has improved by 114MHz, in case of the array with 75% ground plane.

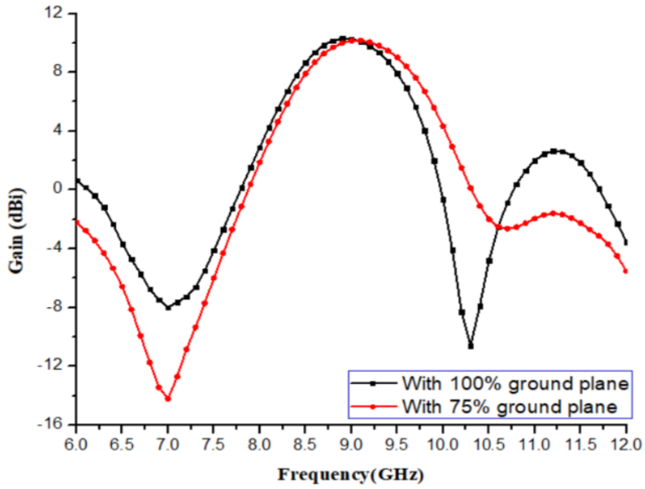

Figure 11. Gain versus frequency comparison plot for 4-element array

From table 2, 3 and 4, it is observed that the peak gain has also improved by 0.28dB compared to peak gain with the full ground plane. The front to back ratio (FBR) has increased to 38.42 dB from 13.72dB at 9.1GHz. It has increased to 42.58dB from 14.33dB at 9.0 GHz. At 8.9 GHz, it has increased to 46.57dB from 14.77dB.

Table 2. Radiation parameters with variation in ground plane at 9.1GHz

S.N0	% Ground Plane						
	100	85	80	75	70	66.3	63
S_{11} (dB)	-20.36	-20.88	-20.71	-20.03	-18.78	-18.76	-20.05
Peak gain (dBi)	10.09	10.49	10.39	10.37	10.386	10.37	10.18
Peak Sidelobe level (dB)	-10.74	-11.03	-11.13	-10.815	-10.81	-10.86	-12.34
3dB Gain bandwidth (GHz)	1.207	1.285	1.311	1.321	1.312	1.269	1.095
Radiation efficiency(%)	72.47	72.13	71.91	72.16	72.38	73.17	69.31
FBR (dB)	13.72	16.99	28.94	38.42	27.76	22.86	15.91

Table 3. Radiation parameters with variation in ground plane at 9.0 GHz

S.N0	% Ground Plane						
	100	85	80	75	70	66.3	63
S_{11} (dB)	-21.19	-20.81	-20.53	-20.16	-19.76	-20.97	-16.61
Peak gain (dBi)	10.27	10.52	10.55	10.53	10.56	10.57	10.06
Peak Sidelobe level (dB)	-11.30	-11.62	-11.66	-11.37	-11.39	-11.65	-12.57
Radiation efficiency(%)	72.73	72.216	72.10	72.42	72.94	73.88	67.88
FBR (dB)	14.33	17.485	30.49	42.58	27.77	23.01	15.84

Table 4. Radiation parameters with variation in ground plane at 8.9 GHz

S.N0	% Ground Plane						
	100	85	80	75	70	66.3	63
S_{11} (dB)	-19.67	-18.63	-18.53	-18.62	-19.34	-22.59	-13.61
Peak gain (dBi)	10.29	10.53	10.57	10.55	10.64	10.65	9.73
Peak Sidelobe level (dB)	-11.97	-11.90	-11.89	-11.68	-11.85	-12.24	-12.22
Radiation efficiency(%)	72.06	71.45	71.49	71.90	72.63	73.62	65.43
FBR (dB)	14.77	23.28	31.52	46.57	20.76	20.52	15.67

Figure 12 shows the H-plane Co-polarization and Cross-polarization patterns of 4-element array,in two cases of ground plane at 9.1GHz. Very low Cross-polarization levels up to -62dB are obtained. The Cross- polarization with 75% ground has reduced compared to Cross-polarization with the full ground over an angle of 2100. Similarly, low Cross-polarization levels are achieved at 9.0 GHz. It is shown in Figure 13.

