

Ku Band Microstrip Patch Antenna Array

Omar Masood Khan, Zaid Ahmad, Dr Qamar Islam
Department of Communication Systems Engineering
Institute of Space Technology

Abstract — Design of a Microstrip single element and three different array antennas are presented in this paper. Two different array configurations are designed and simulated for 4 element arrays, along with a 2 element array. The design is done for Ku Band Applications at 16 GHz. The substrate height is 0.254 mm and the dielectric constant is 2.2 of RT/duroid 5880 (tm). Simulation is done in HFSS and the results are exhibited, which show increase in directivity and gain with the increase in patch elements.

I. INTRODUCTION

There are wide ranges of Ku band applications for which the Microstrip antenna arrays can be used due to light weight and low fabrication costs. The Ku band Microstrip antennas can be used in light weight radars, VSAT, Radiometric ground based fire-detection and Microelectromechanical Systems. In this paper a single patch, 1 by 2 array, 2 by 2 array and 1 by 4 array antennas are theoretically designed and then simulated in HFSS. In the conclusion the results of all four antennas are compared.

II. SINGLE PATCH THEORETICAL DESIGN

A single patch Antenna is designed for 16 GHz. The patch antenna consists of a radiating patch, transmission line of 50 Ohms, ground plane, substrate and a 50 Ohms coax connector. The substrate used is Rogers RT/duroid 5880 (tm) with a dielectric constant of 2.2 and height of 0.254 mm. The layout of the single patch antenna is shown in Fig. 1. One end of the transmission line is connected with the coax connector and the other end is connected with the patch. Impedance matching is achieved through inset feed design. For the design the following classical equations are used [1]:

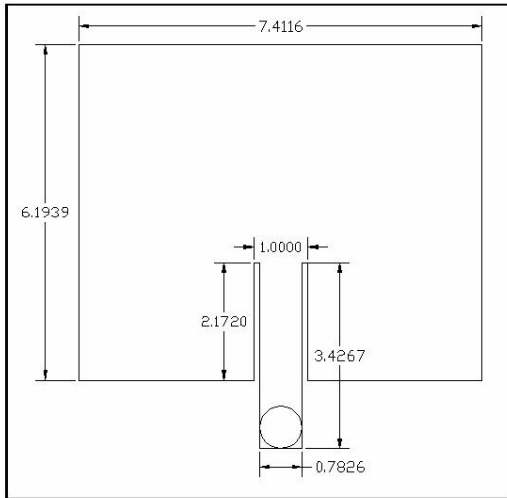


Figure 1: Single Element Patch Antenna

$$W = \frac{\lambda_0}{2} \sqrt{\frac{2}{\epsilon_r + 1}} ; L = \frac{\lambda_0}{2\sqrt{\epsilon_{reff}}} - 2\Delta L$$

$$\frac{\Delta L}{h} = 0.412 \frac{(\epsilon_{reff} + 0.300) \left(\frac{W}{h} + 0.264 \right)}{(\epsilon_{reff} - 0.258) \left(\frac{W}{h} + 0.800 \right)}$$

$$\epsilon_{reff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left(1 + 12 \frac{h}{W} \right)^{-1/2}$$

III. SINGLE PATCH SIMULATION AND RESULTS

HFSS is used for simulation of single patch antenna [4]. Table 1 give details of the dimensions of the single patch antenna and the transmission lines. Table 2 shows the summary of results of the single patch. HFSS design model is exemplified in Fig. 2 and Fig. 3 depicts the S₁₁ response of -22 dB at 15.80 GHz. The directivity is 7.43 dB. Fig. 4 gives an idea about the 3-D picture of gain, with maximum of 6.809 dB. Fig. 5 illustrates the radiation pattern. The radiation efficiency is 0.866. The antenna E-field plot is demonstrated in Fig. 6. The 3 dB beamwidths in the two principal plane planes are 38.00° and 36.00°.

