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DESIGN AND ANALYSIS OF MICROSTRIP PATCH ANTENNA FOR SATELLITE COMMUNICATION

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ABSTRACT

A microstrip patch antenna for satellite communication is proposed in the paper. This paper designed and simulated a rectangular microstrip patch antenna measuring 25mm x 30mm x 1.6mm. The antenna has a frequency bandwidth of 0.1806 GHz (4.2831 GHz–4.4637 GHz) centered at 4.3 GHz with a return loss of -19.7936 dB. The proposed rectangular patch antenna has been devised using a glass epoxy substrate (FR4) with a dielectric constant (Ɛr = 4.4). The basic theory and design of the antenna are analyzed, simulated, and optimized using HFSS. The results explain that the antenna has characteristics for 4.3 GHz satellite communication. This rectangular patch is excited using transmission lines of length and width. Performance parameters of the antenna, such as gain, S parameters: voltage standing wave ratio, system gain, radiation efficiency, directivity, polarization ratio, S parameter chart, VSWR chart, S parameter table, and VSWR table of the designed rectangular antenna.

Keywords : ANSYS HFSS (high-frequency structure simulator), FSS (Fixed Satellite Service), MSS (Mobile Satellite Service), VSWR (Voltage Standing Wave Ratio), RPA (Rectangular Patch Antenna), RF (Radio Frequency),
rE (Radiation Efficiency), S-Parameters (Scattering Parameters).

1.0 INTRODUCTION

Antennas are vital parts of any wireless communication network. Their ability to transform any kind of signal into waves that can be wirelessly and across a greater distance. Transmitted signals are received via a signal-receiving antenna. The electromagnetic waves are used to transport the data or information. These electromagnetic waves are transformed into a signal or voltage that is sent as input to the other end of a communication system by the reciprocal process of the reception antenna. The provision of radiation characteristics is the antenna's primary duty. This is defined by the transmission line. A transmission line is a straight line with an infinite length that does not radiate power and transmits current at a constant speed.

A printed antenna that is most used is the micro-strip patch. It plays a significant role in systems for wireless communication. A micro-strip antenna is simple to fabricate. This antenna's structure includes the radiating patch, substrate, and ground plane. Patch dimensions specify the antenna's radiating characteristic.

Length and width parameters are used for representing patches. The material used to make the substrate is FR4 epoxy. These materials are durable for a long range of frequencies. The frequency range used to excite and analyze antennas is 4.3 GHz.

1.1 OBJECTIVES

The main objectives of this paper are as follows:

- To develop a high-performance antenna for satellite communication, use a resonated frequency of 4.3 GHz.
- To obtain and optimize the return loss, VSWR, band width.
- To enhance the overall communication and data transmission capabilities of satellite communication.

1.2 NECESSITY OF THE DESIGN

A patch antenna is the most often used kind of microstrip antenna. It is also possible to create antennas that use patches as constituent elements within an array. An insulating dielectric substrate, like a printed circuit board, is attached to the antenna element pattern of a patch antenna, which is a narrowband, wide-beam antenna, by etching it. A continuous metal layer is bonded to the opposite side of the substrate, forming a ground plane. While square, rectangular, circular, and elliptical are the most common forms for microstrip antennas, any continuous shape can be used. Some patch antennas are constructed from a metal patch placed atop a ground plane utilizing dielectric spacers rather than a dielectric substrate; this results in a less durable structure.

Satellite Frequency Band Applications

Band spectrum	**Frequency range**	**Type of satellite service**
L Band	1.518-1.675 GHz	MSS (Mobile Satellite Service)
S Band	1.97 - 2.69 GHz	MSS
C Band	**3.4GHz - 7.025 GHz**	**FSS (Fixed Satellite Service)**
X Band	7.25 - 8.44 GHz	FSS

In the electromagnetic spectrum, the 4GHz–8GHz frequency region reserved for satellite communications is referred to as the "C-band." C-band satellite antennas are commonly used in regions of the world where heavy rain or other harsh weather conditions might impair communications. C-band satellite antennas are typically between 1.8 and 2.4 meters in size. Rain attenuation has less of an impact on C-band satellite communications, even though they are mostly used in Asia, Africa, and Latin America and require larger antennas.

