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High-Gain Pencil-Beam Microstrip Antenna Array for RADAR Application

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Abstract—For long-range communication, the directivity and gain of a millimeter wave antenna should be high. The aim of the paper is to design an antenna array that works at higher frequencies X/Ku-band (8–12 GHz)/(12–18 GHz) respectively for applications such as RADAR. This can be achieved by an array of antennas as single antenna cannot provide such high gain and directivity. The radiation pattern has directional pencil beam in which the frequency and gain plot is shown at 11.32 GHz. The maximum gain of 29.0994 dB has been achieved at 11.32 GHz frequency. The software High Frequency Structure Simulator (HFSS) has been used for simulation, and the simulated and measured results are found in agreement with each other.

1. INTRODUCTION

Aerial refers to the interface between flowing current through metal conductors and millimeter waves that are travelling in the space [1]. When we deploy single antenna, it radiates in 360° [2]. The radiation loss for isotropic antenna is very high [3]. Scientists have separated two vertical antennas by half a wavelength and fed them so, and they found out that the directivity of the antenna increases. This experiment led to the development of radar [4]. When the number of array elements increases, the half power beam width (HPBW) will become narrow. The antenna arrays came into the picture which can provide high gain, directive beam pattern, and low return loss [5]. However, the array antenna has some limitations such as poor efficiency, gain, and mutual coupling [6]. Different types of antenna [7] and array antenna [16] have been proposed for many years. By optimizing and characterizing the antenna parameters, overall gain will increase; steering of the beam and side lobes can be reduced; signal to interference plus noise ratio (SINR) of the signal can be maximized which has led to microstrip antenna for many military radar applications. Many antennas have been reported which are individually designed for some purposes [8]. In [2], a microstrip antenna with a conducting patch was designed at 2.4 GHz which gives the antenna gain of 8.27 dB. Also, various feeding techniques using CST microwave studio have been proposed [9–13]. Ref. [19] has shown that by increasing the number of patches array the gain of antenna can be improved. In this article, 2×1 and 4×1 rectangular antennas are designed which resonate at 2.4 GHz. The 2×1 antenna has the return loss of −18.54 dB with a gain of 5.26 dB, and the 4×1 antenna array provides the return loss of −7.25 dB, gain of 9.24 dB, and sidelobe level (SLL) of −14.84 dB. In [17], a microstrip patch antenna was designed at 10.3 GHz which can provide a gain of 4 dB to 6 dB. The paper [3] has presented a 4-patch antenna which yields 12.56 dBi gain with a efficiency of 75%. When the patch was doubled to 8, the gain of antenna was improved to 13.9 dBi, but the efficiency decreased to about 63%, and SLL increased to near −12 dB. This high gain finds application in RADAR. Military radar has early warning along with weapon control system. The detection and evaluation capabilities of the radar in combination with effective defence control system

