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Design and Analysis of Microstrip Patch Antenna using Inset Feed Method for X-Band Application

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Abstract:- A Microstrip patch antenna has been proposed and designed for X-band communication due to its compact size, and low weight by using inset line feeding techniques. A resonant frequency used is 9.5 GHz which is between (8GHz-12GHz) which is for X band frequency space. Selecting a suitable substrate for dielectric materials can enhance the antenna performance for the next generation of space communication. In this paper Rogers RO3004C substrate is used having a dielectric constant of 3.55 and thickness of 1.5 mm is used as a substrate material for the designing of the proposed antenna. The different parameters are calculated and analyzed such as return loss, VSWR (Voltage standing wave ratio), radiation pattern, bandwidth, and S-parameter magnitude of the antenna are estimated using CST microwave studio software. The proposed microstrip antenna is having the main aim of x-band satellite applications, weather forecasting, medical purposes, and even military systems like radars, aircraft missiles.

Keywords: *Microstrip, 9.5 GHz, X band, inset feed, satellite Communication, CST microwave studio, high gain.*

1. Introduction

In today's era of technology, connectivity has played a crucial role as it connects with our lives. Microstrip Patch antenna miniaturization helps for the great design of microstrip patch antenna. Many improvements have been made to quality antennas, by designing MPAs such as lightweight, lower profile, and lower volume, fabrication, and compatibility [1]. The Special areas where wired connectivity is still not reachable, those areas still rely on wireless technology to reach. For IOT devices, IoT gateways, and other communication [2]. Nowadays wideband antennas and multiband antennas are used widely in place of different antennas used for different tasks. The rapid growth of mobile systems towards 5G technology requires Multiband, wideband, and UWB antennas [3]. The MPA design requires the selection of the parameters of both the substrate and the shape and the shape of the patch [4]. The following design is for 8 GHZ-12GHz. for space technology. This is suitable for the X band; having frequencies has an advantage that is less affected by rain [5]. MPA structure requires a metallic radiating patch implanted on a grounded dielectric substrate [6]. Microstrip patch antennas are used to show favorable satellite communication and improve the invulnerability to multipath mutilation to reduce multipath mutilation. Different shapes and sizes of microstrip antennas with different feeding techniques have been developed [7]. The demand for small and broadband antennas has greatly in demand for small and broadband antennas [8]. An MPA for satellite application is proposed by using inset feed technology. The antenna design has a planar rectangular geometry with an inset feed and symmetric losses. Miniaturization of an antenna is an essential task in achieving optimal design for wireless communication. Fractal geometry is also one of the techniques to compact the design of MPA [9]. The design is simulated for different characteristics such as voltage standing wave ratio, field distribution, gain, radiation pattern, and return losses. MPAs gain high demand in navigation, communication, meteorological, geospatial, space based asset navigation, communication, meteorological, and imagery services, and early warning detection. When ground-based means are not reachable MPAs make their availability necessary. When communication is not possible then MPAs make it possible, reliable, or available. Satellites are in great demand in the ability of the state to respond [10]. X-band stands for extended band which is generally known as AM broadcast band. For the super high frequency spectrum which is designated by ITU, the X band performs its operation. The frequency band assigned for ITU is in the range of 7.25 GHz to 7.75 GHz for downlink frequency that is from space to earth and 7.9 GHz to 8.4 GHz for uplink frequency that is from earth to space for government use. The X band is overcoming other bands by having the advantage that it is less affected by rain fade and provides higher rain resilience compared to other higher frequency bands like Ku or ka used for satellite communication. A high link availability is allowed in this case. X band microstrip Patch antenna has a wide range of applications for space traffic control operations, terrestrial communication, and networking [11]. A fringing effect arises due to electric field lines which broadens the antenna size after excitation. A low dielectric thick substrate is suitable for good antenna performance because it gives a wide bandwidth and improved efficiency. But in such designs, the antenna size increases, so again a high dielectric constant substrate insert which has a narrow bandwidth and is less efficient. Hence a proper tradeoff must be performed at the design stage to realize an antenna performance efficiency at a particular operating frequency and constrained physical dimensions [12]. Due to short-range features and high transmission line, this band is quite important to study [13]. Radar antennas play an important role in defense as well as surveillance and battle a state [14]. Table I shows the parameters and material used for the designing of inset feed MPA.

Satellite use nowadays is increasing and impressively significant because of the following factors

(i) The antenna's bandwidth and radiation efficiency are effected by the substrates dielectric constant

(ii) The substrate thickness has more effectiveness to the bandwidth and coupling levels of the designs.

(iii) Shapes of the MPA affect the bandwidth and radiation pattern.

Table I. Parameters and material used for designing of inset feed MPA

Parameters	Material Name
Microstrip Line	Copper
Patch	Copper
Substrate	Dielectric Substrate Materials Rogers RO4003C
Ground Plane	Copper

The dielectric materials have different ranges of dielectric constant and loss tangent constant (dissipation factor). The selection of dielectric material plays a crucial role; electrical potential energy is dissipated in all dielectric materials usually in the form of heat. Table II below shows the dielectric material used and their dielectric constant. Table II is the list of dielectric materials used in the research and their dielectric constants.