Software prerequisite

The antenna design process is carried out using the ANSYS High Frequency Structure Simulator (HFSS) tool. It is a 3D simulation tool that may be used with antennas and antenna arrays, which are high frequency electronic components. This software program has global applications in wireless communication, Internet of things devices, radar applications, and satellite communication. It provides solutions for 3D EM design issues. comprehensive analysis and delivers accuracy that is assured. For a precise analysis, the parameters required to examine the antenna can be seen in 2D and 3D models.

1.3 DESIGN METHODOLOGY

1.3.1 Feeding Techniques

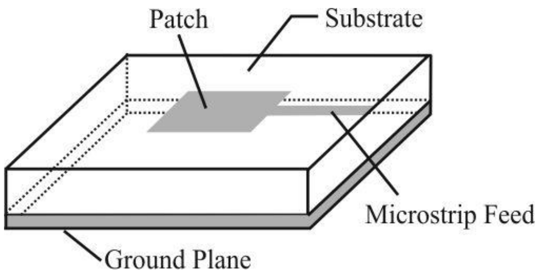


Fig.1 Microstrip Patch Antenna Feeding Techniques

The fundamental procedure (Fig. 1) for connecting the transmitter and receiving antennas so they may exchange information is called feeding. The feeding is produced within the same range since the antenna runs at a radio frequency. Radio frequency transmissions are used by the antennas to communicate with one another.

1.3.2 Edge Feed Technique

A feed line that joins the radiating patch with the substrate's external edge feed provides this feeding. The radiating patch and the feed element's width are less than one another thanks to the design.The edge of the microstrip patch is immediately attached to a conducting strip during this feeding operation. One advantage of this feeding approach is that it allows the conducting line to be carved on the patch antenna's substrate, giving it a planar shape. Comparing the conducting element to the patch antenna, the former has a narrower width.

1.3.3 Design Equation for Rectangular Patch Antenna

For use in a 4.3 GHz satellite communication application, a rectangular microstrip antenna was developed. The substrate used in the proposed rectangular patch antenna is FR4, with a height of 1.6 mm and a dielectric equal to $\varepsilon r = 4.4$. The frequency at which this microstrip antenna operates is 4.3 GHz. The following are the fundamental stages involved in creating a rectangular patch antenna (RPA):

A parameter Width of the radiating RPA is computed from this equation:

$$W = \frac{C}{2 f_o} \sqrt{\frac{2}{\varepsilon_r + 1}} \qquad (1)$$

Where:

C: Velocity of light, $3*10^8$ m/s,

ϵ_r: dielectric constant of the substrate.

f_o: resonant frequency of antenna

Effective Dielectric constant of the RPA is determined as:

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \left[\frac{1}{\sqrt{1 + \frac{2h}{W}}} \right] \qquad (2)$$

The effective length is specified at the resonance frequency.

$$L_{eff} = \frac{C}{2 fr \sqrt{\varepsilon_{eff}}} \qquad (3)$$

Extension length of the RPA compute with this equation

$$\Delta L = h \times 0.412 \times \frac{(\varepsilon_{eff} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{eff} - 0.258)\left(\frac{W}{h} + 0.8\right)} \qquad (4)$$

The length " L" of the RPA is calculated as:

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

The proposed rectangular patch antenna is designed using electromagnetism simulation software HFSS.

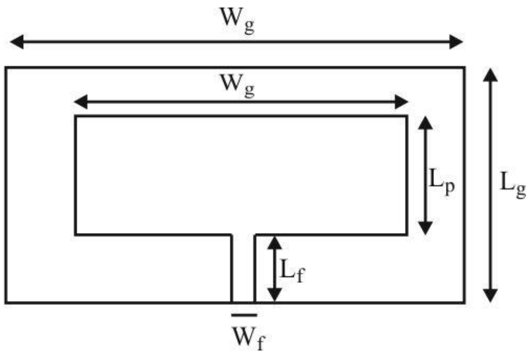


Fig.2 Schematic of Antenna Design

1.3.4 Design Calculation For Microstrip Patch Antenna For 4.3 GHz.

C = 3 x 10^8
ε_r = 4.4 FR_4
h = 1.6 mm
f_o = 4.3 GHz. = 4.3 x 10^9 Hz

Width of Patch

$$\omega = \frac{C}{2 f_o \sqrt{\frac{\varepsilon_r + 1}{2}}}$$

$$= \frac{3\times10^8}{2\times4.3\times10^9 \sqrt{\frac{4.4+1}{2}}}$$

$$= 21.2304$$

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1+12\left(\frac{h}{w}\right)\right]^{-1/2}$$

$$= \frac{4.4+1}{2} + \frac{4.4-1}{2}\left[1+12\left(\frac{1.6}{21.23}\right)\right]^{-1/2}$$

