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Design of Microstrip Patch Antenna Array

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Abstract: Throughout the years there has been a crisis for low gain and efficiency in Microstrip patch antennas. Therefore, the microstrip patch antenna was designed for better gain, directivity and efficiency using array configuration of microstrip patch antenna with low dielectric constant at 10.3GHZ resonant frequency. The proposed design is of a triangular shaped patch array and a substrate RT duroid-5880 of dielectric constant 2.2. The results after simulation shows a good return loss, bandwidth around 950Mhz-1Ghz, directivity of 11.4db in a particular direction, gain of 11.4 dB with 99% radiation effect. The design proposed is helpful for applications like military defence and communication purposes.

Index Terms: Dielectric substrate, array, microstrip antenna, bandwidth, microstrip patch, Dielectric constant, Resonant frequency, Directivity, milli-meter wave bands.

1. Introduction

There have been issues coming up with the patch of the antenna and its large size and heavy weight of the antenna due to the material thickness applied to different patch shapes being circular, rectangular, square, triangular, elliptical etc. [1,2]. The antenna has been radiating I mts signals at different frequencies making it difficult to have its specified frequency on which it radiates efficiently. Different methodologies are being used to create an antenna according to the requirement of the applications [3]. This causes difficulty in operation of the antenna having less directivity. Authors have taken a few parameters into consideration and successfully designed an Antenna Array with the combinations of different specifications for developing a directional Antenna Array with directivity of 11.4db following with higher gain and better efficiency. the substrate used is of less dielectric constant, helpful for mechanical and electrical stability [4,5].

Antenna which is fabricated using microstrip techniques on a printed circuit board is called a printed antenna or microstrip antenna.Its advantages include light weight, low profile and cost, portable, planar configuration, best suitable for array implementation with ease in integration and fabrication with microwave circuits.. Antennas are mainly judged upon their Impedance, bandwidth, Gain, Directivity, Radiation patterns, return loss and efficiency are the parameters based on which the antenna's performance is judged. The triangular shaped patch has a slight edge over other shapes as it reduces the side lobe levels from the radiation pattern and provides better parameters and efficiency operation [6].

Whereas, Inset feed method is known best as it is simple to implement and the impedance can be controlled through array which also helps in gain improvement considering different patch shapes being circular, rectangular, square, triangular, elliptical etc[7,8].

Above the substrate is a patch of the antenna which is coated of metal foil such as copper. Size of the microstrip patch has been a constant challenge over the years. Hence, the triangular patch antenna is more advantageous over other shapes according to the characteristics.

Dimensions: Width (single element) = 25mm, Length (single element) = 7mm, Thickness of the substrate = 3.2mm.

2. Related Work

2.1 Literature Review

Several works are available in the literature on designing Microstrip patch antenna.

Analyzing different situations for the resonant frequency of 28, 38, 54 GHz being considered where 28 GHz is mostly used resulting in the radiation efficiency not more than 98%. Observing these parameters Authors designed a microstrip patch antenna of rectangular shape at 26 GHz resonant frequency which gives high bandwidth, high gain, good reflection coefficient, and excellent antenna radiation efficiency using 5G millimeter wave bands providing high Multiple Input Multiple Output and offers high performance. The proposed work has improved bandwidth of 4.7 GHz and return loss of -57 dB at 28 GHz resonant frequency. RT duroid as the die-electric substance has been used as the lower dielectric substrate gives high efficiency and better bandwidth. The Authors have designed a microstrip rectangular patch antenna and successfully implemented it at the resonance frequency of 26 GHz using FEKO software which is more reliable to design and consisting the capability of viewing high-quality results especially 3D radiation patterns than other antenna design software. The rectangular Microstrip patch antenna has a higher gain of 10 dB for good signal strength, increased bandwidth of 3.49 GHz for high-quality e-learning or teaching application. Furthermore, we can download and upload other 4K/8K ultra-high definition content and other 5G applications, with a better and good return loss of – 33.4 dB, voltage standing wave ratio of 1.04 and finally higher antenna radiation efficiency of 99.5% is observed.