TABLE 1
SINGLE ELEMENT PATCH ANTENNA DIMENSIONS

Single Element Microstrip Patch Antenna Dimensions (in mm)	
Patch	
Width	7.41159
Length	6.19392
Inset	
Inset Width	1.0000
Inset Length	2.1720
Transmission Feedline 50 Ohms	
Width	0.78263
Length	3.42674

TABLE 2
SINGLE ELEMENT PATCH ANTENNA PARAMETERS

Antenna Parameters	Single Element
S ₁₁ Response	-22 dB at 15.80 GHz
Directivity	7.43 dB
Gain	6.809 dB
Radiation Efficiency	0.866

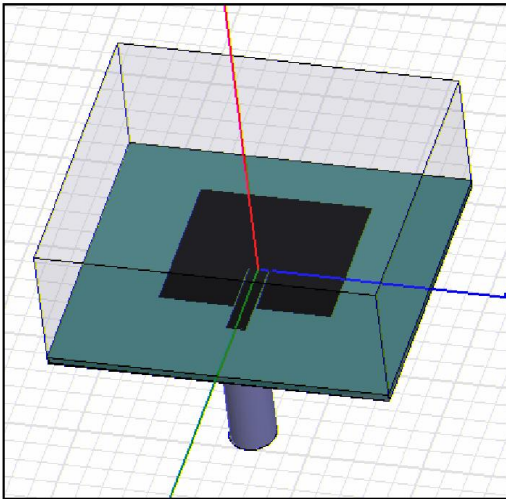


Figure 2: Single Element HFSS Design

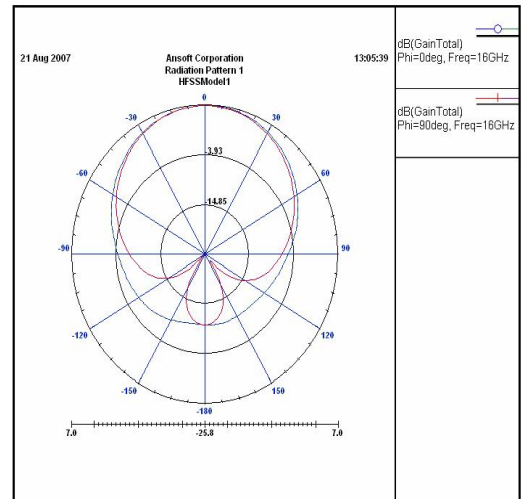


Figure 5: Single Element Patch Antenna Radiation Pattern Plot

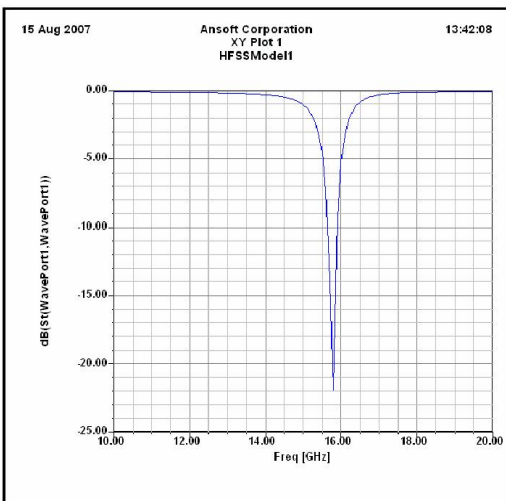


Figure 3: Single Element Patch Antenna S11 Response

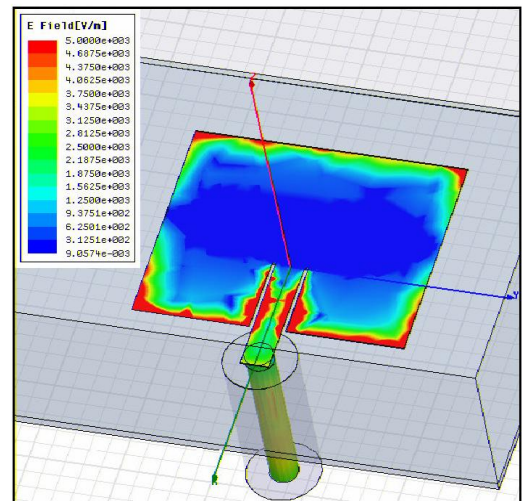


Figure 6: Single Element Patch Antenna E-Field Plot

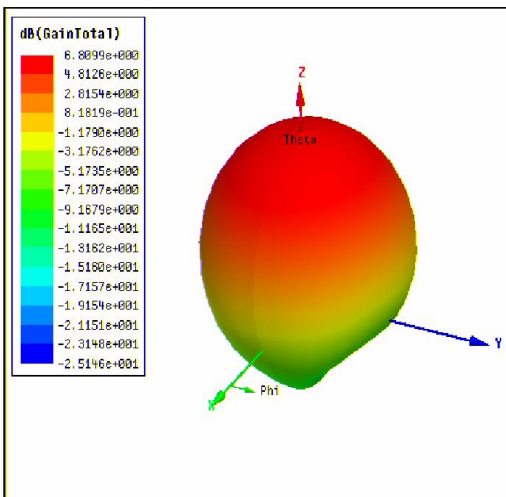


Figure 4: Single Element Patch Antenna Gain

IV. 1 BY 2 ARRAY THEORETICAL DESIGN

