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A Dual-Band Wearable Antenna for X and Ku Frequency Bands for Satellite Communication Applications.

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Abstract: In the present research, a novel 3 cut-pentagon dual-band antenna design has been introduced, and its attributes and performance are enhanced through the use of a specialized substrate called "Jeans" with a permittivity of 1.7. The conducting element employed is copper tape. The design and study of a dual-band wearable antenna optimized for X and Ku frequency bands, specifically tailored for satellite communications applications. The antenna is engineered to offer reliable and efficient performance within the X-band (6.31 GHz) and Ku-band (8.07 GHz) and extended resonant frequency 12.118GHz facilitating seamless connectivity in satellite communication networks. The board size is 43x25.5 mm^2. The Bandwidth for the first band of the suggested antenna is 37.58% for the frequency range between 5.87 GHz. To 8.587 GHz and the bandwidth for the second band is 12.85% for the frequency range 11.447 GHz to 13.02 GHz. The dual-band wearable antenna, which operates in two frequency bands, is created and simulated using CST software. The antenna's dual-band capability makes it appropriate for a broad variety of satellite communication uses, including data transmission, global positioning, and remote sensing. The design's compact form factor and flexibility ensure seamless integration into wearable devices, allowing users to stay connected to satellite communication networks while maintaining comfort and mobility. The resonant frequencies in X and Ku bands make this antenna an excellent choice for wearable technology that requires high-data-rate communication and connectivity with satellite systems. The presented antenna design showcases its potential for enhancing satellite communication capabilities in wearable devices for various applications, including healthcare, remote sensing, and outdoor navigation.
Keywords: dual wearable antenna, satellite communications, CST software, X frequency band, Ku frequency band.

I. INTRODUCTION

The fourth generation (4G) of mobile communication systems now includes Body Centric Wireless Communication (BCWC), which has recently grown in importance. The highly anticipated 5G technology not only addresses the need for high data rates in mobile phones and associated devices but also promises seamless integration with a wide array of high-value services [1]. The market for wearable technology is anticipated to rise from around $27 billion in 2019 to $64 billion in 2024, as per the report published by Global Data. The COVID-19 pandemic has enhanced health characteristics and knowledge, notably in areas like patient monitoring, predicting symptoms, and recording disease contact according to Global Data. This is what is mostly responsible for the expected benefit. At Global Data, senior medical devices analyst Tina Deng claims that "the pandemic substantially enhanced awareness of wearable devices as their use cases increased." Device innovation has exploded as more companies try to come up with creative methods to profit from the situation and help stop the virus' spread. Typically, individual antennas have been designed to operate at specific frequencies. However, The swift advancement of contemporary wireless communication systems and their wide-ranging use has created a demand for wider bandwidths, necessitating the use of multiple antennas for various purposes. On the other hand, an increasing demand exists for wireless devices that are small in size, lightweight, visually appealing, and versatile in functionality. In modern radar as well as space satellite communication uses, microstrip patch antennas are highly sought after because of their qualities, including their slim profile, robust mechanical design, compatibility with MMIC (Monolithic Microwave Integrated Circuit) configurations, compact and lightweight characteristics, and the capacity to function at two different frequencies Microstrip patch antennas are an economical choice for production and can adapt to both flat and curved surfaces. However, they do come with specific limitations and drawbacks [2-3]. To address these shortcomings, researchers have explored a wide array of techniques, including microstrip patch antennas on electrically thick substrates, slotted patch antennas, probe feed stack antennas, and the utilization of multiple resonators [4-11]. Presently, there is a growing demand for broader bandwidth to satisfy the rising needs of modern wireless communication system applications.

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Typically, individual antennas are optimized for specific frequencies, necessitating a variety of antennas for different purposes, which can result in spatial constraints and issues such as reduced efficiency, undesired feed radiation, limited frequency coverage, and increased cross-polarization radiation.

To work with a variety of communication systems and applications, dual-band antennas [12–14] are specifically made to function at 2 different frequency bands. These antennas respond to the growing need for wireless communication systems that need to be able to operate across several frequency bands. Dual-band antenna design and optimization present particular difficulties and opportunities that need careful study of antenna geometry, feeding procedures, and radiation patterns. [15,16]. The antenna of the future is thought to be a microstrip antenna. Nowadays, all traditional antennas are produced in microstrip form. The advantages of microstrip antennas include their small weight and portability. The construction of microstrip antennas will be based on a dielectric substance referred to as "Substrate." Another crucial element is the substrate's height.