Equilateral Triangular Microstrip Antenna for circular polarization dual-band operation. The characteristic of a two-layer triangular patch antenna is examined on an equilateral triangular microstrip antenna. At frequencies 3 and 3.5 GHz, the two-layer triangular patch radiates maximum power, VSWR, return loss. The proposed antenna comprises a triangular planar patch element embedded with two spur line slots. The targeting frequency of this antenna is 0.90 GHz (first resonant frequency) and 1.80 GHz (second resonant frequency). It is seen that the return loss of - 16.176 dB, bandwidth of 33 MHz (0.919 GHz to 0.952 GHz), and a gain of 3.52 dB first resonant frequency. At the second frequency, the return loss is - 28.159 dB with a bandwidth of 115 MHz (1.714 GHz to 1.829 GHz) and a gain of 3.380 dB. The return loss is a measure of impedance matching around -12dB. Enhancing the different characteristics such as radiation pattern, bandwidth, return loss, V.S.W.R, etc. The result demonstrated that the radiation properties of triangular antennas have better properties than other antenna shapes.

Researchers reported that patch antenna arrays can be improved for better gains over the single element. The patch can be of any shape, It was found that the triangular patch antenna array allows better sidelobe suppression than the rectangular patch antenna array, especially in the 4x1 array however it produces a high parasitic effect at the edge of the antenna. A microstrip rectangular single patch antenna and a microstrip rectangular 4x1 patch array antenna were proposed using the inset-fed feeding technique. The antennas were designed at 2.5 GHz, simulated, and fabricated to validate the work. The performance of both antennas was measured and compared with simulations and the microstrip rectangular inset-fed of 4x1 patch array antenna had successfully achieved the gain improvement of 4.88 dB and directivity of 9.69 dB compared to the single patch antenna gain of 1.25 dB and directivity of 7.25 dB.

A microstrip-fed antenna offers better isolation between the feed and the material under measurement compared to the microstrip-fed microstrip antenna. They are more flexible in integration with other active and passive devices in a hybrid MIC and MMIC design. The main reason for using microstrip patches is the ability to construct array antennas with the feed network and the radiating elements on a single surface. The four feeding techniques available to us are line feed, probe feed, aperture coupled feed, and proximity coupled feed. By using different shapes of slots, we can improve the efficiency of an antenna as compared to a conventional microstrip patch antenna. Specifically inserting a proper shape slot will enhance the gain, bandwidth, and reduction in the size of microstrip patch antennas. It also helps to achieve the multiband operation with considerable gain and bandwidth. Using a slotted microstrip, the antenna can be used in various applications.

Wideband antennas can resonate over larger frequency bands, but it limits the impedance bandwidth and gain. This leads to the development of the solution which is proposed as compact multi-band antennas. They offered a triangular microstrip patch antenna for bands running in multiple frequencies ranges like 2 to 4 GHz, bands having a density of 4 to 8 GHz, and bands operating in 8 to 12 GHz applications designed and developed. The proposed antenna has satisfactory results regarding co and cross-polarization. The proposed antenna yields better return and gain by resonating at 3.5 GHz (Wi-MAX), 4.1 GHz (Downlink satellite communication), 5.6 GHz (WLAN), and 9.7 GHz (Radar systems).

2.2 Conclusion

Theoretical survey on microstrip patch antenna has been done in this chapter. While designing the antenna the things to be considered are the substrate of which material is used, feeding technique, dielectric constant of the substrate and its height and width. When the substrate from the ceramic family is used then it gives the low microwave loss and also good insulation at high temperature. Array configuration could improve the gain and directivity while bandwidth depends on the thickness of the substrate. The thicker it is the better would be the Bandwidth.Particular microstrip patch antennas can be designed for specific applications and it is believed that the small size antenna will continue to benefit the human race for future years.

3. Design Methodology

The radiation of triangular antennas has better properties than other antenna shapes [1]. A single patch of triangular antennas was designed using Ansys software R2. During the process, we have experimented with few changes in dimensions and observed the best possible outcome that has least input impedance along with its simulation for single patch with feeding line input.

The operating frequency (fr), dielectric constant and height of the dielectric substrate are the essential parameters of this design.

In order to design a triangular patch, we have primarily designed a rectangular shaped patch of same resonant frequency (fr). Then we have designed a triangular patch by removing the excess patch from the existing rectangular patch, where height is similar to that of the breadth of the rectangle antenna following the width.

