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Design and Simulation of 3x1 Circular Stacked Proximity Coupled Microstrip Patch Array Antenna using HFSS at 6.5 GHz Frequency

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Abstract: Circular stacked microstrip proximity coupled feed antenna widely used in wider bandwidth applications. This paper presents the design of proximity coupled antenna at 6.5 GHz frequency with dielectric constant as 2.2 and having thickness of 1.2 mm for lower substrate and 1.2 mm for upper substrate assigned with material Rogers RT/duroid 5870 (tm). Even though it gives wider bandwidth, in order to increase its gain, series fed array is used. 2X1 and 3X1 series fed arrays are designed and simulated using High Frequency Structure Simulator software (HFSS). The important characteristics of an antenna are gain and directivity .Gain of about 8.7 dB and directivity of 8.669dB are achieved by using array as compared with single antenna which is about 5dB and directivity of5.66dB. Antenna parameters like S-parameters, directivity, radiation intensity, Voltage standing wave ratio (VSWR) etc., are all observed in simulated software and are agreed with required results

Keywords: S-parameters, stacked patch antenna, HFSS, proximity coupling, High gain.

1. INTRODUCTION

In microwave signal communication, an antenna plays a major role for conversion of EM radiation to electrical energy and vice versa. It acts like a transducer and as an impedance matching device between free space and electrical network. The major problem in antenna communication system is bandwidth and gain of an antenna. Different types of antenna are available to provide high gain and large bandwidth. But the problem is size and compactness. Microstrip patch antenna is an antenna which is compactable, easy installation and miniature in size. To feed microstrip antenna different techniques are available like inset feed, coaxial feed, aperture coupled and proximity coupled etc. Each technique has its own advantages and disadvantages. Out of these feeding techniques, proximity feeding technique is the one which provides larger bandwidth and moderate gain.

This paper presents design procedure for proximity coupled microstrip feed antenna at 6.5 GHz frequency. A circular patch has been chosen to provide circular polarization. A single circular patch is designed and simulated using HFSS software. Return loss is observed at 6.5 GHz. But gain of the antenna is about 5 dB only.

The gain requirement is about 7-9 dB in biomedical applications, wireless communication, PCS applications, microwave communication systems etc. As current fed to the antenna or dimension of the antenna is increased, gain also increases but its efficiency falls down. This is due to increasing the loss resistance and radiation resistance of antenna. The only way to increase the gain is to choose an array (collection of similar elements). A series feed technique is used for this array because only one feed is required rather than multiple feeds and makes fabrication process easy.

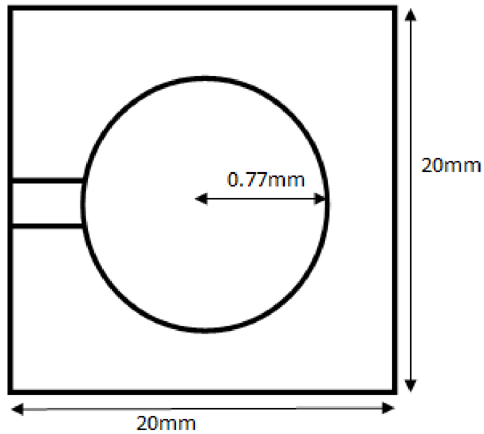


Figure 1: Top view of proposed antenna

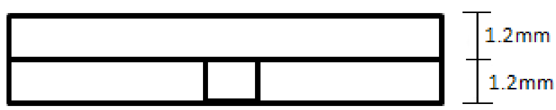


Figure 2: Side view of proposed atnenna

Stacked type of dielectric material causes to increase in height of the antenna, which in turn improves wider bandwidth and mechanical support. Figure 1; Figure 2 represents top and side views of single patch. In this coupling technique a 50 ohm microstrip line is inserted between two dielectric materials of equal heights. When it is excited almost EM radiation takes place within stacked dielectric materials. In this feeding technique, patch plane is not physically connected to feed line but electrically connected by EM radiation. The designed antenna is simulated using High frequency Structure Simulated software and antenna parameters are observed. A 3X1 array antenna is designed and is represented in the fallowing in Figure 3.