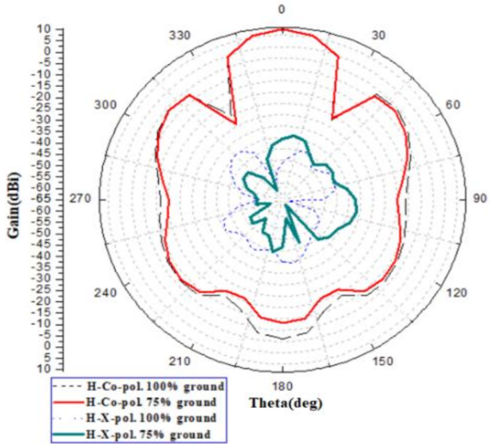

Figure 12. H-plane radiation patterns of 4-element array at 9.1GHz

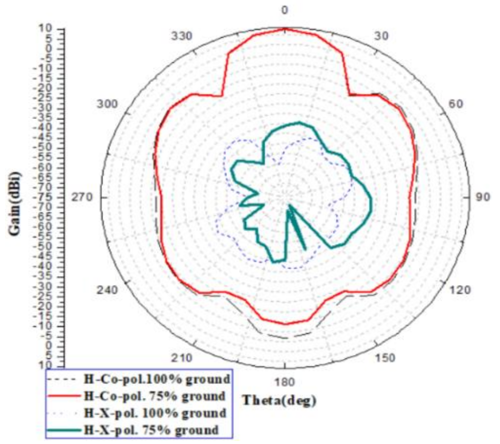

Figure 13. H-plane radiation patterns of 4-element array at 9.0 GHz

Figure 14 shows the comparison of simulated and measured radiation patterns of the array with 75% ground plane at 9.1 GHz. Except at few points, good matching is observed between simulated and measured values within 3dB deviation.

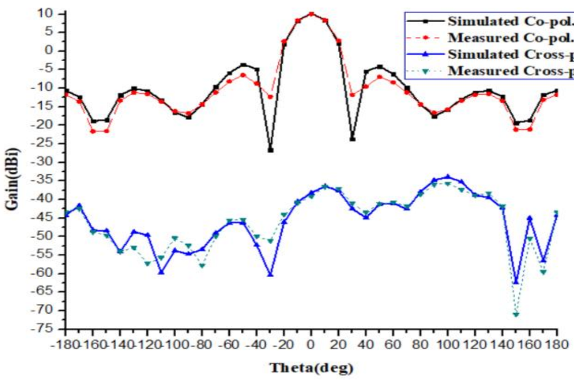

Figure 14. Radiation patterns of 4-element array with 75% ground plane

Figure 15(a) shows the front view of the fabricated array with 75% ground plane and Figure15(b) shows its back view with 75% ground plane.

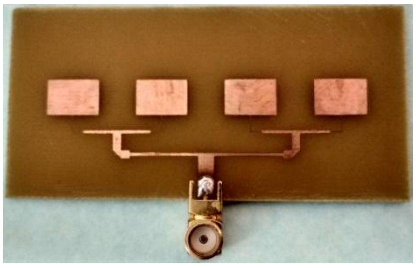

Figure 15(a). Front view of fabricated array

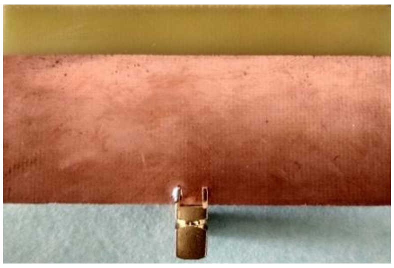

Figure 15(b). Array with the partial ground plane

Figure 16 depicts the S11measurement setup with Vector Network Analyzer (VNA E5071C) and Figure 17 gives the comparison of simulated and measured values of S11, for the 4-element array with 75% ground plane. The measured value of S11 at 9.1GHz is -18.5dB. The measured value deviated by 1.5dB form the simulated value. The resonance is observed at 9.2GHz rather than 9.1GHz. The deviations between measured and simulated values are due to the manufacturing errors and connector leads.

Figure 16. Measurement of S11 with Network Analyzer

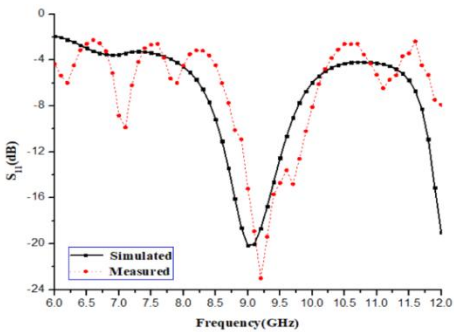

Figure 17. S11 plot of the array with 75% ground

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V. CONCLUSION

Four-element rectangular microstrip antenna array is designed with the full ground plane, at X-band frequency of 9.1 GHz with FBR of 13.72dB. Partial ground plane variation technique is applied and very high FBR value of 38.42dB is observed with 75% ground plane at 9.1 GHz. This is equivalent to maintaining ground plane up to 3.2h distance from patch edge. This technique is even validated for 9.0 GHz and 8.9 GHz. For the same size of 75% ground plane, FBR of 42.58dB and 46.57dB are obtained at 9.0 GHz and 8.9 GHz respectively, without compromising the peak gain. The FBR has improved by 24.7dB at 9.1 GHz and it has improved by 31.8dB at 8.9 GHZ. The back lobe has reduced by 7dB from -13.72dB. The 3dB gain bandwidth is also improved by 114MHz. In this paper, this technique is applied for linear microstrip array. This can also be extended for planar microstrip array antennas with low dielectric substrates. This partial ground plane technique can be employed in the design of microstrip antenna arrays for satellites, missiles, aircraft, and cellular communications to reduce the electromagnetic interference problems.

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