ε_{eff} = 3.93192

$$L_{eff} = \frac{C}{2 f_o \sqrt{\varepsilon_{eff}}} = \frac{3\times10^8}{2\times4.3\times10^9\sqrt{3.93192}}$$

= 17.5922 mm

$$\Delta L = \frac{0.412h\left(\varepsilon_{eff}+0.3\right)\left(\frac{W}{h}+0.264\right)}{\left(\varepsilon_{eff}-0.258\right)\left(\frac{W}{h}+0.8\right)}$$

$$= \frac{0.412\times1.6\left(3.93192+0.3\right)\left(\frac{21.23}{1.6}+0.264\right)}{\left(3.93192-0.258\right)\left(\frac{21.23}{1.6}+0.8\right)}$$

ΔL = 0.7303911

Length of Patch

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

$= 17.59 – 2(0.7303911)$

$L = 16.12922$

Width of Substrate

$\omega s = 6h + \omega$

$= 6(1.6) + 21.2304$

$\omega s = 30.8304$

Length of Substrate

$LS = 6h + L$

$= 6(1.6) + 16.12922$

$LS = 25.72922$

Ground Dimensions

$Lg = L + 6h$

$= 16.12922 + 6(1.6)$

$Lg = 25.72922$

$\omega g = \omega + 6h$

$= 21.2304 + 6(1.6)$

$\omega g = 30.8304$

Feed Length

$$L_f = \frac{\lambda_g}{4}$$

$$\lambda_g = \frac{\lambda}{\varepsilon_{eff}}$$

$$\lambda = \frac{C}{f} = \frac{3\times10^8}{4.3\times10^9} = 0.069767$$

$$\lambda_g = \frac{0.069767}{3.93192} = 0.017743$$

$$L_f = \frac{\lambda_g}{4} = \frac{0.017743}{4} = 0.004435$$

$L_f = 4.435$ mm

Table 1: Dimensions of Simulated Antenna

Name of the parameters	Length (mm)
Length of Substrate (Ls)	25.72mm
Width of Substrate (Ws)	30.83mm
Length of Patch (Lp)	16.129mm
Width of Patch (Wp)	21.23mm
Height of Substrate (H_s)	1.6mm
Length of Feedline (L_f)	4.43mm
Width of Feedline (W_f)	2mm
Width of Ground (Wg)	30.83mm
Length of Ground (Lg)	25.72mm