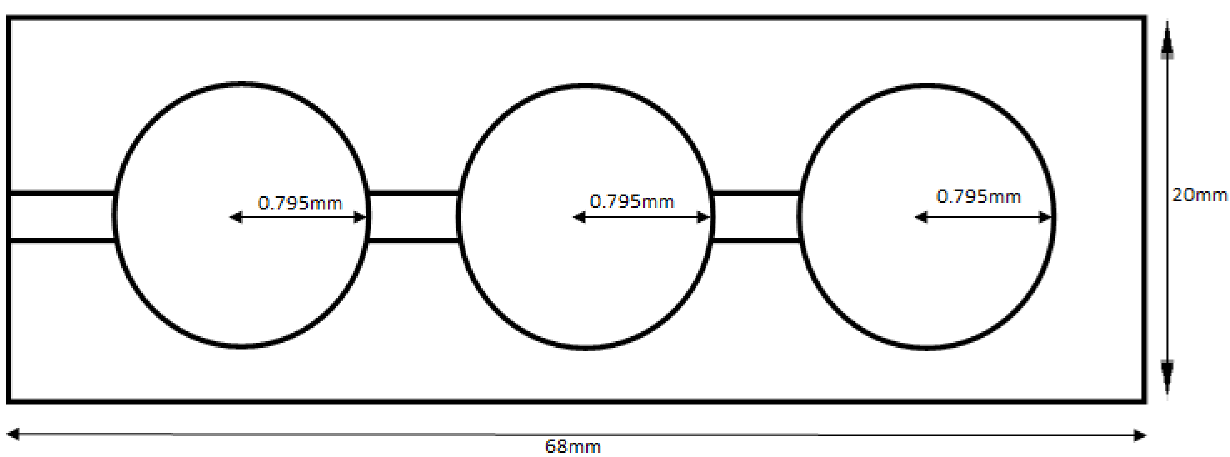


Figure 3: Top view of a 3X1 array

2. DESIGN OF ANTENNA

Specifications

The proposed antenna is designed with the fallowing specifications

(i) Cut off frequency = 6.5 GHz

(ii) Dielectric constant = 2.2

(iii) Thickness of upper material = 1.2 mm

(iv) Thickness of lower material = 1.2 mm

(v) Characteristic impedance of feed line = 50 Ω

Single Element

Circular antenna is designed by using following formulae for the given above specifications and are

$$a = \frac{F}{\left\{1 + \frac{2h}{\pi\varepsilon_r F}\left[\ln\left(\frac{\pi F}{2h}\right) + 1.7726\right]\right\}^{1/2}} = 0.77 \text{ mm} \tag{1}$$

The radius calculated by using above formula would not consider the fringing effects. By considering this effect the effective radius of the circular patch is

$$a_e = a\left\{1 + \frac{2h}{\pi\varepsilon_r a}\left[\ln\left(\frac{\pi a}{2h}\right) + 1.7726\right]\right\}^{1/2} \tag{2}$$

The resonant frequency of the circular patch for TM_{110} mode is

$$(f_r)_{110} = \frac{1.8412 v_0}{2\pi a_e\sqrt{\varepsilon_r}} \tag{3}$$

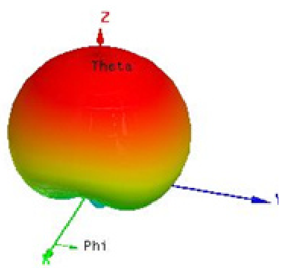
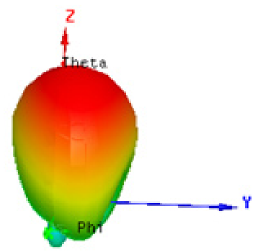
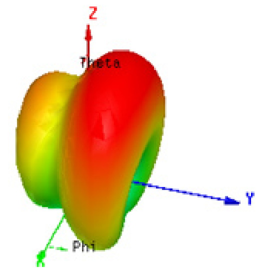
3X1 Array Element

An array is a collection of similar elements which gives the higher gain and directivity. This paper presents designing of a uniform linear array of two elements and three elements with series fed type. The spacing between the elements is half wave length and are fed with inphase currents. The radiation patterns will be observed only in broadside array (i.e. ∅ = 90°). No radiation pattern in endfire direction because all elements are fed with inphase currents. If the phase between the elements is changed the beam pattern will change from broadside to endfire. Scanning can be achieved by using this process. But in this paper only the radiation pattern is observed in broadside direction. Table 1 gives the radiation patterns in three cases and is shown that for array narrow beamwidth is obtained. From this radiation patterns different radiation patterns are studied and are tabulated in Table 2. The array factor for n element array in general is given by

$$\text{AF} = \sum_{k=0}^{n-1} \frac{\sin\left(\frac{k\Psi}{2}\right)}{\sin\left(\frac{\Psi}{2}\right)} \tag{4}$$

where, Ψ = progressive phase shift = $\beta d \cos \varnothing + \delta$; Here d is the separation between elements and is 0.5λ and δ phase given to the elements.