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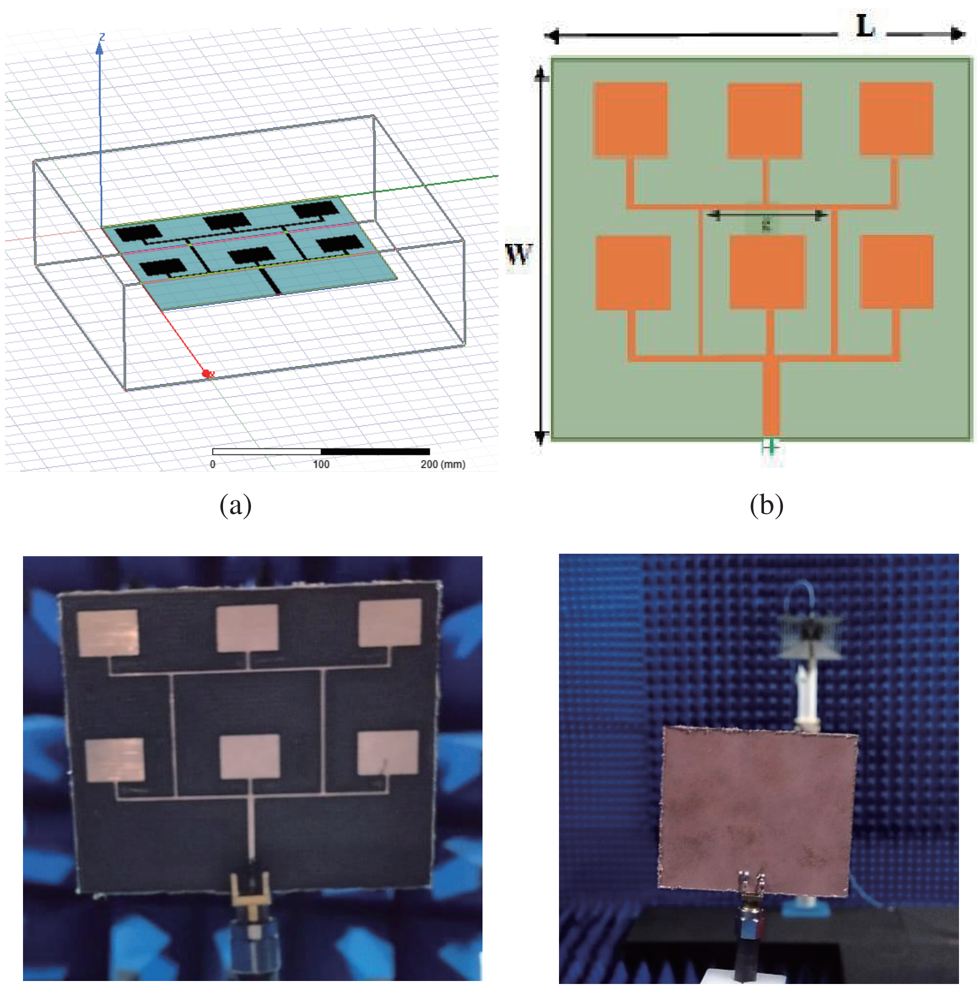
provide maximal operational effectiveness [18]. X band radar has got paramount importance in air defence system as well as the operation of offensive missiles and other weapons. Surveillance radar includes detection, recognition, and tracking of system. In our study, we have designed a 6-element array which can improve the performance of antenna. Since array itself has many advantages over one structure, the gain and return loss are plotted using both simulated and measured fabricated antennas in the preceding section.

2. PROPOSED MICROSTRIP ANTENNA ARRAY

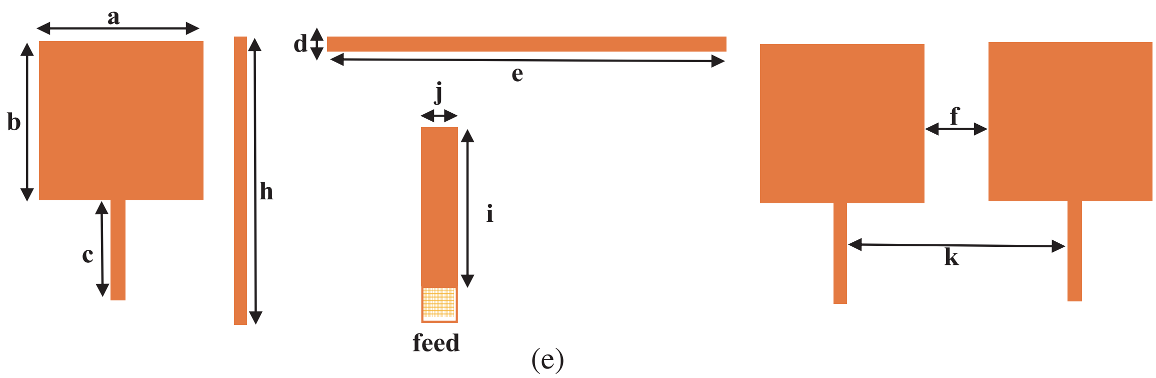
The proposed microstrip antenna array 2×3 is designed and simulated using high frequency simulator (HFSS) fed with a microstrip line with 50-ohm impedance. The proposed antenna array has been described, with full dimensions, in Figures 1(a)–(e).