The substrate material's dielectric constant and its height are utilized to design a microstrip antenna at a fixed resonant frequency. FR4, Rogers, Duroid, etc. are examples of materials that are utilized as substrates. Substrates like leather, denim, cotton, and tiny strip antenna could be designed and created. Textile or wearable antennas are the titles provided for these devices. These substrates can be used as clothing because they are made of cloth. Carrying the wearable antenna is simpler. This study designs and simulates a dual-band wearable antenna with a rectangular shape. Two rectangular shapes that are joined together by 'arms' are needed for the dual band. The number of arms and their breadth are altered, and the consequences on the antenna's properties are investigated [17].

In this research, the focus is on designing and improving a dual-band wearable antenna for satellite communication applications. This antenna is made of a special substrate called "Jeans" with a permittivity of 1.7, and the conductive element used is copper tape.

The goal of this antenna design is to operate efficiently in 2 specific frequency bands: the X-band at 6.31 GHz and the Ku-band at 8.07 GHz. Additionally, it has an extended resonant frequency of 12.118 GHz, which makes it suitable for use in satellite communication networks. The antenna board's physical size is 43x25.5 mm^2. The antenna's first band has a bandwidth of 37.58%, covering a frequency range between 5.87 and 8.587 GHz. The second band has a bandwidth of 12.85%, spanning from 11.447 GHz to 13.02 GHz. This dual-band wearable antenna was designed and simulated with CST software. Essentially, it's a compact and efficient antenna that can provide a reliable connection in both X and Ku frequency bands, making it well-suited for satellite communication applications.

II. WEARABLE ANTENNA

A wearable antenna is a type of antenna designed to be integrated into clothing, accessories, or other items that can be worn on the body. These antennas are typically used for wireless communication, such as for connecting to cell phone networks, Wi-Fi, Bluetooth, or other wireless devices. Wearable antennas are commonly used in applications such as smartwatches, fitness trackers, smart clothing, and other wearable technology. Fig. 1 illustrates the usual uses of wearable antennae it displays the flow chart for the different wearable antenna devices.

X-band (8-12) GHz as well as Ku-band (12-18) GHz frequencies are commonly utilized in satellite communication for various applications due to their specific characteristics. Here are some typical applications for each frequency band:

A. Ku-band (12-18 GHz)

1) *Direct-to-Home (DTH) Satellite TV:* Ku-band is widely used for broadcasting television signals to consumers' satellite dishes.
2) *VSAT (Very Small Aperture Terminal) Communication:* Ku-band is employed for two-way data communication, including internet access, in remote areas.
3) *Satellite News Gathering (SNG):* Journalists and broadcasters often use Ku-band to transmit live video and audio feeds from remote locations.
4) *Military Communications:* Some military communications and surveillance systems utilize Ku-band frequencies.
5) *Commercial Satellite Services:* Many commercial satellite services, such as broadband internet and telecommunication networks, operate in the Ku-band.

B. X-band (8-12 GHz)

1) *Military and Defence Communications:* The X-band is commonly used for secure military communication and radar systems due to its resistance to interference and high data throughput.
2) *Weather Radar:* X-band radar is used for weather monitoring, including tracking precipitation, cloud movement, and severe weather patterns.

3) *Satellite Earth Observation:* X-band frequencies are suitable for high-resolution remote sensing applications, including earth observation, environmental monitoring, and disaster management.
4) *Deep Space Communications:* The X-band is used for communication with deep space probes and missions to planets and celestial bodies in our solar system.
5) *Aerospace and Aviation:* X-band is employed in aviation radar systems, including weather radar on aircraft and ground-based radar for air traffic control.

Applications of wearable antenna

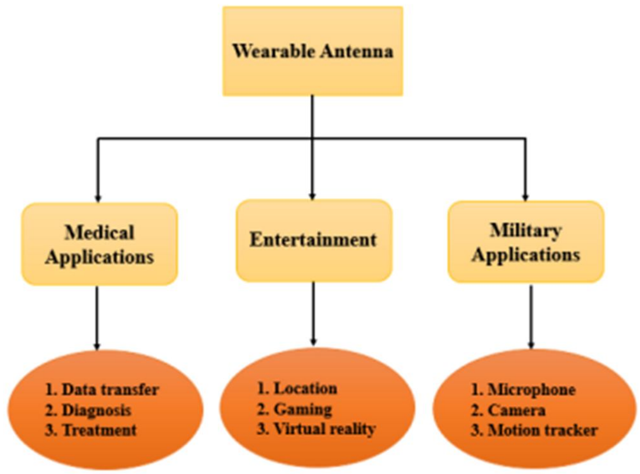

Fig.1. Flow chart of Wearable Antenna For Different Devices.