Table 1
Radiation patterns

Single element	*Two element array*	*Three element array*
		

3. SIMULATION USING HFSS

HFSS is a High Frequency Structural Simulator used to simulate passive and active microwave components, and antennas designed at microwave frequency. It is based on Finite Element Method (FEM). Using HFSS simulator tool a circular patch of single element, array elements i.e. 2X1, 3X1 are designed. A mesh frequency of about 5 GHz is chosen to get accurate result. HFSS is user friendly and 3D modeling support to design components. Figure 4, Figure 5 and Figure 6 are shown below are the layout of single, 2X1, 3X1 array elements respectively.

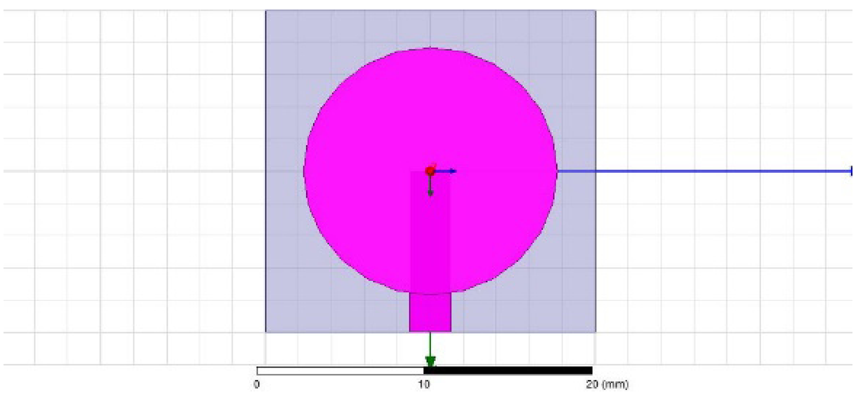


Figure 4: Single circular patch simulation in HFSS

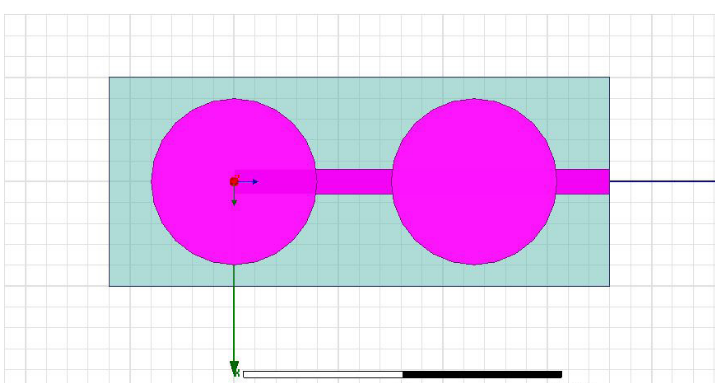


Figure 5: A 2X1 array patch simulation in HFSS

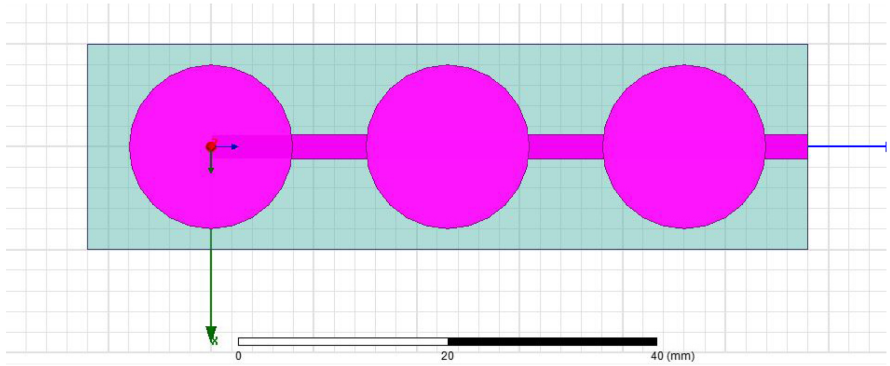


Figure 6: A 3X1 circular patch simulation in HFSS

4. RESULTS AND DISCUSSIONS