1.4 RESULTS AND DISCUSSION

1.4.1 Antenna Simulation

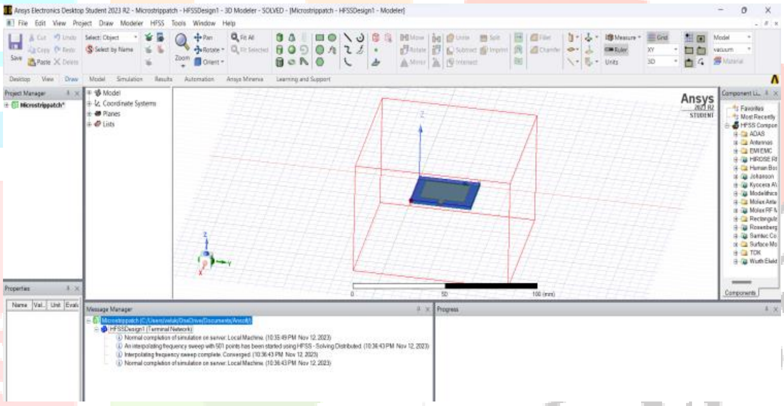


Fig.3 Design of the Antenna

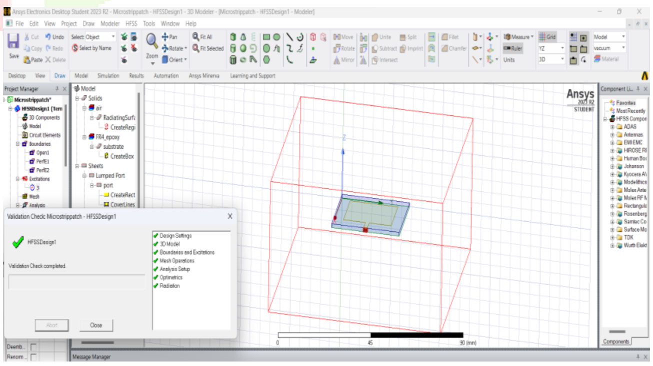


Fig. 4 Validation Check of the Antenna

1.5 SIMULATION RESULTS

1.5.1 S-Parameters (Scattering Parameters)

S-parameters are used to describe how an electrical network (such as an antenna or a network of components) responds to signals at different frequencies. There are various S-parameters, such as S11, S12, S21, S22, which describe the input/output relationships and signal reflections.

S11 Plot S-Parameter plays a critical role in assessing the antenna's performance. S11 measures the amount of input power reflected back and uses that information to calculate the antenna's return loss. S11 should ideally be endlessly negative. However, in practice, it never goes to negative infinity, and the ideal design has a large S11 in the negative direction.

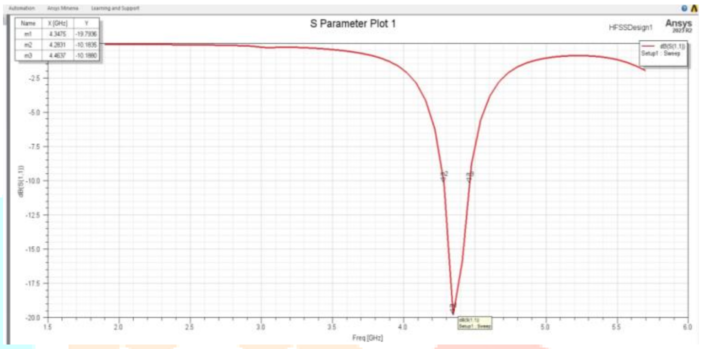


Fig.5 Output of the Antenna S Parameter

1.5.2. Voltage Standing Wave Ratio (VSWR)

The efficiency with which radiofrequency power is transferred from the source, across a transmission line, and into the load is measured by the voltage-slope ratio (VSWR). Along the transmission line, it is the ratio of the greatest voltage to the minimum voltage.Voltage standing wave ratio is referred to as VSWR. This is an indication of the antenna's power reflection and impedance matching. VSWR has a range of 1 to infinity. The ideal VSWR is near to 1. A excellent structure has a VSWR that is close to 1.

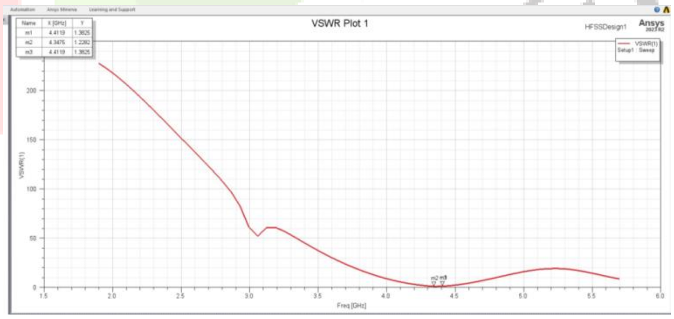


Fig.6 Output of the Antenna VSWR

1.5.3. Group Delay

Group delay is a measure of the time delay experienced by a signal through a system at different frequencies. It's the rate of change of the phase response with respect to frequency.