Rogers^{TM} substrate RT-duroid 5880 is used as it supports higher frequency application. The property of the substrate material used is mentioned in Table 1. Other materials like FR4 are mostly used for WI-FI, WLAN, Bluetooth, and other lower range of wireless application [13]. The properties of the substrate material used are shown in Table 1 while the exact dimensions used for fabrication purpose are mentioned in Table 2.



(a) (b)

(c) (d)



(e)

Figure 1. The antenna array, (a) side and (b) top, view in HFSS software, (c) Fabricated antenna top view, (d) bottom view, in Anechoic chamber and (e) dimension of antenna segment drawn to scale.

Table 1. Material.

Substrate	ε_r	δ	**Thickness (t)**
RT duroid 5880	2.2	.0009	1.6 mm

Table 2. Dimension of designed antenna (in mm).

a	**b**	**c**	**d**	**e**	**f**	**g**
9.59	7.36	2.4	0.775	43.484	11.76	22.475
h	i	j	k	L	W	
19.325	15.59	1.275	22.475	57.2	48.64	

3. ANALYSIS OF MICROSTRIP ANTENNA

A low-profile antenna is mounted on an upper surface of the substrate called patch [6]. Here we have used a rectangular patch. A metal strip is connected to the patch for the feeding [7, 12]. Microstrip antenna is a single layer design which has different parts [14]. We model a rectangular patch antenna in which a substrate of height in mm with width Ws and length Ls is imposed upon the ground plane. A resonating rectangular patch with dimension of Wp and Lp is chosen; however, Wp is less than $2Lp$ and provided with a microstrip feed line L_f [14, 15].

$$W = (2M+1)/\sqrt{(\varepsilon_r+1)/2} \times (\lambda_0/2) \tag{1}$$

$$\varepsilon_{reff} = (\varepsilon_r+1)/2 + (\varepsilon_r-1)/2 \left| 1/\sqrt{1+12\left(\frac{h}{W}\right)} \right| \tag{2}$$

$$L_{eff} = C/2f\sqrt{\varepsilon} \tag{3}$$

where L_{eff} is the effective length of antenna. Now, the extended length of antenna ΔL:

$$\Delta L = 0.412h\frac{(\varepsilon_r+0.3)(w/h+0.264)}{(\varepsilon_{eff}-0.258)(w/h+8)} \tag{4}$$

Hence, the length of patch,

$$L = L_{eff} - 2\Delta L \tag{5}$$

$$L = (2N+1)/\sqrt{\varepsilon_{eff}} \times (\lambda/2) - 2\Delta L \tag{6}$$

The dielectric constant (ε_r) of the material varies as $2.2 \leq \varepsilon_r \leq 10$. The operating frequency fr ranges between 1 and fr, and thickness of the substrate material is $\lambda_o \leq h \leq 0.05\lambda_o$, where λ_o is the wavelength in vacuum. M and N are integers where $M = 1$ and $N = 0$.