III. SIMULATION OF 3-CUT PENTAGON DUAL BAND ANTENNA

A. *Fabric Antenna*

A novel dual-band antenna design is presented, featuring a three-cut pentagon shape, with resonant frequencies at 6.31, 8.07, and 12.11 GHz. The antenna is constructed on a 43x25.5 mm square substrate, with a central pentagon-shaped patch having a 6 mm radius along the x-axis & y-axis. Within this patch, a smaller pentagon is cut out, measuring 4 mm along the x-axis & y-axis. Additionally, a circular cutout with a 6 mm radius along the x-axis and positioned 20mm from the y-axis is incorporated into the design. A 27 mm long and 2 mm wide strip line connects these various shapes. The entire antenna design is situated on a rectangular ground plane measuring 43x25.5 mm

Table I-Simulated Parameters

S.NO	Simulated Parameter	Pre-existing work	Proposed Work
1.	Dielectric Permittivity	1.7	1.7
2.	Ground (LgxBg) [mm]	61x17.5 mm	43x25.5 mm
3.	Length of the stripe line	Not used	27 mm
4.	The breadth of the stripe line	Not used	2 mm
5.	Substrate Dimension	61x51 mm	43x43 mm
6.	Substrate Thickness [mm]	1mm	1mm
7.	Resonant Frequency	7.5 GHz	6.31,8.07 and 12.118 GHz
8.	The thickness of the ground	0.0038	0.0038

Table I provides a concise overview of the key parameters relevant to the suggested design.

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Fig.2. displays the layout structure of the flexible antenna which is designed on the textile jeans material with a dielectric constant of 1.7 and it is simulated with the aid of CST software also it includes a patch with asymmetric microstrip line feed and ground.

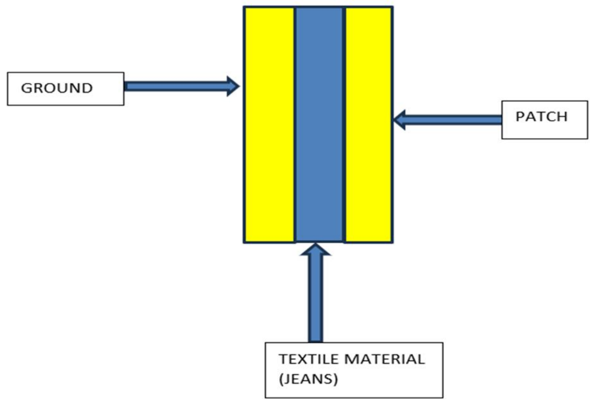

Fig.2. Layout of the antenna on textile material.

IV. PROPOSED DESIGN STRUCTURE

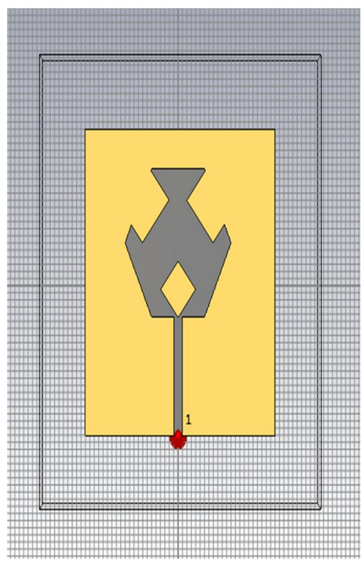

Fig.3. Front view of the proposed antenna

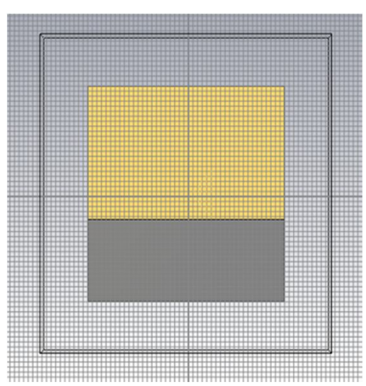

Fig.4. Reverse view of the suggested antenna

V. DIRECTIVITY PATTERN

The suggested fabric antenna was subjected to simulation, and the findings have been visually presented in several figures. Specifically, Fig. 5, 6, and Fig. 7 depict the polar radiation patterns at the respective resonant frequencies of 3.224, 6.31, 8.07, and 12.118 GHz. Meanwhile, Fig. 8, Fig. 9, and 10 illustrate the 2D Cartesian plane, and Fig. 10, Fig. 11, and Fig. 12 showcase the 3D radiation patterns at the resonant frequencies of 6.31, 8.07, and 12.118 GHz, respectively.