Table 3 presents the summary of the Microstrip 1 by 2 array Dimensions and Fig. 7 shows the 1 by 2 array layout.

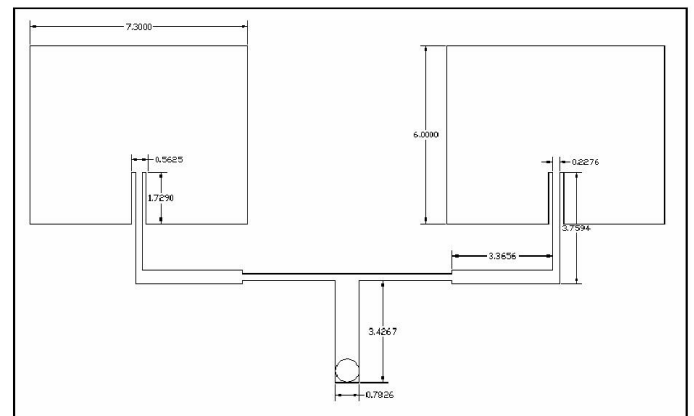


Figure 7: 1 by 2 Patch Antenna Array Layout

TABLE 3
1 BY 2 PATCH ANTENNA ARRAY DIMENSIONS

Microstrip Patch Array Antenna Dimensions (in mm)	
Patch	
Width	7.3000
Length	6.0000
50 Ohms Transmission Feedline	
Width	0.78263
Length	3.42674
100 Ohms Transmission Feedline	
Width	0.22764
Length	3.53490
70 Ohms Quarter-Wave Transformer	
Width	0.44893
Length	3.47941
Inset	
Width	0.45
Length	1.729

V. 1 BY 2 ARRAY SIMULATION AND RESULTS

Table 4 exemplifies the summary of results of 1 by 2 array. The HFSS model of 1 by 2 array is demonstrated in Fig. 8. and Fig. 9 shows the S11 response is -10.26 dB at 16.24 GHz. The directivity is 9.423 dB and gain is 9.354 dB. The radiation efficiency is 0.91456. Fig. 10 and 11 demonstrate the 1 by 2 Patch Array E field and Radiation Pattern Plots respectively. The 3 dB beamwidths in the two principal plane planes are 18° and 20°.