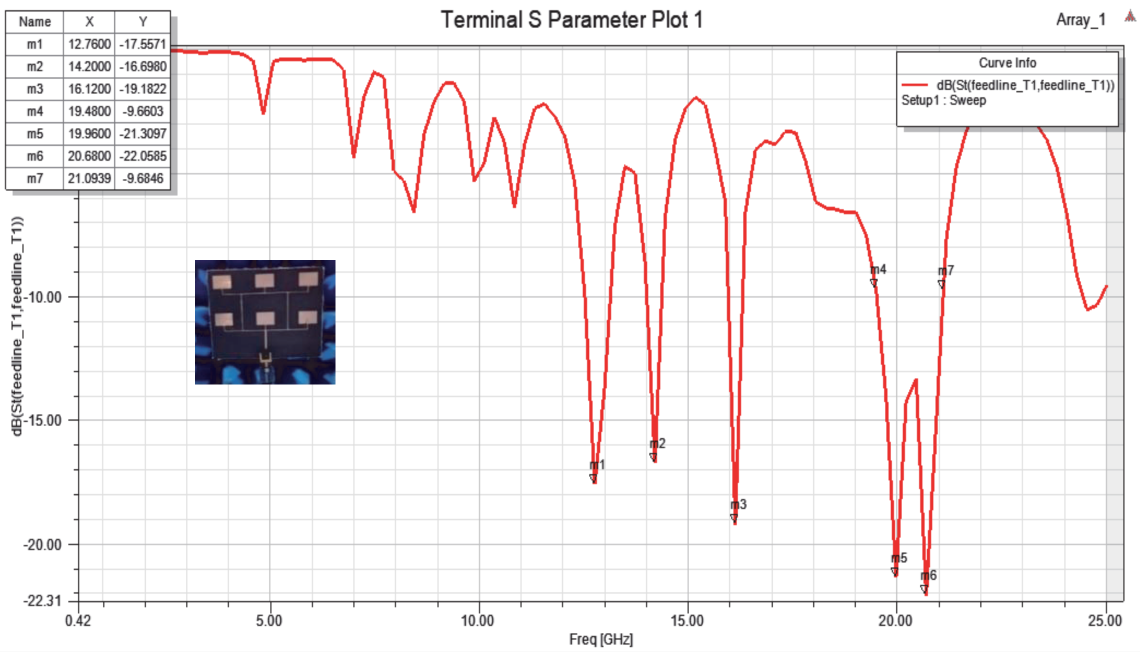


Figure 2. The simulated return loss vs frequency plot.

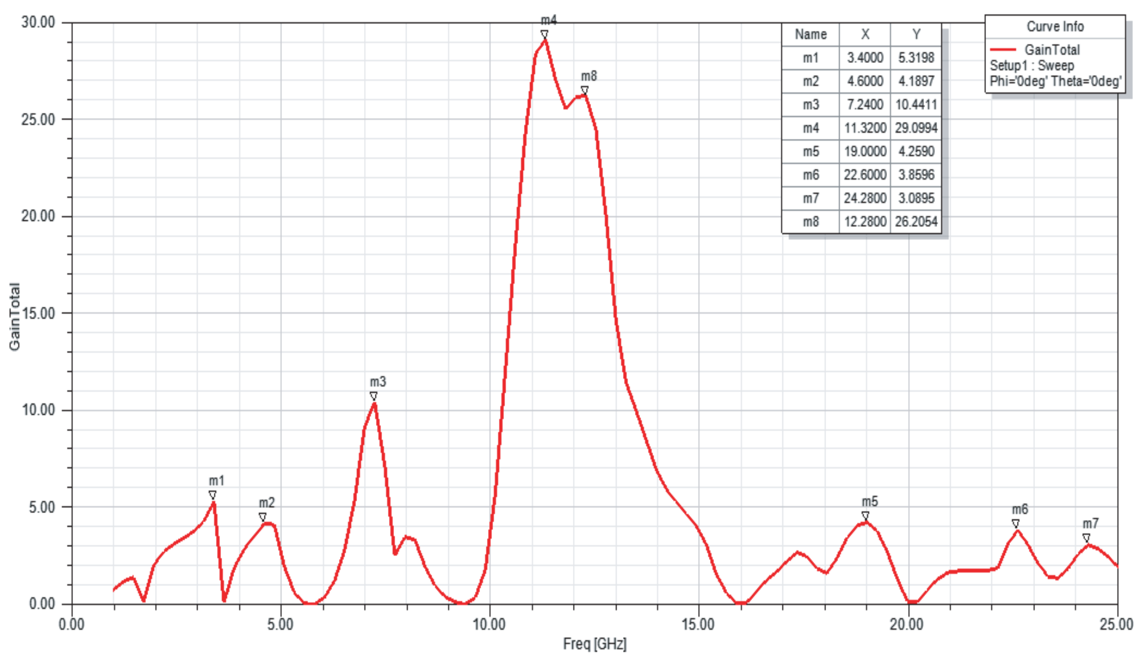


Figure 3. The simulated gain of the array antenna.