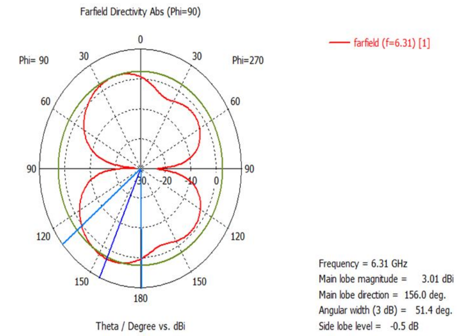

Fig.5.Polar plot directivity pattern at 6.31GHz.

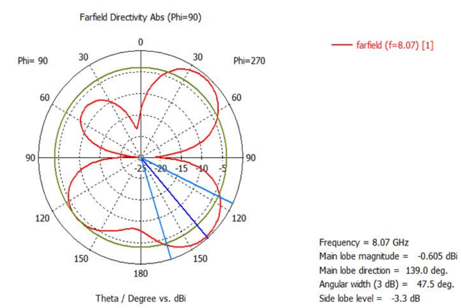

Fig.6.Polar plot directivity pattern at 8.07 GHz.

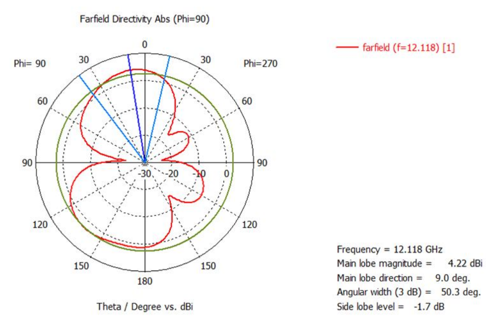

Fig.7. Polar plot directivity pattern at 12.118 GHz.

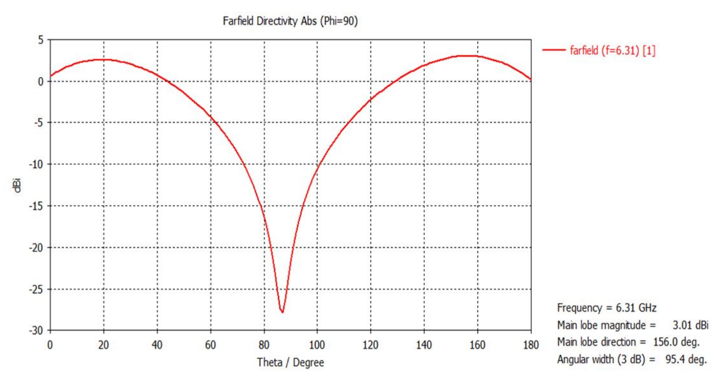

Fig.8. 2D Cartesian directivity pattern at 6.31 GHz.

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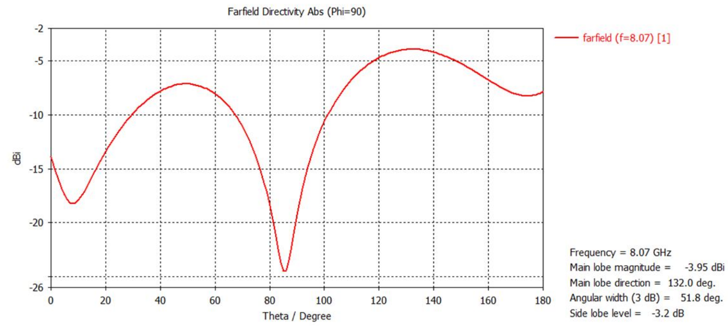

Fig.9. 2D Cartesian directivity pattern at 8.07 GHz.

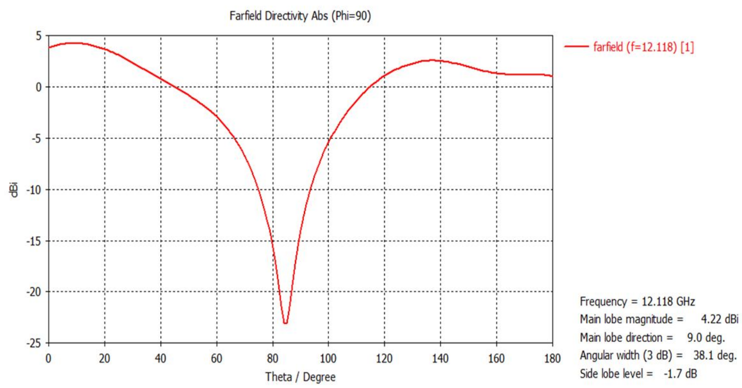

Fig.10. 2D Cartesian directivity pattern at 12.118 GHz.