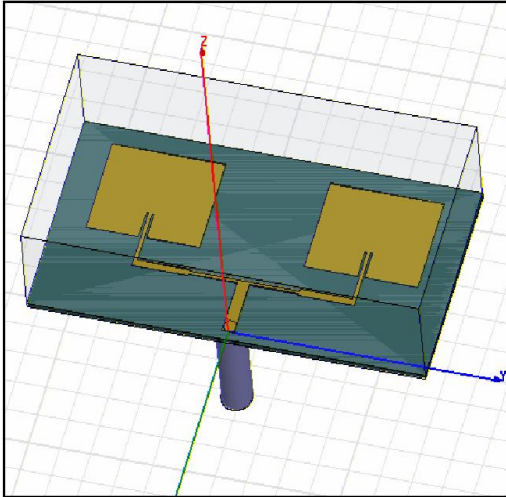


Figure 7: 1 by 2 Patch Array HFSS Design

TABLE 4
1 BY 2 PATCH ARRAY PARAMETERS

Antenna Parameters	1 by 2 Patch Array
S11 Response	-10.26 dB at 16.24 GHz
Directivity	9.423 dB
Gain	9.354 dB
Radiation Efficiency	0.91456

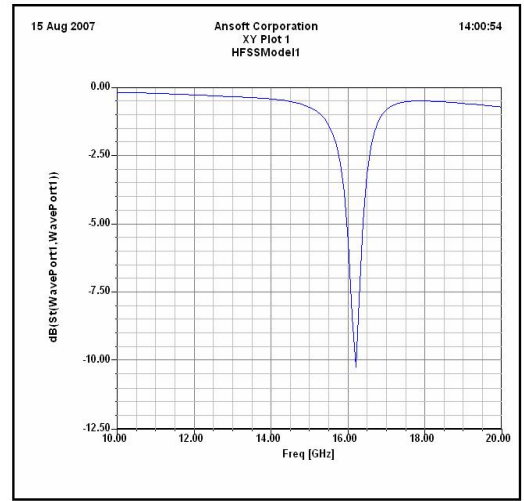


Figure 8: 1 by 2 Patch Antenna Array S₁₁ Response

VI. 2 BY 2 ARRAY THEORETICAL DESIGN

The 2 by 2 Array consists of 4 rectangular patches of same size and each element is separated with an equal distance of 0.428λ . Table 5 shows the summary of the Microstrip 2 by 2 Array Dimensions. Feeding network is designed to realize impedance matching by using quarter wavelength impedance transformers [2]. Network begins with a center line of 100Ω which is fed at its center by a 50Ω coaxial probe. Then impedance is transformed to 50Ω through a 70.7 quarter wavelength line. At the end of the transformer, network splits into two 100Ω lines, which is transformed to 50Ω again by following 70.7Ω quarter wavelength lines. Impedance fed into patches finally is 100Ω after split again. The feeding network ensures each patch has the same feed excitation [3]. 2 by 2 array layout is depicted in Fig. 13.