The designed circular patch antenna is simulated using HFSS and S parameters, VSWR, gain are observed. At 6.5 GHz these values are -24.143 dB, 1.114 and 5.13 dB. Even it is achieving higher return loss at resonant frequency of 6.5 GHz, but gain is moderately low. To improve gain factor array are used. A series fed array is used because of simplicity of feeding with single microstrip line. A 2X1 array and 3X1 array are designed and S-parameters, gain are −15.192 dB, 6.716 and -20.66 dB, 8.66. Figure 7 shows the S_{11} parameter and VSWR values over a frequency range of 4.5 GHz to 8GHz. Observed high return loss at 6.55 GHz which is desirable. Similarly Figure 8 and Figure 9 shows S parameter and VSWR variations as of function of frequency. Table 2 and Table 3 gives complete observations in HFSS simulator for single and array elements. Figure 10 and Figure 11 shows the radiation patterns of single element and array elements of 3X1 in HFSS simulator.

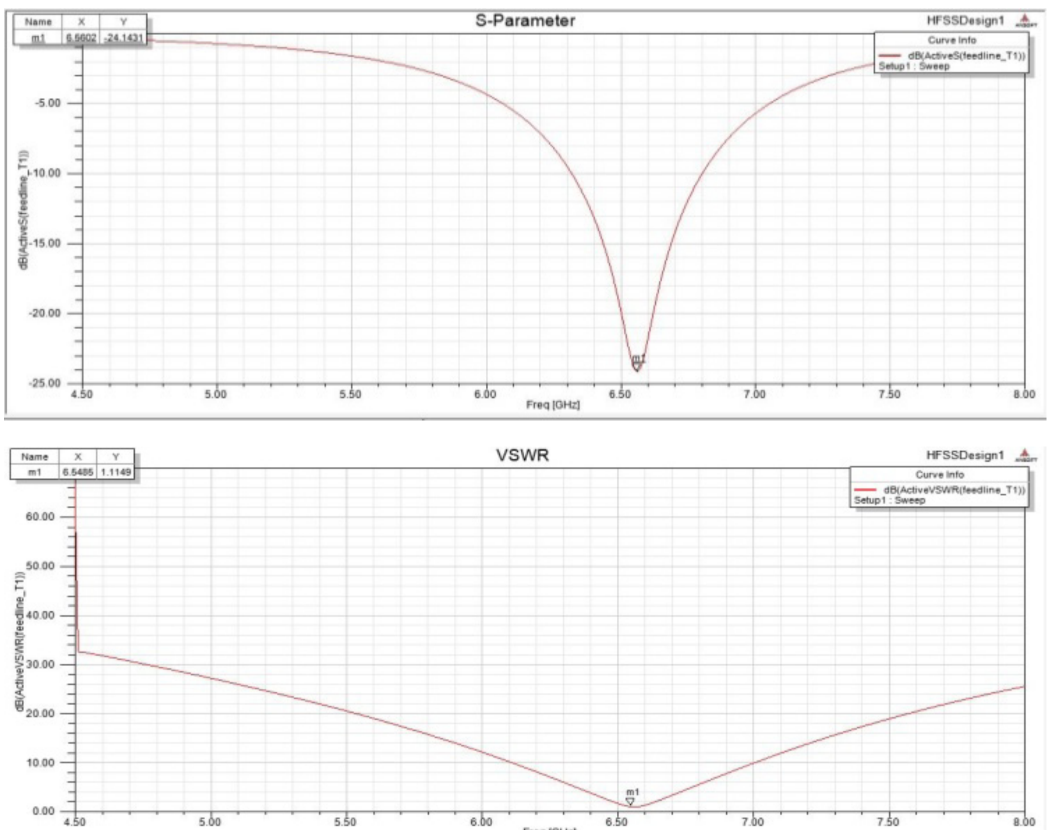
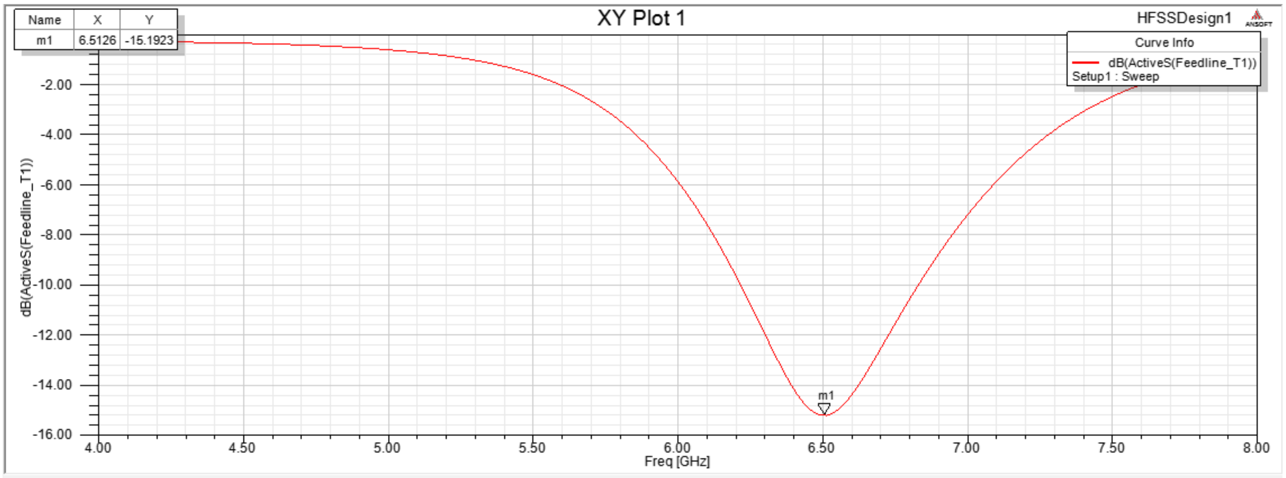