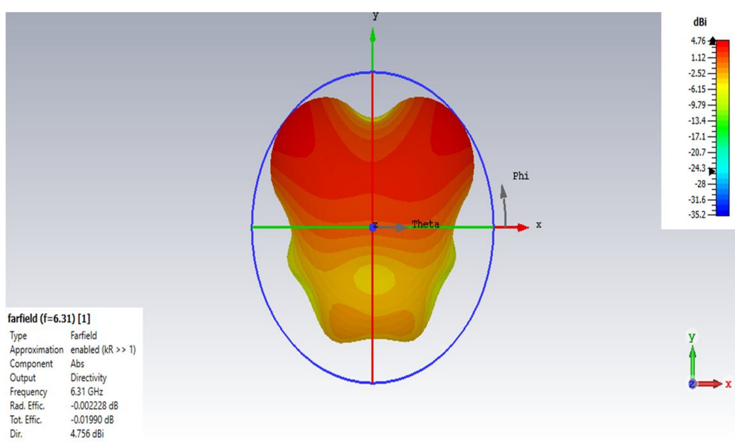

Fig.11. 3D directivity pattern at 6.31 GHz.

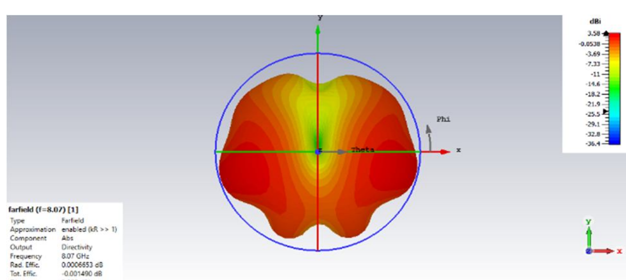

Fig. 12. 3D directivity pattern at 8.07 GHz.

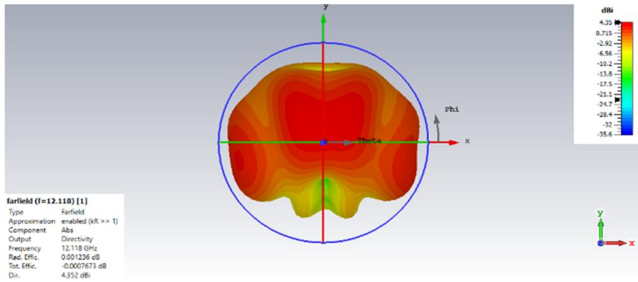

Fig.13. three-dimensional directivity pattern at 12.118 GHz.

The suggested textile microstrip antenna. Figure [8,9,10]. depicts the two-dimensional Cartesian radiation pattern at 6.31GHz, 8.07GHz, and 12.118GHz. Figures [11,12,13]. Depicts the three-dimensional radiation patterns at resonant frequencies 6.31GHz, 12.118 GHz, and 12.118 GHz. The radiation pattern indicates the major lobe's orientation is 156.0 degrees, 139.0 degrees, and 9.0 degrees. An angular width (3dB) of 51.4 degrees, 51.8 degrees, and 38.1 degrees, with a major lobe magnitude of 3.01 dBi at a resonant frequency of 6.31 GHz, -3.95 dBi at a resonant frequency of 8.07GHz, and 4.22 dBi at a resonant frequency of 12.118 GHz. With a radiation efficiency of almost 0.002228dB for 6.31GHz, 0.0006653dB for 8.07GHz, and 0.001236dB for 12.118 GHz, directivity is 4.756dBi, 3.583dBi, and 4.352dBi.

VI. RESULTS AND DISCUSSION

The first design is a diamond-shaped antenna that works only for single-band applications at a resonant frequency of 7.5 GHz Our Proposed design works on three frequency bands 6.31 GHz,8.07 GHz, and 12.118 GHz resonant frequencies which is suitable for multi-band frequencies.

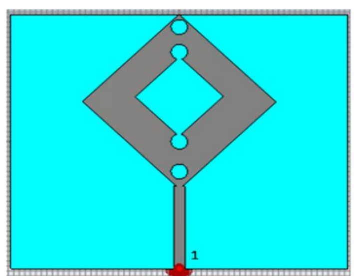

Fig. 14. Pre-existing design Diamond-shaped antenna

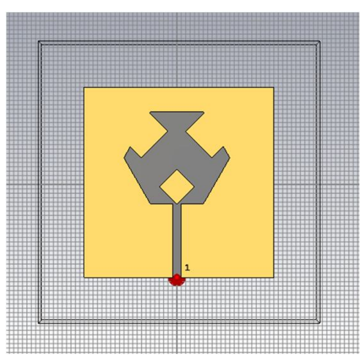

Fig.15. Proposed Design 3 cut pentagon Dual band antenna.