Table II. List of dielectric Materials used in the research and their dielectric constants

Dielectric Material	Dielectric constant
FR4, Glass Epoxy, substrate	4.3
RT Duroid 5880	2.2
Arlon 255	2.5
Taconic RF 35P	3.5

Dielectric Material	Dielectric constant
Rogers RO3004C	3.55
PTFE	2.1
Polypropylene	2.18
Teflon glass	2.55
Teflon Quartz	2.47
Nylon Fabric	3.6
Rogers 4350	3.48
Arlon 255	2.55

2. Designing Process of Microstrip Patch Antenna

MPA is a crucially open resonator. Mounted above the ground plane and field space in between the patch antenna and ground plane determines a set of Eigen modes. When the mode is excited Antenna can radiate strongly just like other resonant structures, and the frequency of operation is easily tuned by adjusting the length and width of the patch antenna. After the design of the monopole and dipole, microstrip patch antennas are the easiest to design. In the UWB radar system, the microstrip antenna plays a crucial role. So microstrip UWB microwave antennas are developed. The antenna polarization is determined when the radiation of the wave is similar in a specific direction.

First, we have an effective dielectric constant for a given PCB substrate Dk value which then determines the width and length of the patch for a given operating frequency.

1. Specifying the frequency of operation (f_0)
2. Calculate the Patch width (W) using the substrate dielectric constant (Dk) and thickness (h)
3. Calculation of Length of patch and width of patch
4. Select feeding method
5. Determine the feed location.

The antenna is fed through a microstrip inset feed line. Feeding the edge is not practical, the edge impedance of the patch is very high. Approximately one-third of the total length of the antennas an inset is made and then the feed is inserted. As we go to the inner side of the patch, the patch impedance decreases. And it's about one-third the length of the antenna impedance is approximately 50 ohms. There are numerous other feeding techniques like probe feeding, proximity-coupled feeding, aperture-coupled feeding, etc. Fig 1 shows the microstrip patch antenna design.

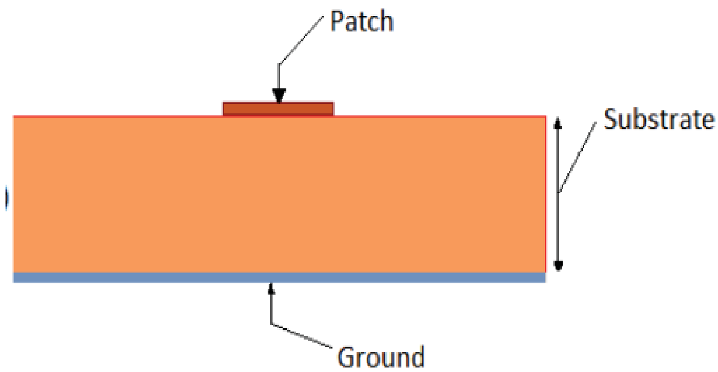

Fig 1: Microstrip Patch Antenna

The following equations are used for the calculation of the parameters of the microstrip patch antenna.

1. Width of patch
2. Length of patch
3. Width of substrate
4. Length of substrate
5. Feeder Length and width

Width of Patch

$$\omega = \frac{c}{2f_0\sqrt{\frac{\varepsilon_r+1}{2}}} \tag{1}$$

Calculate the effective length of the Antenna

$$L = L\,eff - 2\Delta L \tag{2}$$

Calculate the Actual length of antenna

$$Leff = c\ /2fr\sqrt{}Ereff \tag{3}$$

The effective constant of the microstrip antenna from the equation

$$\varepsilon_{rff} = \frac{\varepsilon r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+12\frac{h}{w}\right]^{-\frac{1}{2}} \tag{4}$$

The patch length extension is obtained from

$$\Delta L = 0.412h\frac{(\varepsilon_{reff}+0.3)(\frac{W}{h}+0.264)}{(\varepsilon_{reff}-0.258)(\frac{W}{h}+0.8)} \tag{5}$$

Determination of inset feed depth: An inset-fed microstrip line feed is to be used in this design. Where the input impedance (Zo) is 50 ohms for resonant frequency, the feed point must be located at that point on the patch. The resonant input edge resistance (Zi) of the rectangular patch is calculated by using an online microstrip patch antenna calculator as Zi = 209.7 ohms [15]. Table III shows the calculated parameters for designing a microstrip patch antenna.

$$y_0 = \frac{L}{\pi}cos^{-1}\sqrt{\frac{Z_0}{Z_{in}}} \tag{6}$$

Table III. Calculated Parameters for designing Microstrip Patch Antenna

Name of parameter	Expression	Value
Length of Patch	Lp	7.8
Width of Patch	Wp	10.66
Length of substrate	Ls	16
Width of substrate	Ws	19
Thickness of substrate	Ts	1.524
Thickness copper	Tc	0.035
Length feeder	L_f	4.73
Length ground	Lg	16
Width Ground	Wg	19

3. Design of Microstrip Patch Antenna for X Band Application for 9.5 GHz in CST Microwave Studio

The key performance parameters for microstrip Patch antenna are reflection coefficient, bandwidth, VSWR, bandwidth, radiation pattern, and surface current, gain, input impedance, return loss, and polarization [16]. There is a wide range of availability. Transmission line model, Cavity model, Method of moments, FDTD method, Finite Element Method. The transmission line model is the simplest of these methods. The transmission line model and cavity model furnish good physical insight but it is difficult to model coupling. In the design first of all we select the patch length, width, substrate length width, and ground dimensions. Then designing the feedline width is the next step for the microstrip patch antenna. Different programming languages with graphical user interface (GUI) have been used to design a calculator for solving antenna equations and designing microstrip patch antenna structures [17,18,19].