4. RESULTS AND DISCUSSION

The synthesized parameters are gain, return loss, and radiation pattern. The optimized structure is simulated, fabricated, and measured using printed circuit board (PCB) machine, vector network analyzer (VNA), and anechoic chamber. Return loss is defined as the amount of power reflected back from the device, it occurs due to the mismatch of load impedance. The return loss of −9.5 dB is sufficient for an antenna to resonate. From the analysis, we obtain that the simulated return loss corresponding to the operating frequency 12.76 ,GHz is −17.5671 dB, which is below −9.5 dB as shown in Figure 2.

In Figure 3, the maximum gain of the array antenna is achieved at 11.32 GHz, and the gain is 29.0994 dB that is quite high.

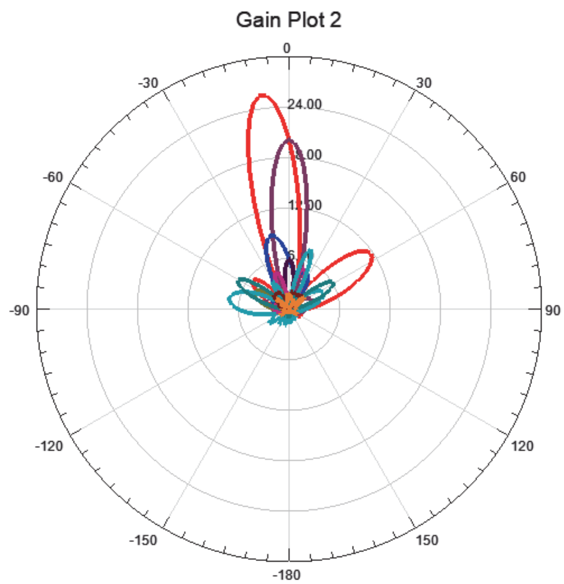


Figure 4. 2D-polar plot.

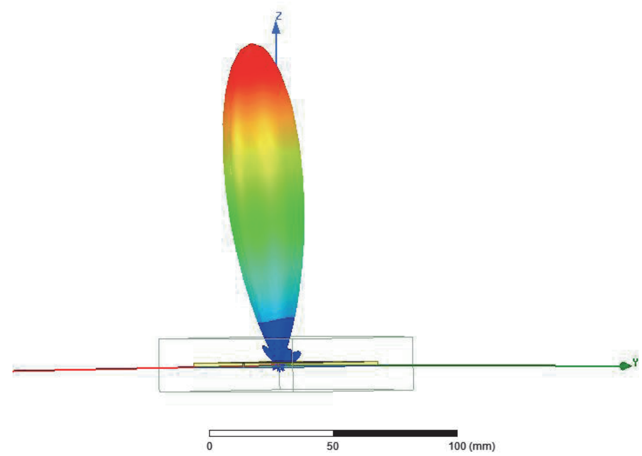


Figure 5. 3D-radiation pattern.

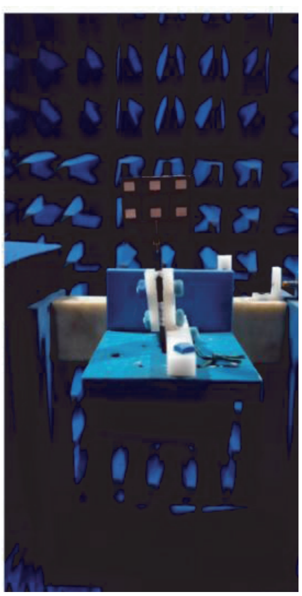


Figure 6. Anechoic chamber.