The first design works only for single-band applications at a single resonant frequency of 7.5 GHz.

The proposed design works on 3 frequency bands 6.31 GHz,8.07 GHz, and 12.118 GHz resonant frequency which is suitable for multi-band frequencies.

Multiband and triple frequencies make the second design preferable over the first design.

The second design is chosen over the first design because it has multiband applications and has frequencies of various uses such as satellite communication, IOTand 5G applications.

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The formula used for calculations of bandwidth is given in the equation.

"Bandwidth =(F2–F1)/[(F1+F2)/2]"

Bandwidth Calculation:

First Band

F1 = 5.87 GHz

F2 = 8.587 GHz

Bandwidth = (F2 – F1) / [(F1 + F2)/2]

Bandwidth = 37.58%

Second Band

F1 = 11.447 GHz

F2 = 13.02GHz

Bandwidth = (F2 – F1) / [(F1 + F2)/2]

Bandwidth = 12.85%

To create a body area network or three bands of frequencies with improved bandwidth, a three-cut pentagon tri-band flexible antenna is constructed and modeled in CST software. It operates at tri resonant frequencies of 6.31GHz, 8.07GHz, and 12.118GHz. With a dielectric constant of 1.7 and a conductor like copper tape, jeans are employed as the substrate for the antenna. The board is 43x25.2 mm 2. The proposed design's bandwidths, which are thought to represent the antenna's ideal bandwidths, are 37.58% and 12.85% for frequency ranges of 5.87 to 8.587 GHz and 11.447 to 13.02 GHz, respectively. The proposed wearable and triple-band antenna is appropriate for multiband.

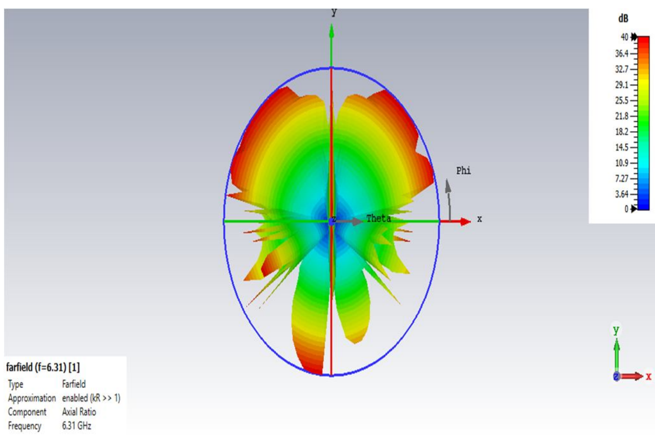

Fig.16. 3D Axial Ratio at 6.31 GHz.

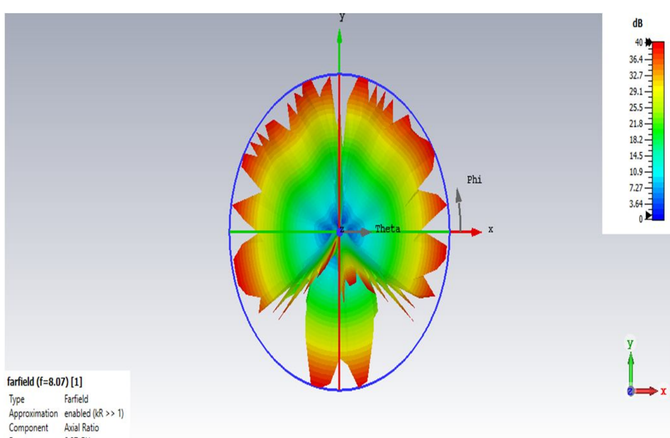

Fig.17. 3D Axial Ratio at 8.07 GHz.

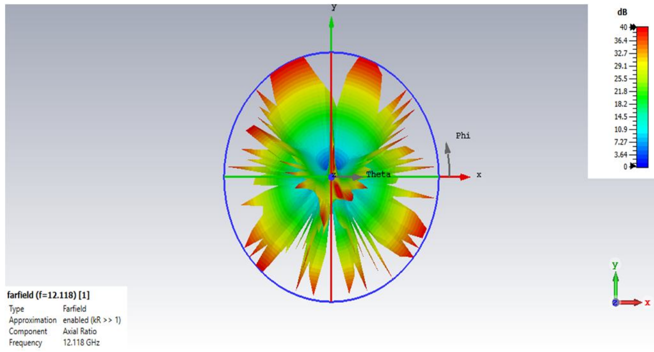

Fig.18. 3D Axial Ratio at 12.118 GHz.