Figure 2 shows the design of the feeder, fig 3 shows a mirror image of the transmission line, fig 4 shows the patch introduction of MPA, fig 5 shows the inset feed introduction in the patch of MPA, figure 6 shows inset feed in the patch by applying Boolean law, fig 7, fig 8 and fig 9 shows getting patch ready with inset patch, and creation of ports, Fig 10 shows calculating port extension coefficient, Fig 11 shows ports created for proposed MPA.

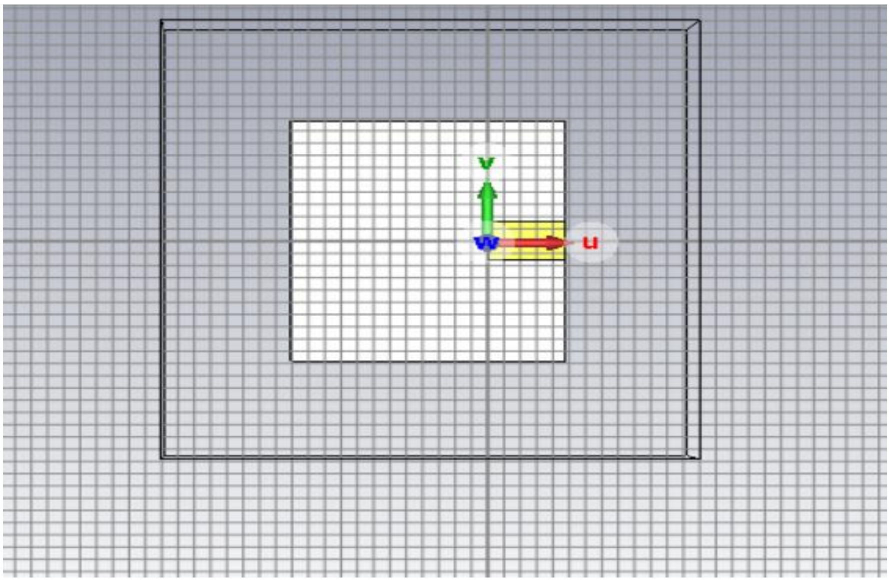

Fig 2: Design of feeder

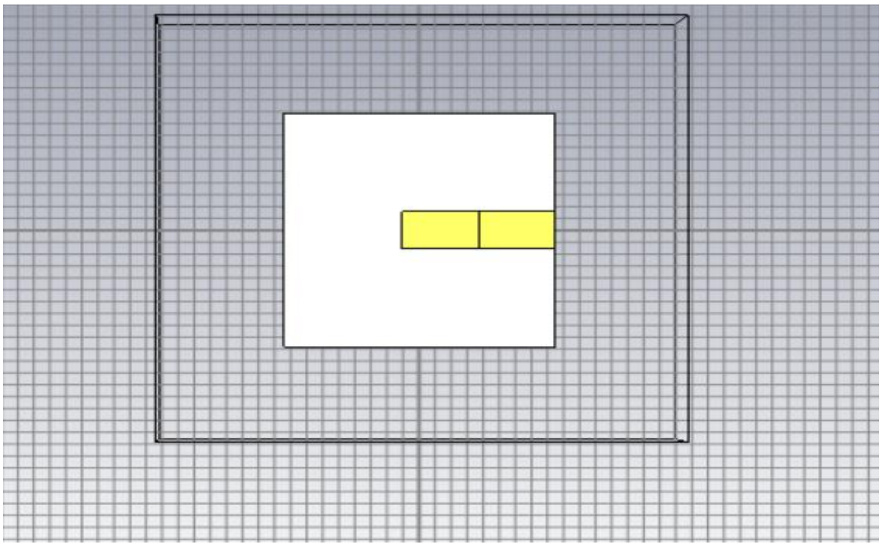