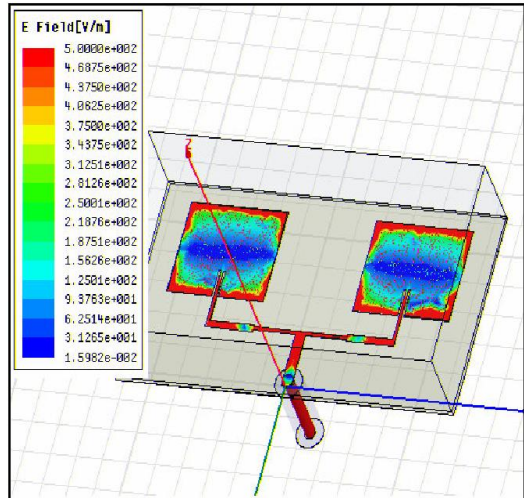


Figure 9: 1 by 2 Patch Array E Field Plot

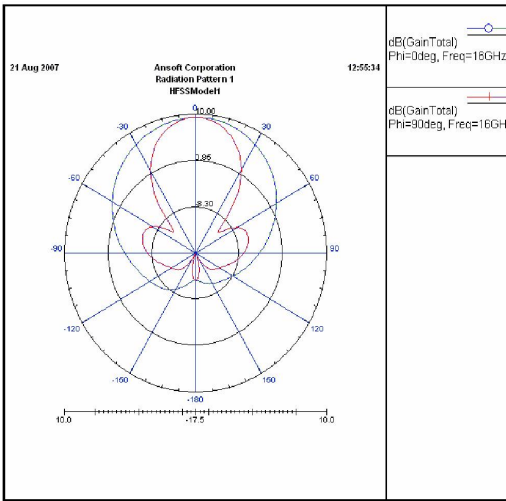


Figure 10: 1 by 2 Patch Array Radiation Pattern Plot

TABLE 5
2 BY 2 PATCH ARRAY DIMENSIONS

Microstrip Patch 2 by 2 Array Antenna Dimensions (in mm)	
Patch	
Width	7.4110
Length	6.1990
100 Ohms Transmission Feedline	
Width	0.22764
Length	3.53490
70 Ohms Quarter-Wave Transformer	
Width	0.44893
Length	3.47941
Inset	
Width	0.4500
Length	1.7290

VII. 2 BY 2 ARRAY SIMULATION AND RESULTS

Summary of results of the Microstrip 2 by 2 Array is depicted in Table 6. The 2 by 2 Patch Array HFSS Design Model is illustrated in Fig. 14 and Fig. 15 shows the S11 response is -15 dB at 15.7 GHz. The directivity is 13.4 dB and gain is 12.54 dB. The radiation efficiency is 0.821. E field plot of the array is demonstrated in Fig. 16. The radiation pattern plots of the 2 by 2 Microstrip array are exhibited in Fig. 17. The 3 dB beamwidths in the two principal plane planes are 17.983° and 15.984°. This radiation pattern shows a peak sidelobe level of 1.88 dB.

TABLE 6
2 BY 2 PATCH ARRAY PARAMETERS

Antenna Parameters	2 by 2 Patch Array
S11 Response	-15 dB at 15.7 GHz
Directivity	13.4 dB
Gain	12.54 dB
Radiation Efficiency	0.821