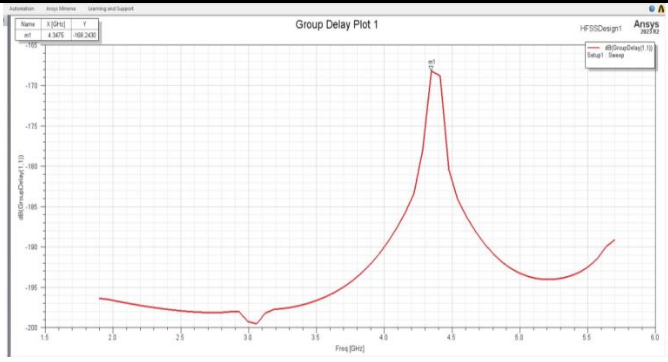


Fig.7 Output of the Antenna Group Delay

1.5.4. Gain Plot:

A gain plot shows the gain of an antenna or a system over a range of frequencies. It provides information about the amplification or attenuation of signals at different frequencies.

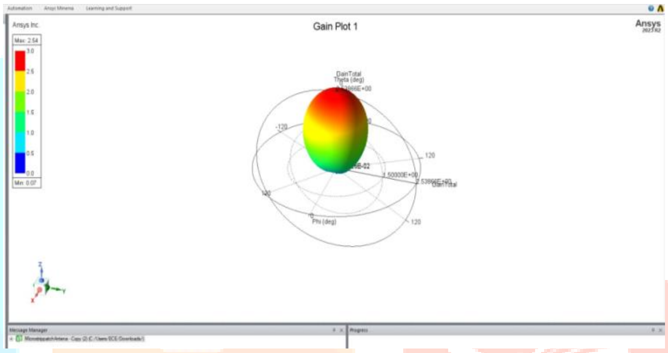


Fig.8 Output of the Antenna Gain plot

1.5.5. System Gain

System gain is the overall gain of a system, considering the gain contributions from all the components in the system, including antennas, transmission lines, and amplifiers.

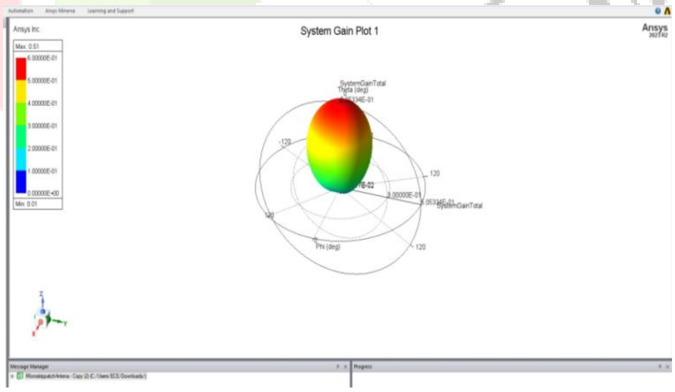


Fig.9 Output of the Antenna System Gain plot

1.5.6. Radiation Efficiency (rE)

Radiation efficiency is a measure of how well an antenna converts input power into radiated electromagnetic energy. It considers losses in the antenna structure and is expressed as a percentage.

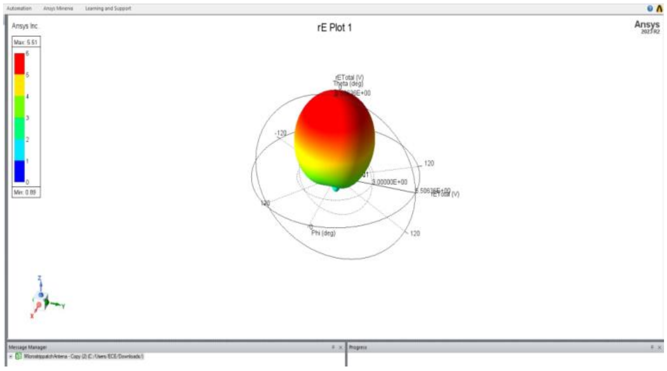


Fig.10 Output of the Antenna rEplot

1.5.7. Directivity Plot

A directivity plot displays the frequency-dependent variation in an antenna's directivity, or its capacity to concentrate radiation in a certain direction. The most important antenna parameter is directivity. It gauges how 'directional' the radiation pattern of an antenna is. The directivity of an antenna with uniform radiation in all directions would be 1, and it would effectively have zero directionality (or dB = 0).