Figure 7: Simulated S_{11} parameter and VSWR results of single element



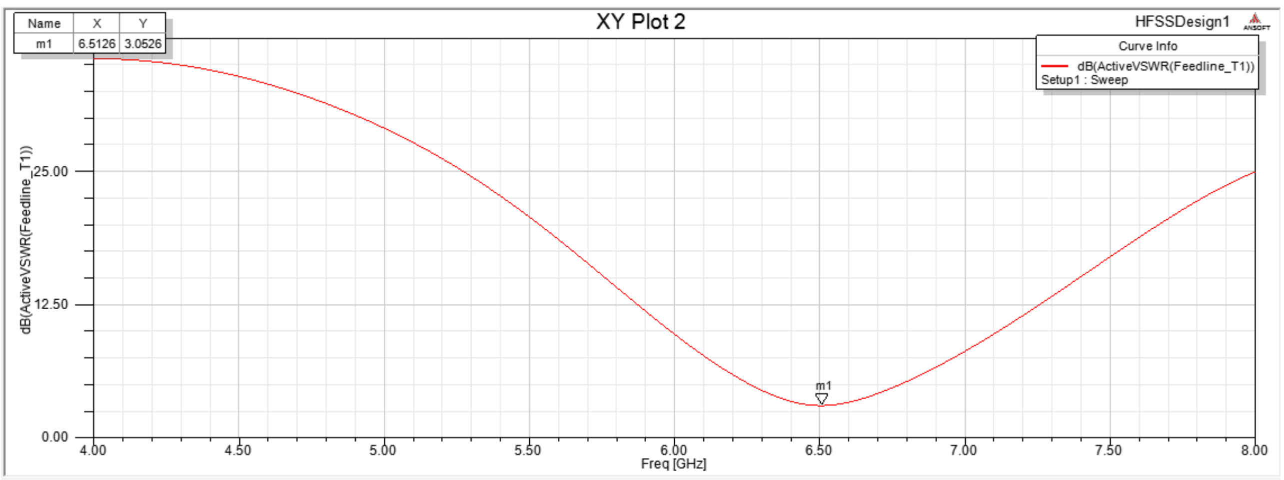
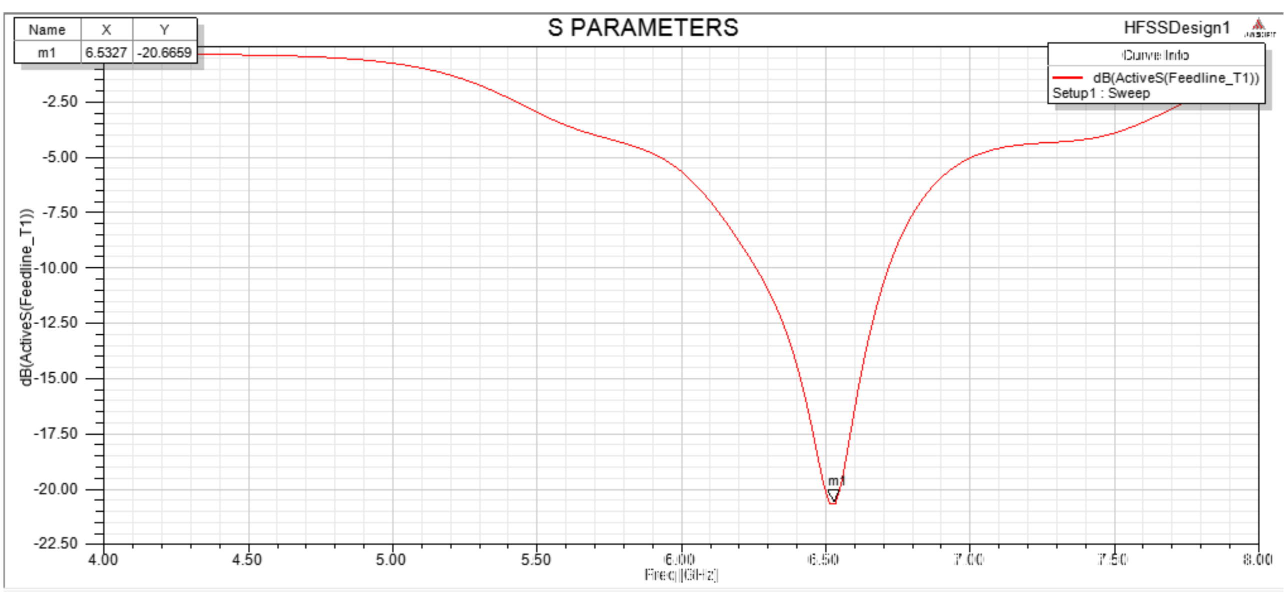