Design of Rectangular Microstrip patch antenna:

1. From equation below we calculate W:

$$W = \frac{1}{2fr\sqrt{\mu_0\varepsilon_0}}\sqrt{\frac{2}{\varepsilon_r+1}}\frac{1}{2fr\sqrt{\mu_0\varepsilon_0}}\sqrt{\frac{2}{\varepsilon_r+1}} = \frac{v_0}{2fr}\frac{v_0}{2fr}\sqrt{\frac{2}{\varepsilon_r+1}}\sqrt{\frac{2}{\varepsilon_r+1}} \quad (1)$$

2. Calculation dimensions of the ground plane.

$$\lambda_{eff} = \frac{v_0}{fr}\sqrt{\varepsilon_{reff}} \quad (2)$$

Length $\geq \frac{\lambda_{eff}}{4} \times 2 + L$

Width $\geq \frac{\lambda_{eff}}{4} \times 2 + L$

3. The feeding method is now via an inset feed technique.

Width of the transmission line:

$$Z_0 = \frac{120\pi}{\sqrt{\varepsilon_{reff}}\left[1.393 + \frac{W}{h} + \frac{2}{3}ln\left(\frac{W}{h} + 1.444\right)\right]} \quad (3)$$

Length of transmission line :

$$R_{in(y=y0)} = R_{in(y=0)}cos^2\left(\frac{\pi}{L}yo\right) \quad (4)$$

$$\text{Inset feed line gap(g)} = \frac{4.6\times10^{-14}}{0.99099}\frac{c}{\sqrt{2\varepsilon_{reff}\times fr\times10^{-9}}} \quad (5)$$

4. Calculation of operating frequency

$$fr = \frac{v_0}{2a\sqrt{\varepsilon_r}} \quad (6)$$

Where

v_0 = speed of light in space

a = side of a triangle

ε_r is dielectric constant

3.1 Single element

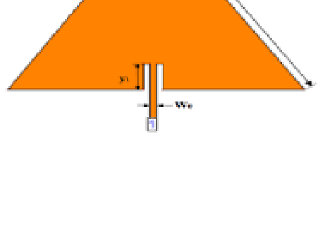


Fig. 1. Triangular patch antenna.

Dimensions of triangular patch:

Length(X-axis): 7mm,
Width (Y-axis): 25mm.

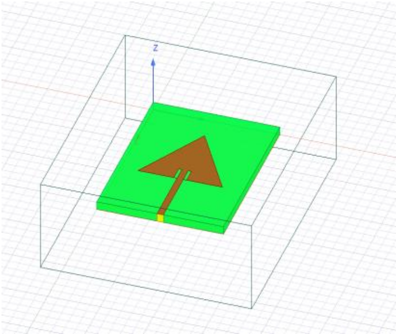


Fig. 2. Single Element MPA Model.

The Position of the triangular patch given in the Ansys Software is (0.5mm,0.5mm, 3.2mm).

The resonant frequency fr and bandwidth BW of the antenna depends on the thickness of the dielectric substrate 'h'. Dielectric substrate (RT Duroid 5880) with dielectric constant 2.2 and thickness 3.2 mm and operating frequency of 10.3 GHz is carefully chosen for designing a microstrip patch antenna to increase the contextual low efficiency gain, low substrate so that bandwidth increases. Though a high electric constant may cause degradation of other parameters but more importantly reduces the size. Whereas, feeding technique inset feed method is applied as it is simple to implement and the impedance can be controlled by the inset. If there is no proper feeding the total efficiency gets affected. It may be reduced to some low level resulting in the rejection of the entire system.

3.2 Implementation of the Array

The Array configuration of single patch antenna is formed by duplicating the existing antenna which enhances the performance by improving the gain, directivity and bandwidth with some other parameters. Each element is separated by a particular distance (λ /2) to eliminate interference of the EM waves radiated from different elements, else with less the gain would be reduced.

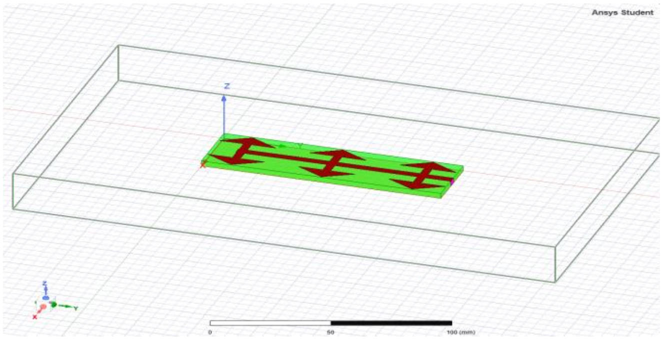


Fig. 3. Design Model of MPA array.