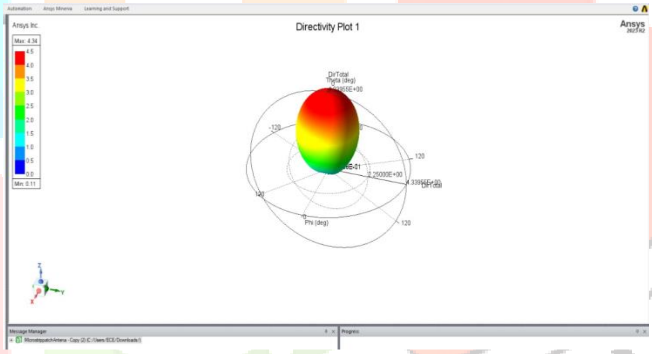


Fig.11 Output of the Antenna Directivity plot

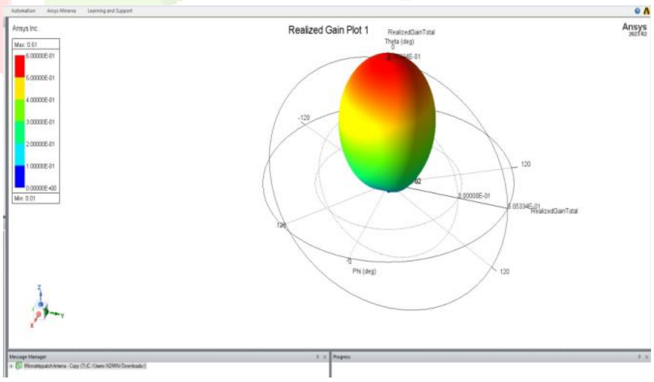


Fig 12 Output of the Antenna Realized Gain plot

1.5.8. Polarization Ratio Plot

This plot shows the polarization characteristics of an antenna over a range of frequencies. It indicates how well the antenna maintains a specific polarization.

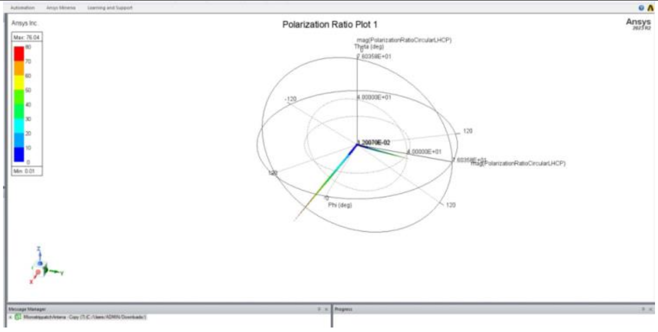


Fig. 13 Output of the Antenna Polarization Ratio Plot

1.5.9. S-Parameter Chart

An S-parameter chart visually represents the scattering parameters of a network or component. It typically includes Smith charts or polar plots to show impedance matching and reflections.

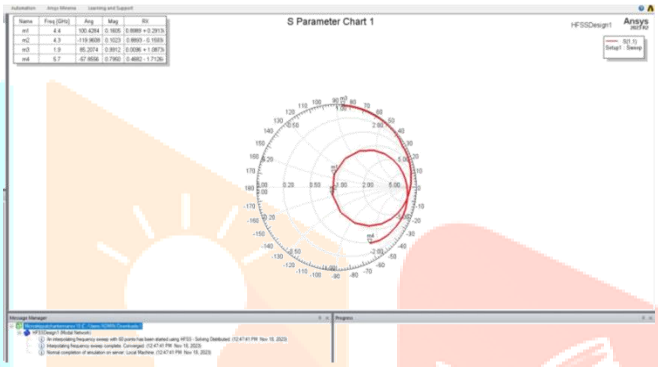


Fig. 14 Output of the Antenna S Parameter Chart

1.5.10. VSWR Chart

A VSWR chart displays the VSWR values at different frequencies. It helps to identify bandwidth and impedance matching characteristics.