Fig 3. Getting a mirror image of the transmission line

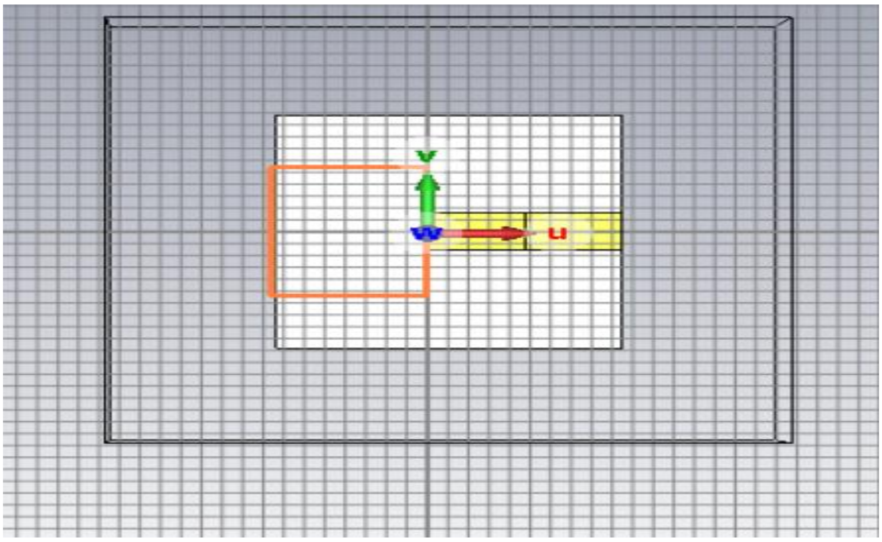

Fig 4. Introducing Patch of the Microstrip Patch Antenna

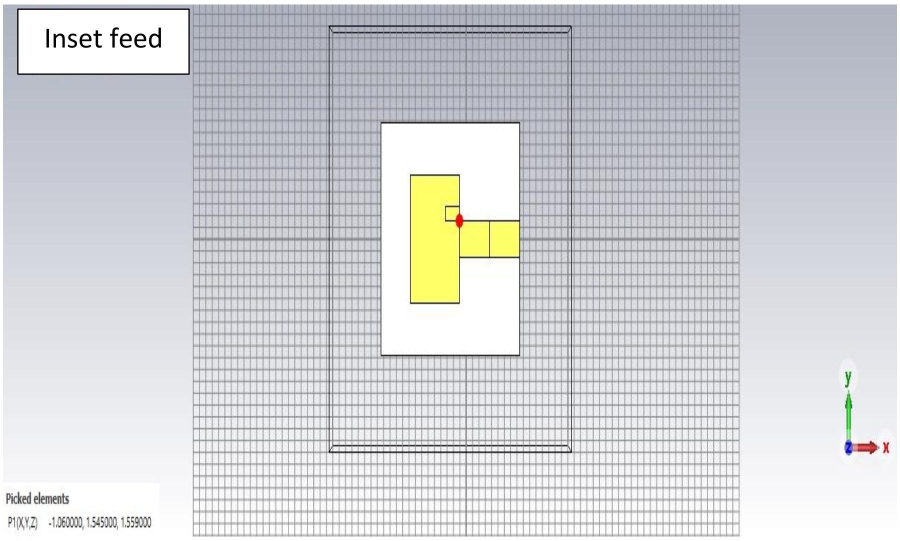

Fig. 5 Inserting Inset feed method

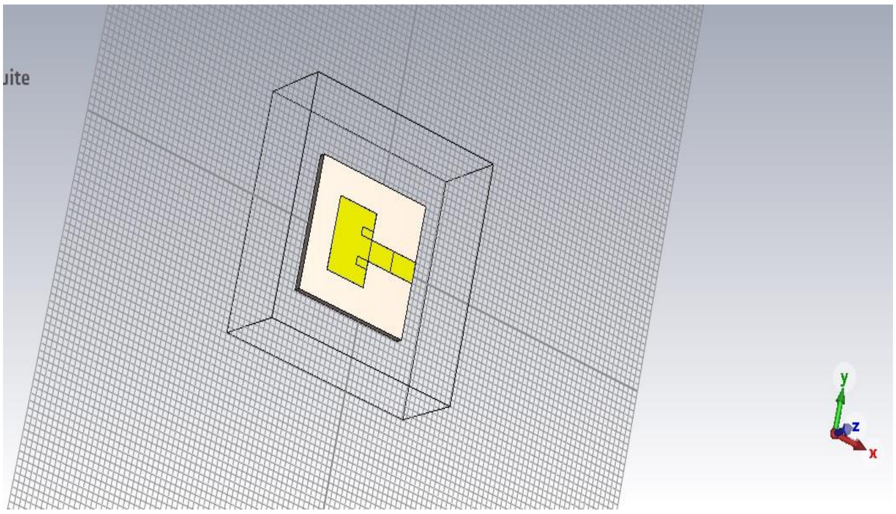

Fig. 6 Applying Boolean law on both inset feed

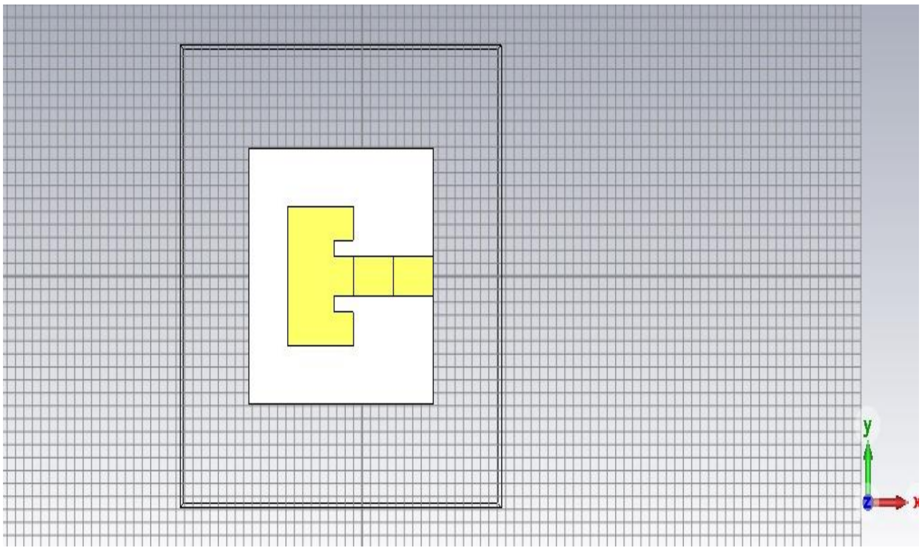

Fig. 7 Getting Patch with inset feed

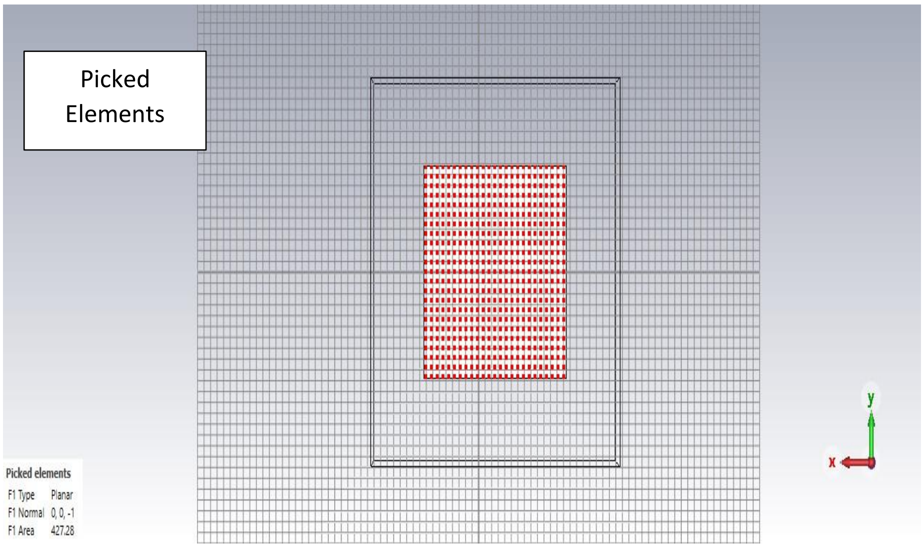

Fig. 8 Picked elements

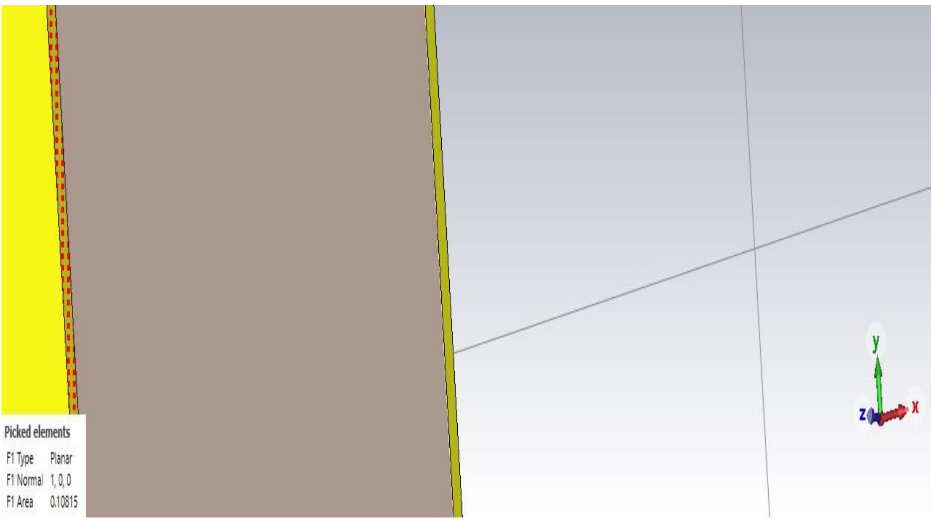

Fig 9. Creating port

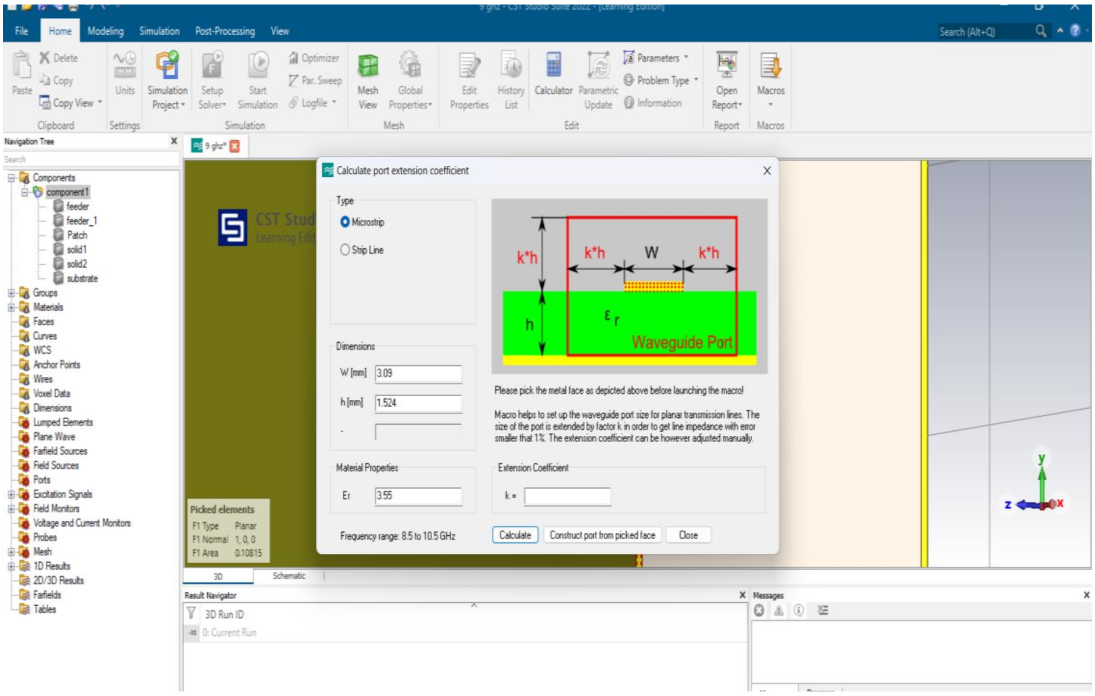