Table 1. Dimensions of elements of MPA

S.no	Dimensions				
		X-Size (mm)	Y-size (mm)	Z-Size (mm)	Starting position in (mm)
1	Ground	30	106	0	(0,0,0)
2	Substrate	30	106	3.2	(0,0,0)
3	Feed	3.48	106	3.2	(13.26, 106, 0)

In the above given table consisting of Ground, substrate and Feed. All the sizes used for fabrication are displayed in mm measurements for different dimensions and position. We can observe, the starting position of feed with the measurement of (13.26, 106, 0), the Y-size dimension for all the elements have been used as similar to eachother following with equal Z-size dimensions for Substrate and Feed.

4. Simulation Result and Analysis

4.1 Gain

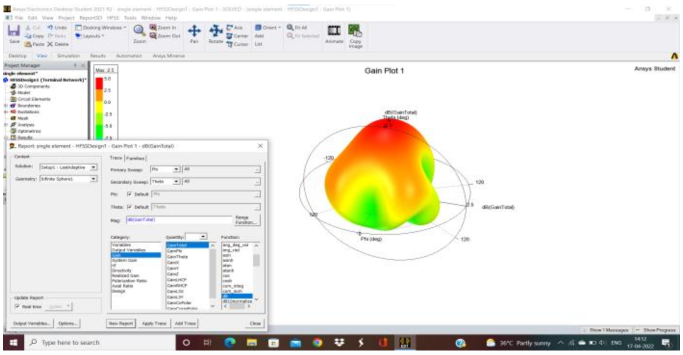


Fig. 4. Gain plot of single element MPA.

In the given fig.4 Single patch having gain 2.5dB with many lobes is resulting an unacceptable gain.

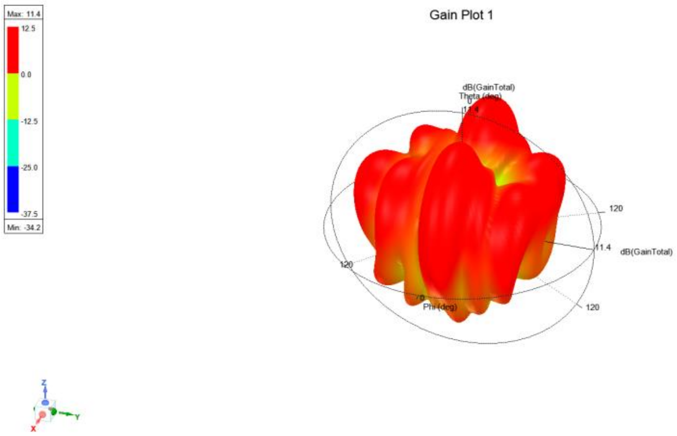
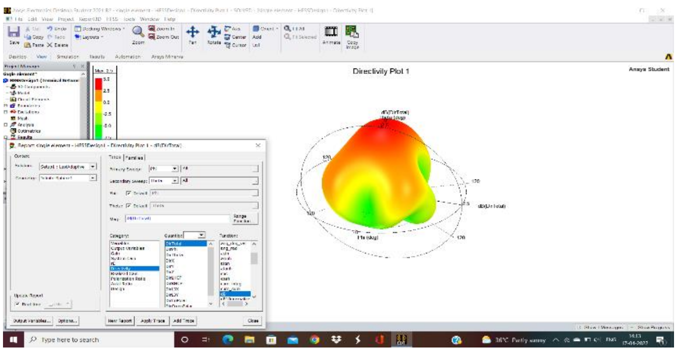


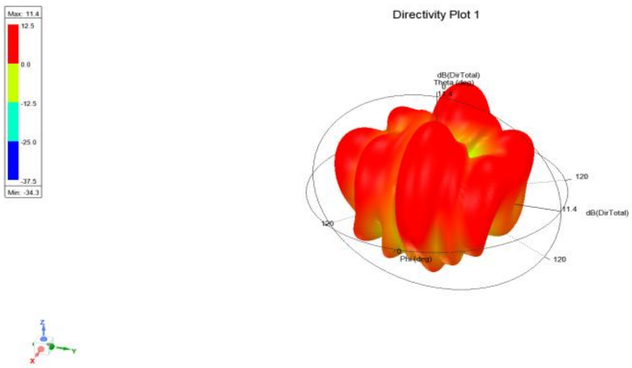
Fig. 5. Gain plot of MPA array.

In array, side lobes were reduced drastically. The gain improved to 11.4dB.

4.2 Directivity



(a)



(b)

Fig. 6. (a)Directivity plot of single element MPA, (b)Directivity Plot1 of MPA Array.