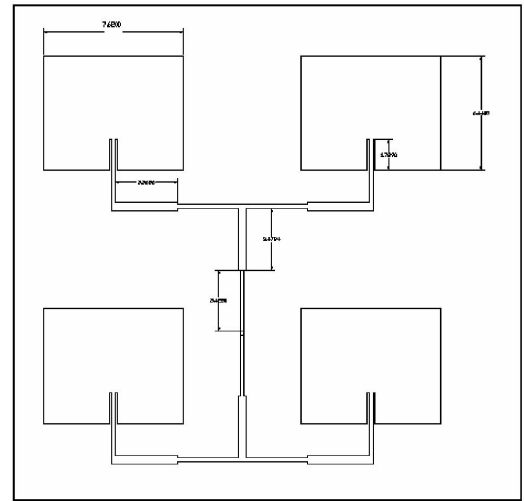


Figure 11: 2 by 2 Patch Antenna Array Layout

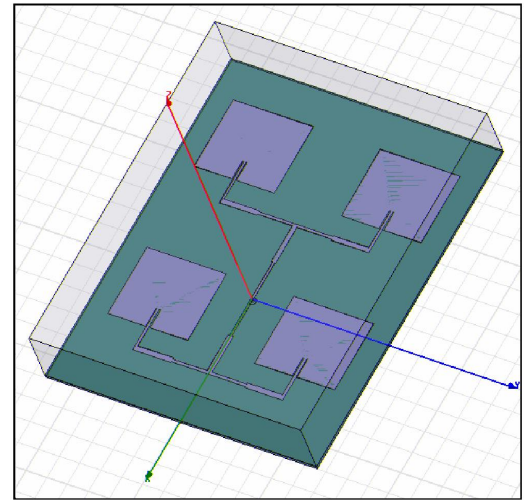


Figure 12: 2 by 2 Patch Array HFSS Design

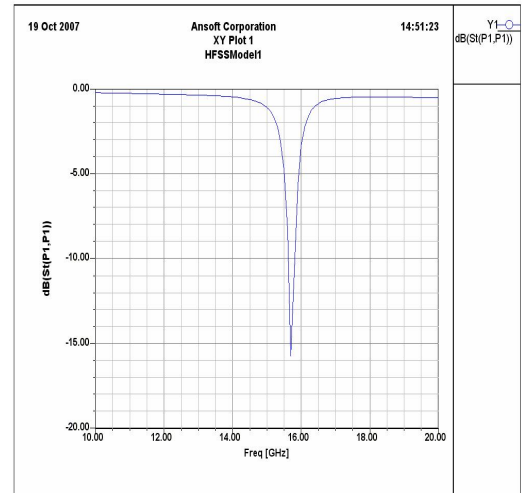


Figure 13: 2 by 2 Patch Antenna Array S₁₁ Response

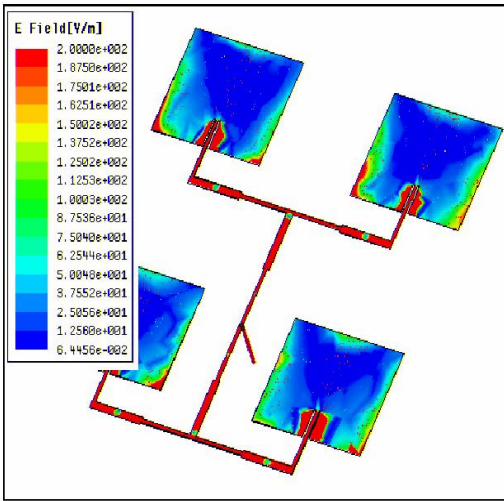


Figure 14: 2 by 2 Patch Array E Field Plot

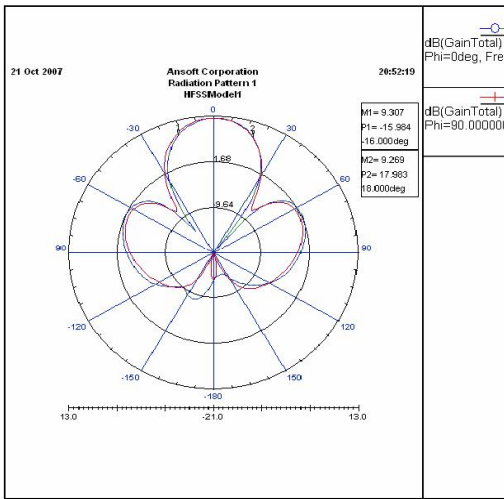


Figure 15: 2 by 2 Patch Array Radiation Pattern Plot

VIII. 1 BY 4 ARRAY THEORETICAL DESIGN

Table 7 shows the summary of the Microstrip 1 by 4 Array Dimensions and Fig. 18 shows the 1 by 4 array layout. For realizing the impedance matching feeding network is designed by using quarter wavelength impedance transformers. Transmission line of 100Ω is fed at its center by a 50Ω coaxial probe. Then impedance is transformed to 50Ω through a 70.7 quarter wavelength line. Between 70.7Ω and 100Ω line a 84Ω transforming network is introduced for keeping the patch elements equally distant. At the end of the transformer, network splits into two 100Ω lines, which is transformed to 50Ω again by following 70.7Ω quarter wavelength lines. Impedance fed into patches finally is 100Ω after split again.