Fig 10. Calculating Port extension coefficient

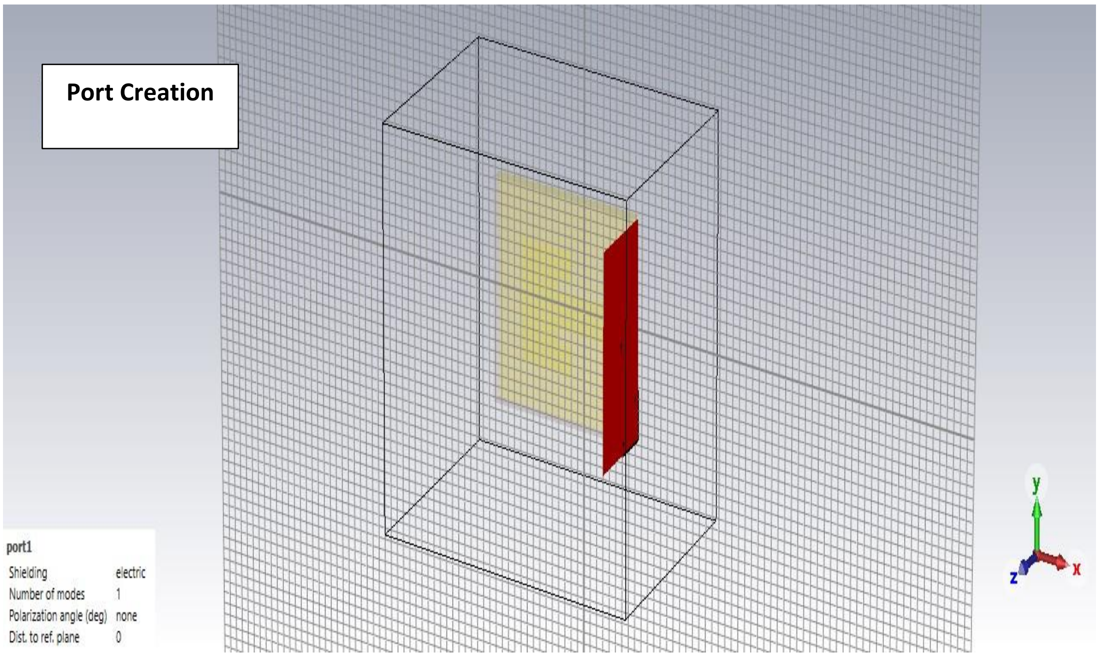

Fig 11. Port created for a microstrip patch antenna

(a) Reflection Coefficient

The reflection coefficient signifies how much of a wave is reflected by an impedance discontinuity in the transmission medium. Its value is equal to the amplitude of the reflected wave to the incident wave. The ratio of the complex amplitude of the reflected wave to that of the incident wave also gives the value of the reflection coefficient [15].

$$\Gamma = \frac{V^-}{V^+} \tag{7}$$

(b) VSWR calculation

Voltage standing wave ratio (VSWR) of the proposed X-Band antenna is defined as the ratio of Vmax to Vmin is infinite, then the reflection coefficient magnitude value is 1 which signifies that all power is reflected. It is also called the standing wave ratio which measures how well matched a transmission line is to the load. The value of VSWR is nearly 1 which is indicated by the graph. It is a required value. SWR is also used to describe the performance of an antenna when attached to a transmission line [14]. Fig 12 shows the VSWR for the X-band of inset feed proposed MPA.