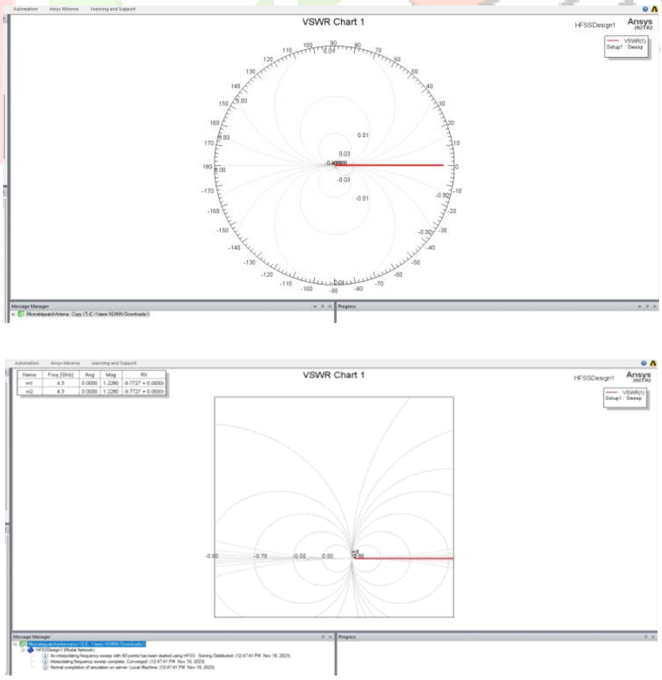
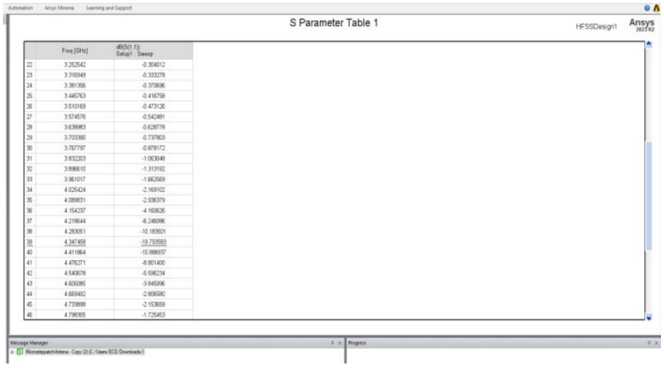


Fig. 15 Output of the antenna VSWR Chart

1.5.11. S-Parameter Table

An S-parameter table provides numerical values of scattering parameters at specific frequencies. It's a tabular representation of the electrical behavior of the system.

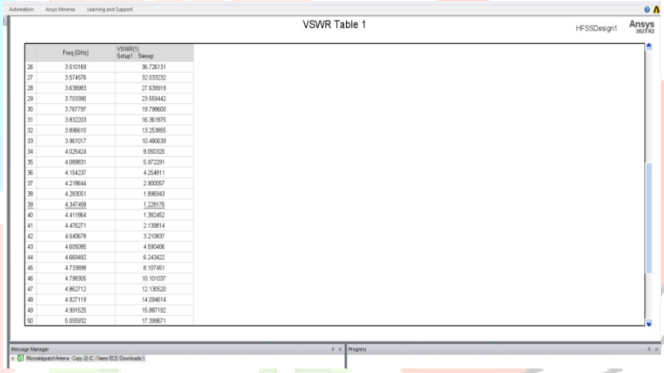


	Freq [GHz]	dB(S(1,1)) Setup1 : Sweep
22	3.252542	-0.304012
23	3.316949	-0.333278
24	3.381356	-0.370696
25	3.445763	-0.416758
26	3.510169	-0.473126
27	3.574576	-0.542481
28	3.638983	-0.628778
29	3.703390	-0.737803
30	3.767797	-0.878172
31	3.832203	-1.063048
32	3.896610	-1.313192
33	3.961017	-1.662569
34	4.025424	-2.169102
35	4.089831	-2.936379
36	4.154237	-4.160626
37	4.218644	-6.246086
38	4.283051	-10.183501
39	4.347458	-19.793583
40	4.411864	-15.888937
41	4.476271	-8.801400
42	4.540678	-5.596234
43	4.605085	-3.845996
44	4.669492	-2.806590
45	4.733898	-2.153659
46	4.798305	-1.725453

Fig. 16 Output of the Antenna S Parameter Table

1.5.12. VSWR Table

Like the S-parameter table, a VSWR table provides numerical values of VSWR at specific frequencies, giving insights into the impedance characteristics of the system.