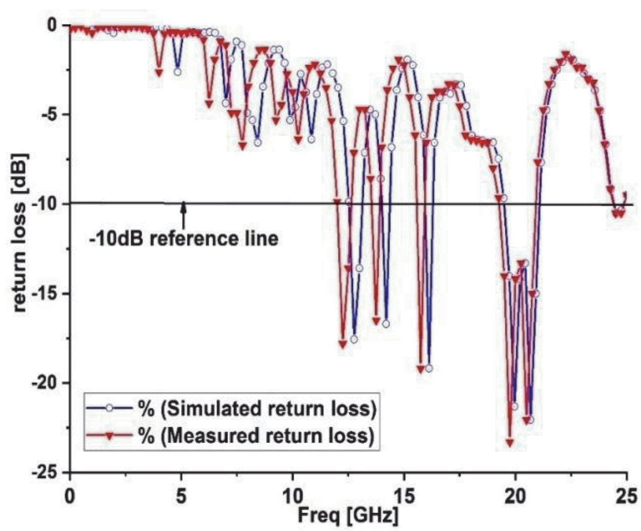


Figure 7. Return loss vs frequency plot of simulated and measured result.

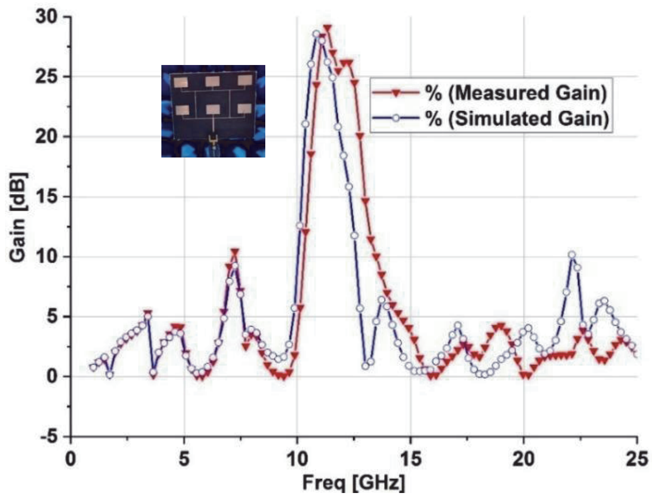


Figure 8. Gain vs frequency plot of simulated and measured result.