$$VSWR = Vmax/Vmin \frac{1+|\Gamma|}{1-|\Gamma|} \tag{8}$$

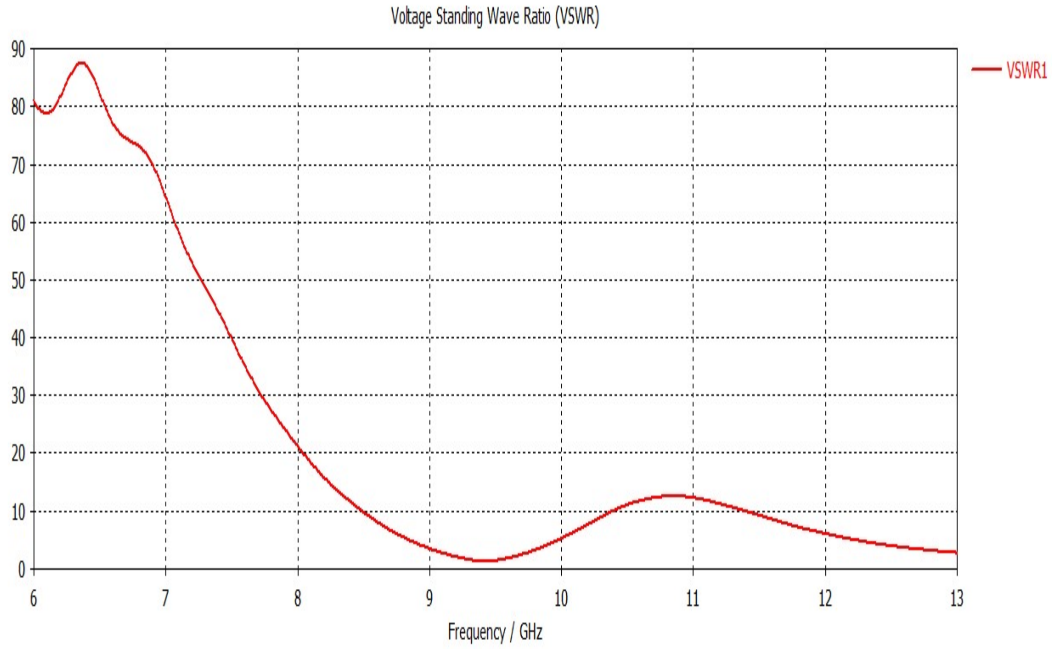

Fig 12. Graphical image of VSWR value obtained in the proposed MPA

This confers the value of the voltage standing wave ratio (VSWR) of the proposed antenna is 1 which is the desired value. Since the standard range of VSWR is 1-2. High VSWR may damage the antenna and decrease the antenna efficiency so it must be below 2.

(c) Radiation Efficiency

X-band MPA radiation pattern is a crucial parameter that expresses the ratio of total power radiated to the net power received by the antenna. The E-plane and H-plane at resonant frequencies 9.5 GHz. Radiation efficiency describes the radio frequency power accepted by the antenna at its terminal into radiated power. Hence this proposed antenna offers high radiation efficiency by greater than 90 %. The radiation efficiency is MPA is inversely proportional to the losses as $\eta = 1$ [5].

(d) S parameters

S parameters of an antenna are called scattering parameters which describe the electrical behavior of linear electrical networks when undergoing various steady-state stimuli by electrical signals. S parameters are also called dispersion parameters which describe the behavior of an antenna in a microwave circuit a set of complex numbers S11 represents the input port voltage reflection coefficient, S12 is the reverse voltage gain, S21 is forward voltage gain, and S22 is the output port voltage reflection coefficient. Return loss assesses power transfer efficiency in the antenna and transmission system. A return loss of -26 dB is obtained for the following microstrip patch antenna. Fig 13 shows the return loss plot for the proposed microstrip patch antenna [6].