TABLE 7
1 BY 4 PATCH ANTENNA ARRAY DIMENSIONS

Microstrip Patch Array Antenna Dimensions (in mm)	
Patch	
Width	7.3000
Length	6.0000
50 Ohms Transmission Feedline	
Width	0.78263
Length	3.42674
100 Ohms Transmission Feedline	
Width	0.22764
Length	3.53490
70 Ohms Quarter-Wave Transformer	
Width	0.44893
Length	3.47941
84 Ohms Quarter-Wave Transformer	
Width	0.32668
Length	3.50703
Inset	
Width	0.45
Length	1.729

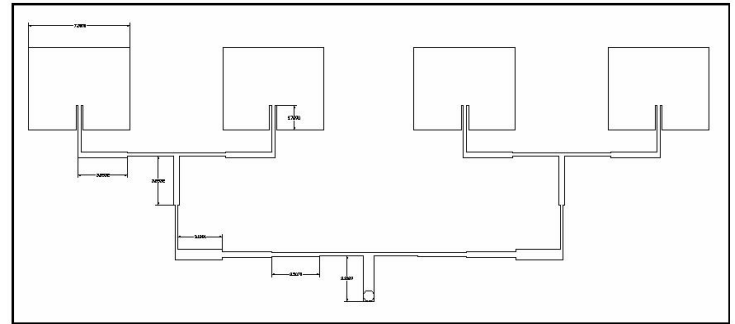


Figure 16: 1 by 4 Patch Antenna Array Layout

IX. 1 BY 4 ARRAY SIMULATION AND RESULTS

Table 8 gives an idea of the summary of results of 1 by 4 Array. Figure 19 illustrates the HFSS Model of 1 by 4 Patch Array. Fig 20 shows the S_{11} response is -3.7 dB at 16.10 GHz. The directivity is 11.522 dB and gain is 10.837 dB. The radiation efficiency is 0.91456 . Figures 21 and 22 indicate the E field and Radiation Pattern Plots. The 3 dB beamwidths in the two principal plane planes are 9.975° and 7.973° . This radiation pattern shows a peak sidelobe level of 4.802 dB.

TABLE 8
1 BY 4 PATCH ARRAY PARAMETERS

Antenna Parameters	1 by 4 Patch Array
S_{11} Response	-3.7 dB at 16.10 GHz
Directivity	11.522 dB
Gain	10.837 dB
Radiation Efficiency	0.8541

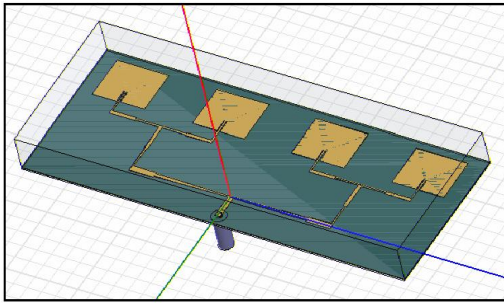


Figure 17: 1 by 4 Patch Array HFSS Design

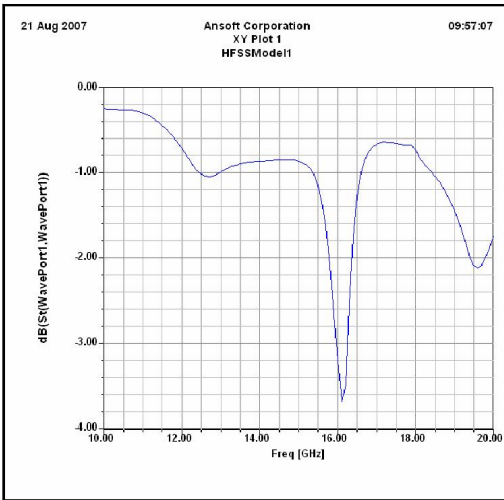


Figure 18: 1 by 4 Patch Antenna Array S11 Response

X. CONCLUSION

The comparative summary of four antennas is shown in Table 9. As the number of elements increase the directivity and gain also increases. The planer Microstrip patch antenna array of 2 by 2 exhibits a greater directivity and gain in comparison with linear array of 1 by 4. Whereas the linear array shows better radiation efficiency of 0.8541 with a loss of 0.6843 dB in contrast with planner array having radiation efficiency of 0.821 with a loss of 0.86 dB. Approximately, half the loss is attributed to the Ohmic loss of the feed network and the remaining loss is due to cross-pot radiation, mismatches, patch loss, etc. As a next step we will be fabricating and testing above designed Patch Antennas.