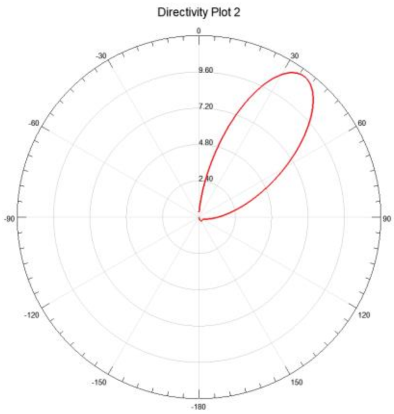
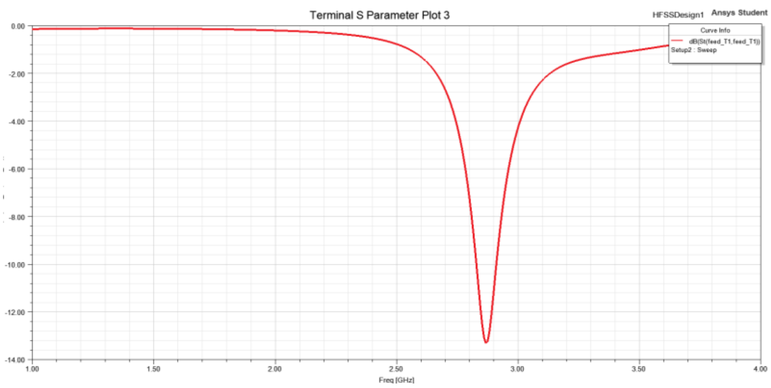


Fig. 7. Directivity plot2 of MPA Array.

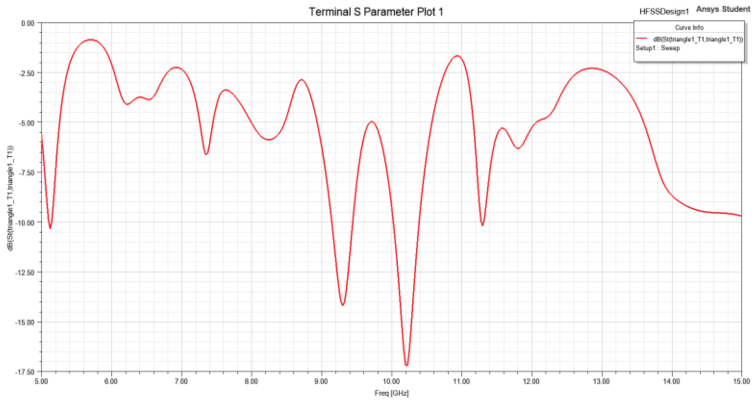
As it is a directional antenna, directivity and radiation intensity in the given direction is 11.4db.

4.3 S Parameter (Return loss)

Single element antenna working at the frequency of 2.85GHz and in the figure 9 there are found to be multiple dips. The maximum dip occurred at 10.3GhHz (operation frequency). Well, the antenna array has the capability to work at multiple frequencies but is most efficient where max dip occurs.



(a)



(b)

Fig. 8. (a)Return loss of single element MPA, (b)Return loss of MPA Array.

4.4 Hardware Fabrication and Testing

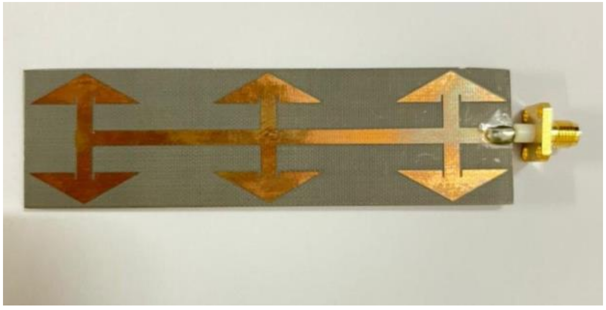


Fig. 9. Hardware of MPA.

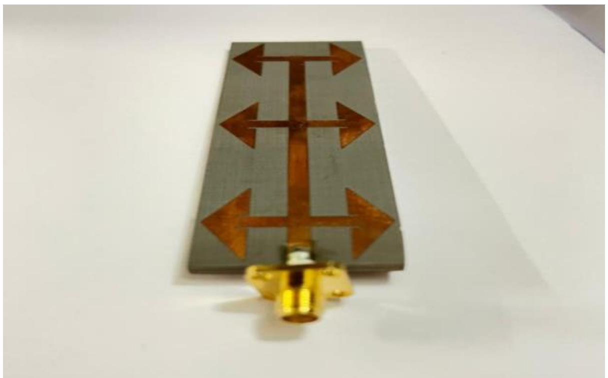


Fig. 10. SMA connector soldered to MPA.