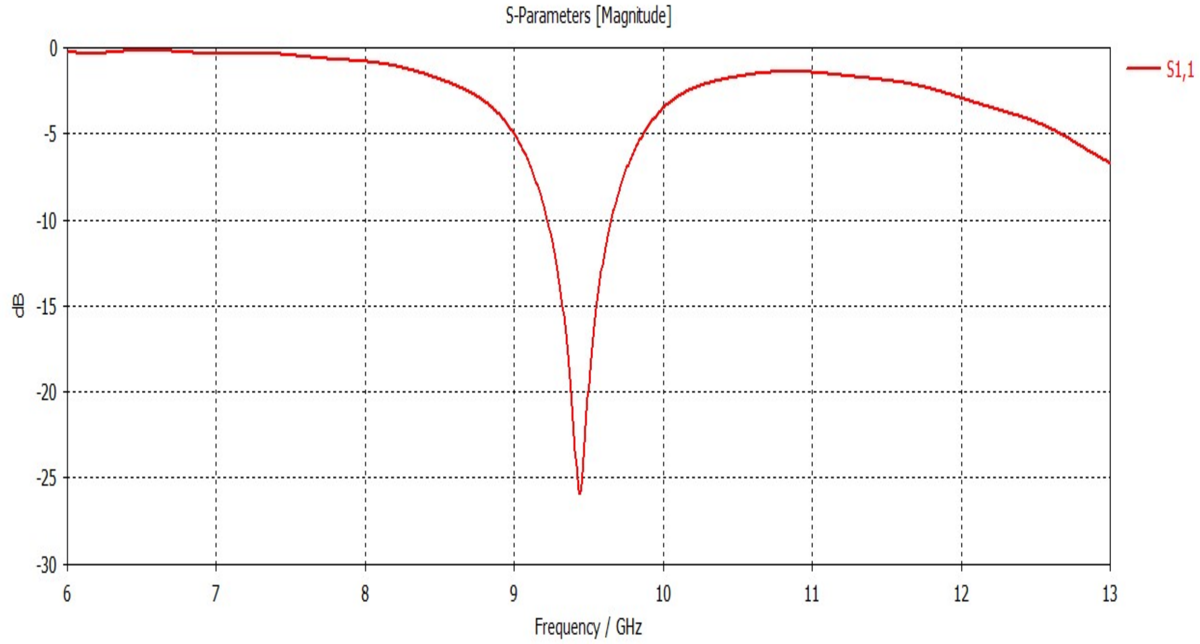

Fig 13. Graphical representation of Return Loss (S11)

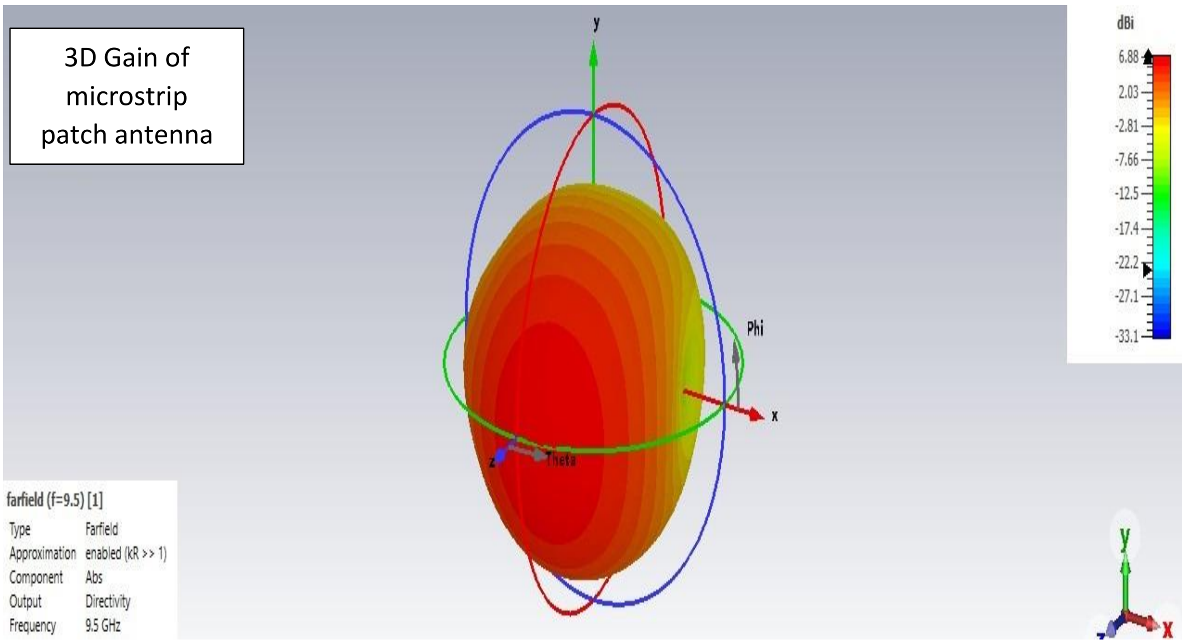

Fig 14. Pictorial image of 3D gain of microstrip patch antenna

Far-field Radiation patterns. The graphical representation of the field strength of radio waves in all directions is known as a radiation pattern. H and E plane represent the magnetic and electric field vector respectively; it also shows the direction of maximum radiation of the proposed antenna. The maximum gain for 9.5 GHz is 6.88 dBi. Fig 14 shows a pictorial image of the 3D gain of the microstrip patch antenna [10].

4. Conclusion

The microstrip patch antenna for the X-band comes under the frequency of 8 to 12 GHz and is designed using inset feed technology. The inset feed method is itself a challenging method for designing of microstrip patch antenna. The directivity calculated is 6.88 dBi which signifies a good value. The return loss S11 value for proposed MPA is -26 dB. The value of VSWR is nearly 1 which is indicated by the graphical representation, indicating a good value. The MPA operates in the X-band performs well in space technology, radar communication, satellite communication, etc. This design should be adopted for future use as a basis for adding improvements or performing various experiments on it.

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