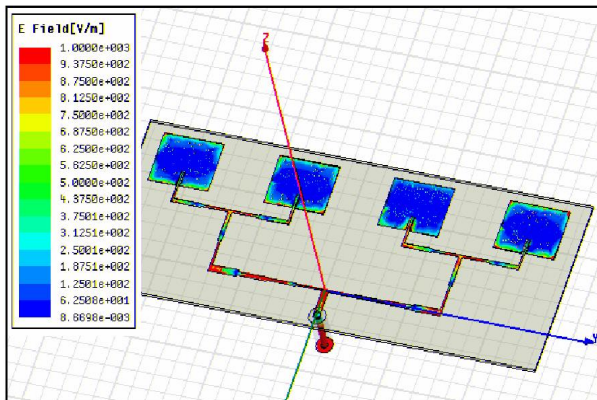


Figure 19: 1 by 4 Patch Antenna Array E Field Plot

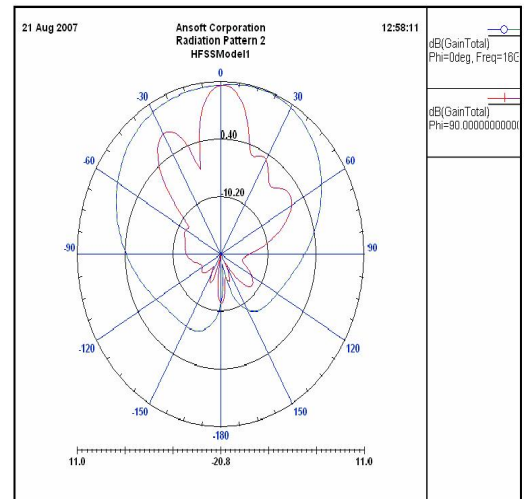


Figure 20: 1 by 4 Patch Antenna Array Radiation Pattern Plot

TABLE 9
COMPARATIVE SUMMARY

Antenna Parameters	Single Element	1 by 2 Patch Array	2 by 2 Patch Array	1 by 4 Patch Array
S11 Response	-22 dB at 15.80 GHz	-10.26 dB at 16.24 GHz	-12 dB at 17.4 GHz	-3.7 dB at 16.10 GHz
Directivity	7.43 dB	9.423 dB	13.4 dB	11.522 dB
Gain	6.809 dB	9.354 dB	12.54 dB	10.837 dB
Radiation Efficiency	0.866	0.91456	0.821	0.8541

ACKNOWLEDGMENT

The authors would like express thanks to Iftekhar Mehmood, Manager Institute of Space Technology for his careful reading and critique of the manuscript. His insights and suggestions greatly improved the paper. The authors would also like to show gratitude to Javed Asad, Manager NESCOM for his supervision and motivation and Ghulam Ahmed, Assistant Manager SUPARCO, for his help in using the HFSS software.

REFERENCES

- [1] Constantine A. Balanis, Arizona State University, "Antenna Theory: Analysis and Design", 3rd Edition, John Wiley & Sons, Inc.
- [2] Ramesh Garg, Prakash Bhartia, Inder Bahl, Apisak Ittipiboon, "Microstrip Antenna Design Handbook", Artech House.
- [3] B. Cui, C. Wang, and X.-W. Sun, "Microstrip array double-antenna (MADA) technology applied in millimeter wave compact radar front-end," *Progress In Electromagnetics Research*, PIER 66, 125–136, 2006.
- [4] HFSS Help, Ansoft HFSS Version 9.2.