SMA connector is soldered at input feeding point as shown in figure 10 &11,

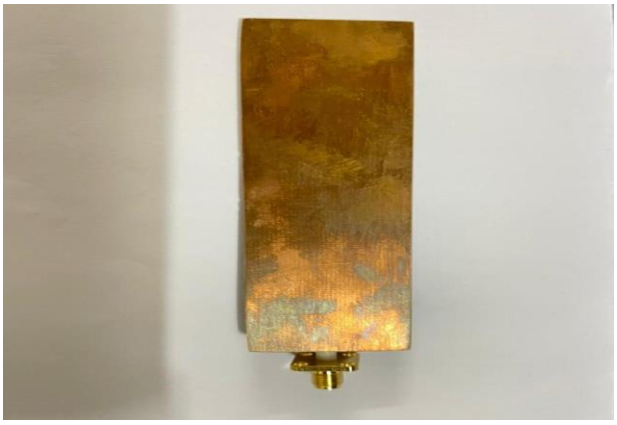


Fig. 11. Ground of MPA.

In the above figure 11. The MPA hardware has been affected with corrosion due to changes in atmospheric temperature.

The design was fabricated and was sent for testing in Osmania University, Hyderabad, Telangana.

4.5 Testing

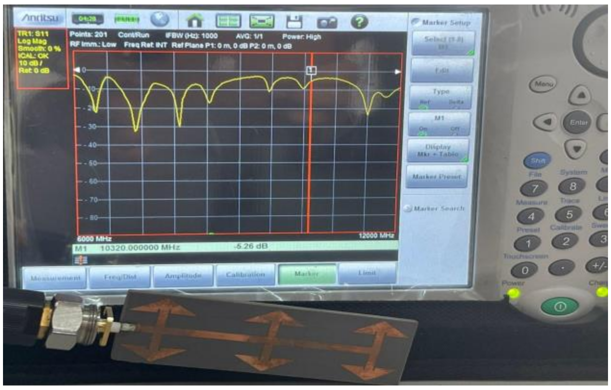


Fig. 12. Testing of return loss

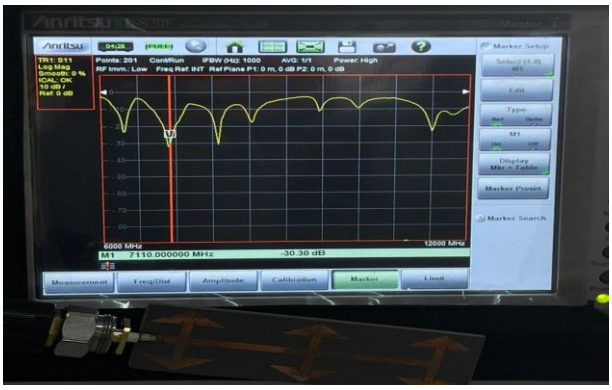


Fig. 13. Return loss deviation

5. Conclusions

While designing the antenna the things to be considered are the substrate used, feeding technique, the height and dielectric constant of the substrate. When the substrate of lower dielectric constant is used it results in good insulation at high temperature and also low microwave losses following efficiency of 99.5%. For specific applications particular antenna patches can be designed and reducing its size further benefits the human race for future years. Its applications include Military defence for detection of targets. The antennas operating in X band provide spectral efficiency, lower chance of interference, less rain fading, greater satellite separation and lower noise. Hence it is reliable for higher speed data and low noise data communication and can handle higher power.

The S-parameter plot (return loss) was tested to find out the operating frequency. But due to corrosion of the patch which was made of copper there were certain calibration errors around 2.5% - 5% compared to simulation results, which caused deviations in the performance of the Antenna array.

6. Future Suggestions

The future scope of this design is that it can be further extended up to 10x10 or even 15x15 matching the ganin required and replacing large size dish antennas with patch antennas of small size. Once the gain is achieved experiment can be done for replacing existing dishes with that of the patch array. It will also reduce the cost and space occupied. The Fabricated antenna got corroded and the deviation was seen in its performance. So, the techniques which resist corrosion can aldo be integrated /implemented to protect the copper patch of the antenna array. Moreover, in future the small size patches (array) cqan take the place of large dish antennas at the said operating frequencies.

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