	Freq [GHz]	VSWR(1) Setup1 : Sweep
26	3.510169	36.726131
27	3.574576	32.033232
28	3.638983	27.639919
29	3.703390	23.559442
30	3.767797	19.798600
31	3.832203	16.361875
32	3.896610	13.253855
33	3.961017	10.480639
34	4.025424	8.050320
35	4.089831	5.972291
36	4.154237	4.254811
37	4.218644	2.900057
38	4.283051	1.896943
39	4.347458	1.228176
40	4.411864	1.382452
41	4.476271	2.139814
42	4.540678	3.210837
43	4.605085	4.590406
44	4.669492	6.243422
45	4.733898	8.107451
46	4.798305	10.101037
47	4.862712	12.130520
48	4.927119	14.094614
49	4.991525	15.887192
50	5.055932	17.399671

Fig 17 Output of the antenna VSWR Table

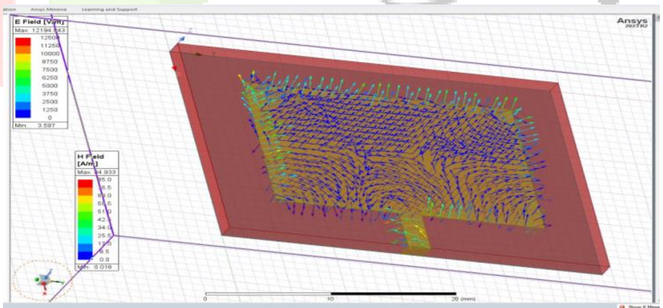


Fig. 18 Output of the Antenna E Field

These parameters and plots are crucial for the design, analysis, and optimization of RF (Radio Frequency) systems and antennas. Engineers use them to ensure proper performance, impedance matching, and efficient signal transfer within a given frequency range.

Proposed Antenna Parameter

S.No.	Parameters	Range of Output
1	S-Parameters (Scattering Parameters)	-19.796db
2	Voltage Standing Wave Ratio (VSWR)	1.2282
3	Group Delay	168.243
4	Gain Plot	2.54
5	System Gain	0.51
6	Radiation Efficiency (rE)	5.51
7	Directivity Plot	4.34
8	Polarization Ratio Plot	76.04
9	S-Parameter Chart	0.8893-0.1593i
10	VSWR Chart	-9.7727+0.000i
11	S-Parameter Table	-19.7935db
12	VSWR Table	1.2281

1.6 DISCUSSION

Figure 4.2 displays the Rectangular Microstrip Patch Antenna's Simulated Results. 4.30 GHz, to be exact. By itself, the frequency-simulated rectangular microstrip patch antenna shows a bandwidth improvement of 180.6 MHz and a return loss of -19.7936 dB. At 4.30 GHz, this RMPA radiating patch resonates. This indicates that the single band antenna's radiating patch tends to the lower side when the antenna's resonant frequency is determined, demonstrating the antenna's compact design and improved gain and bandwidth. An antenna was utilized for satellite communication, and an expanded bandwidth of roughly 0.180 GHz was attained.

Table 2 Comparative Analysis

Comparative Analysis	Antenna Type / Software	Substrate Material	VSWR	Band Width	Operating Frequency	Application
Proposed Work RMPA	Rectangular Patch / Ansys HFSS	FR4	1.2282	180.6 MHz.	4.3GHz.	Satellite Communication
Paul, L.C.: et.al., [4]	Novel Patch Antenna / CST	RT5880	1.0092	1400 MHz.	3.59 GHz.	5G Communication
Hasan, S.O., et. al., [6]	Rectangular Patch / HFSS	RT5880	1.045	85 MHz.	3.60 GHz.	Wireless Communication
	CST	RT5880	1.011	92.28 MHz.	3.60 GHz.	Wireless Communication

1.7 CONCLUSION

Patch antennas are designed using the Ansys HFSS (High Frequency Structure Simulator), and the glass epoxy (FR4) antenna substrate is edge-fed. Patch and ground are created.

Resonating at 4.3 GHz was a planned rectangular microstrip patch antenna for a C Band satellite communication system. For remote fields, the ideal return loss and radiation pattern have been reached. The C Band antenna achieves a high return loss of -19.7936 dB, according to the simulation findings. The best specifications for satellite communications were satisfied by this antenna. Because of its small size and lightweight, the antenna is appropriate for satellite communication.

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