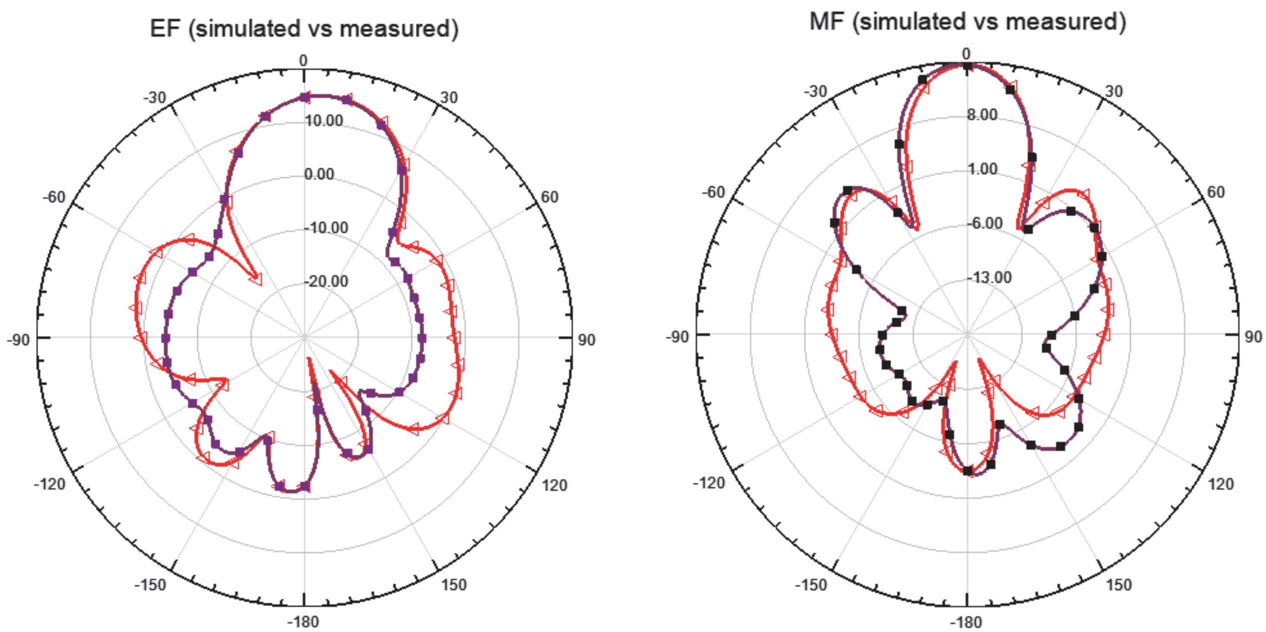


Figure 9. Simulated and measured 2D radiation pattern (electric field and magnetic field) plot.

2-D and 3-D representations of radiation pattern are shown in Figure 4 and Figure 5, which show pencil beam having maximum lobes known as 2D and 3D polar plots. The simulation results have provided a microstrip patch antenna (MPA) with negligible back lobes and has minimum side lobes, and highly directive beam is formed with maximum radiation.

To verify the performance of the microstrip array antenna, the 2×3 antenna is fabricated and tested as in Figure 6. The fabricated antenna shows the return loss of -17.5671 dB at 12.6 GHz and the gain of 29.0994 dB at 11.32 GHz, which are shown in Figure 7 and Figure 8, respectively. The simulated and measured 2D radiation patterns, i.e., electric field and magnetic field plots are shown in Figure 9. It shows the directive nature of the proposed antenna. The plot with triangular symbol is the simulated data while the square symbol represents the measured data.

Table 3 shown the comparison of the proposed antenna with some reference papers.

Table 3. Comparison of proposed antenna with some reference paper.

Reference	Array	S_{11} (dB)	Gain (dB)	material	Application
Ref.[19].	single	−31.0969	8.010	Roger RT5880	Wi-Fi, WiMax
Ref. [20].	single	−45	3.08	Fr4	WLAN
Ref. [19].	2 × 2	−40.4123	13.38	Roger RT 5880	Wi-Fi, WiMax
Ref. [20].	2 × 2	−14.5	7.2	Fr4	WLAN
Ref. [21].	2 × 2	−45.27	15.8	Fr4	satellite communication C-Band
Ref. [22].	4 × 1	−30.93	9.43	Fr4	wireless communication
Proposed antenna	2 × 3	−17.5671	29.09	RT duroid 5880	X band

5. CONCLUSION

The antenna has been designed with a six-element antenna array having high gain. The microstrip antenna arrays of improved size have been studied, and the gain, return loss, and radiation pattern are plotted. The frequency and gain plot has shown that at 11.32 GHz we have obtained the maximum gain of 29.0994 dB. The simulated return loss corresponding to the frequency 12.76 GHz is −17.5671 dB from which we have achieved the return loss of −22.0585 dB, −21.3097 dB at which antenna can resonate. Therefore, from the above simulation results we have fabricated the antenna, which correspond to the maximum gain of 29.0994 dB with the return loss of −17.5671 dB, which is a very high value. The array has improved the directivity and gain of the antenna for higher frequency band application.

ACKNOWLEDGMENT

The simulation, fabrication and measurement are done using software ANSYS^{TM} HFSS, LPKF Pro PCB (printed circuit board) machine and VNA (vector network analyser) respectively, at the Antenna lab, Department of Electronics, Banasthali Vidyapith, Rajasthan.

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