1) *Axial Ratio:* The Axial Ratio (AR) of an antenna is a measure of how closely the antenna's radiation pattern resembles a perfect circle when it comes to polarized waves. When an antenna has perfect circular polarization, the minor and major axes of the circular pattern are in perfect balance, resulting in an AR of 1, which corresponds to 0 decibels (0 dB). In simpler terms, an AR of 1 indicates that the antenna's emitted waves are equally circular in all directions, and there's no preference for any orientation. Fig.[16,17,18]. shows the 3D Axial ratio at frequencies 6.31 GHz,8.07 GHz, and 12.118 GHz respectively.

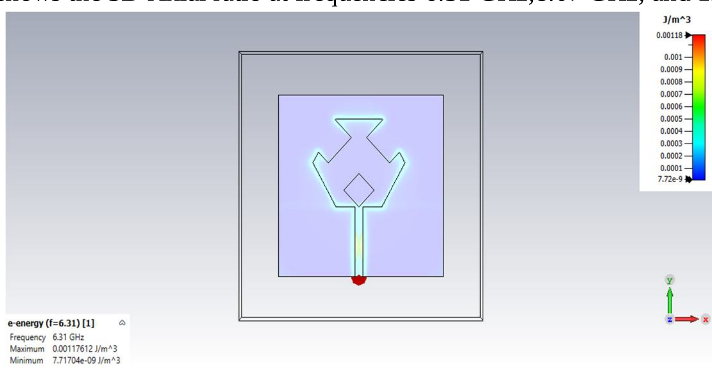

Fig.19.E-energy density at 6.31 GHz.

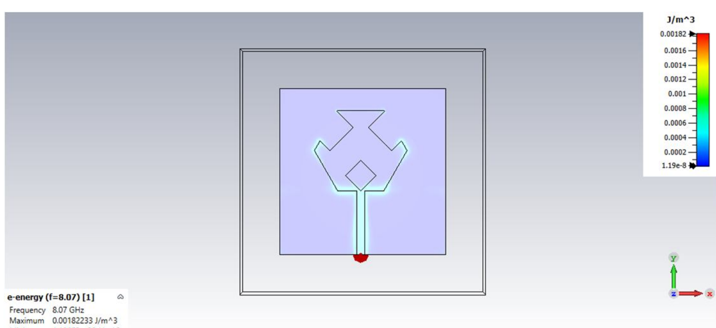

Fig.20.E-energy density at 8.07 GHz.

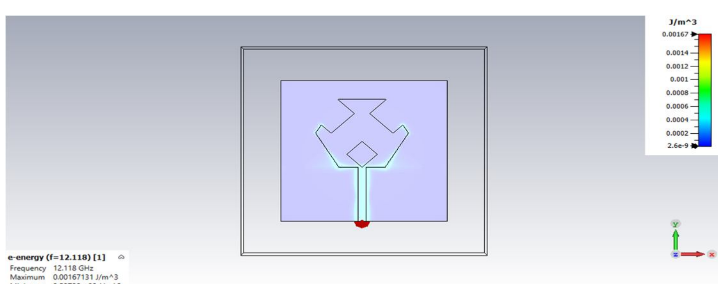

Fig.21.E-energy density at 12.118 GHz.

2) *E-energy Density:* Energy density denotes the amount of energy stored in a given mass or volume of a substance or material. Generally, it is determined in units such as joules per cubic meter (J/m³) or kilogram (J/kg). Fig.[19,20,21]. shows the 3D Axial ratio at frequencies 6.31,8.07, and 12.118 GHz respectively.

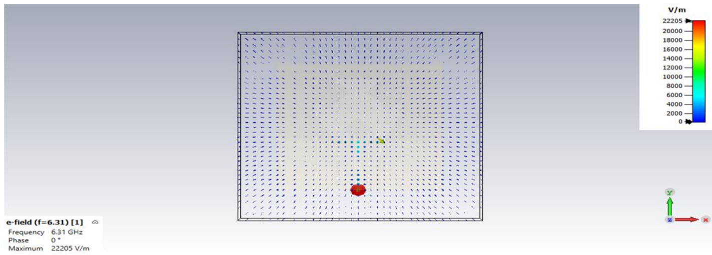

Fig.22. E-field at 6.31 GHz.