Figure 8: Simulated S_{11} parameter and VSWR results of two element array



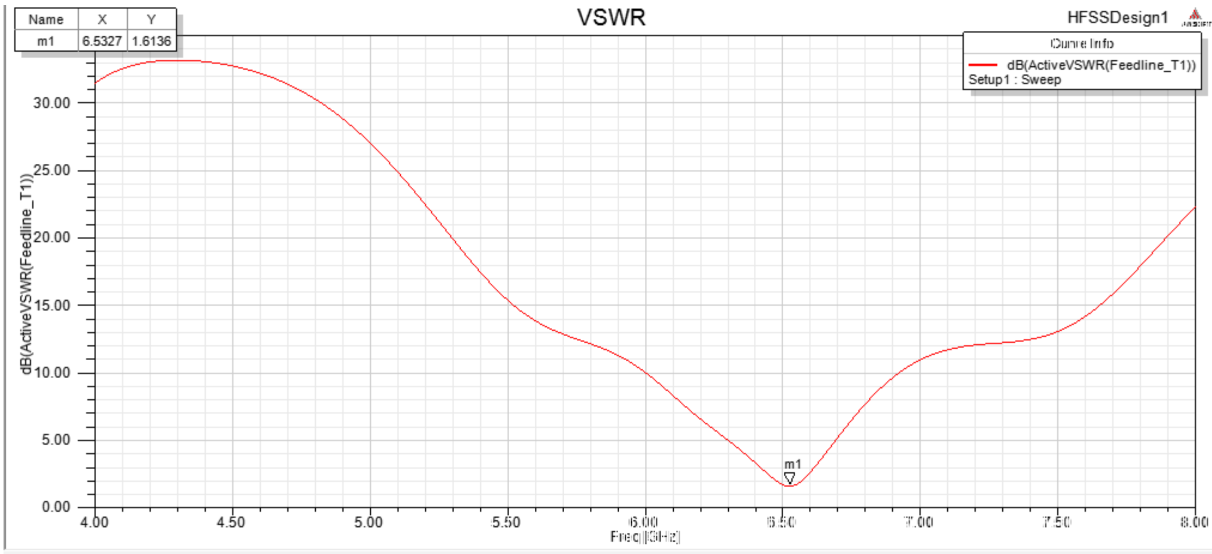


Figure 9: Simulated S_{11} parameter and VSWR results of three element array

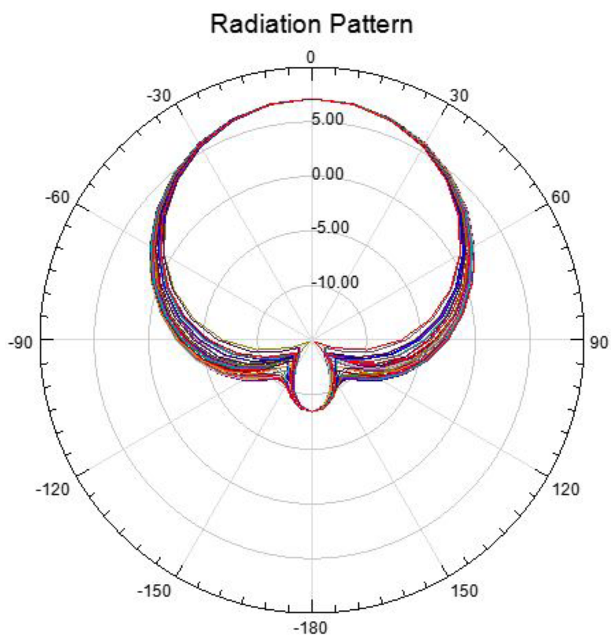


Figure 10: Simulated Radiation Pattern of single circular patch element

Table 2
Radiation characteristics

	Single element	*Two element array*	*Three element array*
Max u	0.0040415	0.051794	0.0068428
Peak directivity	5.125	6.7292	8.7539
Peak gain	5.1334	6.7116	8.6639
Radiated power	0.0099	0.0096725	0.0098232
Radiation efficiency	1.0007	0.99738	0.0099253
Front to back ratio	35.911	27.84	168.49

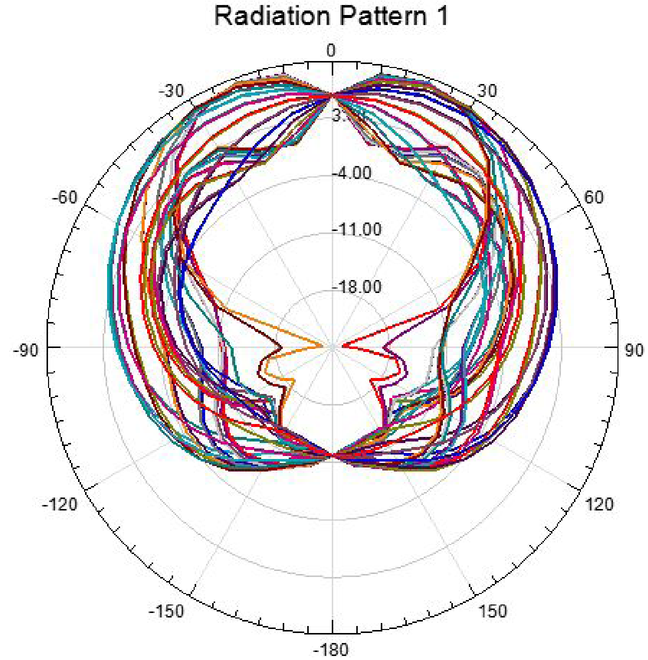


Figure 11: Simulated Radiation Pattern of 3X1 stacked array antenna

Table 3
Simulated S Parameter Values

S parameter and VSWR	*Single element*	*Two element array*	*Three element array*
S_{11}	–24.143	–15.192	–20.66
VSWR	1.114	3.05	1.61

5. CONCLUSION

Primarily, the antenna is analyzed as single patch antenna with various circular patch radii and simultaneously the change in the feed line is being done. By changing these two parameters the functioning of the antenna is being analyzed and their related antenna parameters like s-parameters, directivity, radiation intensity, voltage standing wave ratio (vswr) etc., are observed accordingly. By considering the above antenna parameters parametric analysis is being done and this is extended to 2x1 circular patch array antenna to increase the gain comparatively. Finally 3x1 circular patch array antenna is being designed at 6.5GHz frequency with best characteristics accordingly.

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