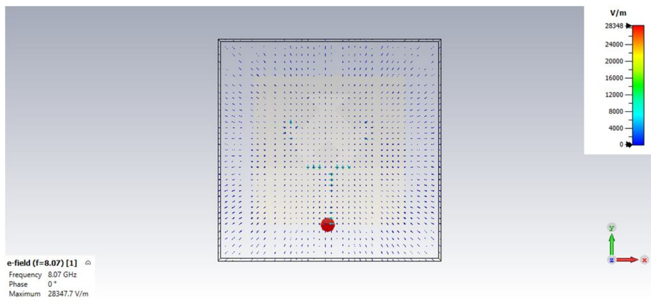

Fig.23. E-field at 8.07 GHz.

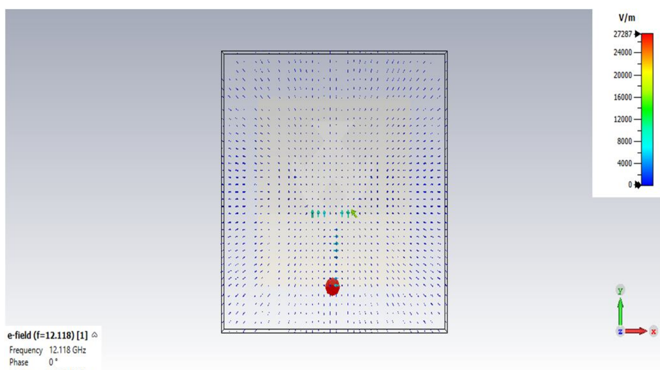

Fig.24. E-field at 12.118 GHz.

3) *E-field:* It represents the electric field strength distribution in the space surrounding the antenna. The E-field plays a vital role in transmitting or receiving electromagnetic waves, such as radio waves or microwaves, and is a key parameter in antenna design and analysis.

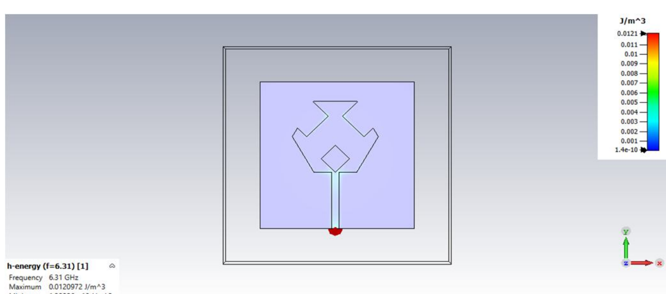

Fig.25. H-energy density at 6.31 GHz.

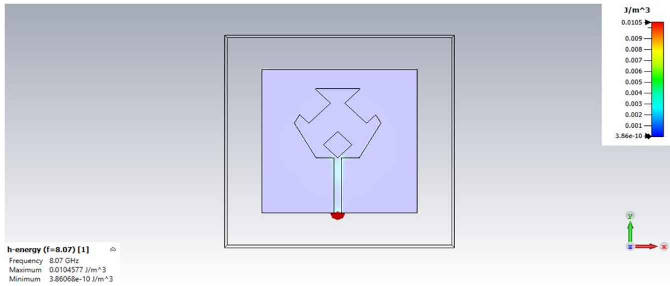

Fig.26 H-energy density at 8.07 GHz.

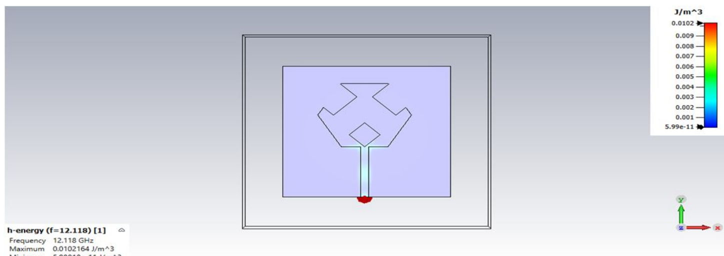

Fig.27. H-Energy density at 12.118 GHz.

4) *H-Energy Density:* Energy density is a measure of the amount of energy stored in a given mass or volume of a substance or material. It quantifies how much energy is contained in a certain amount of space or mass.

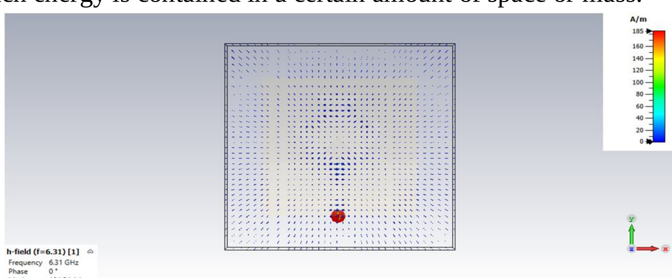

Fig.28. H-Field at 6.31 GHz.

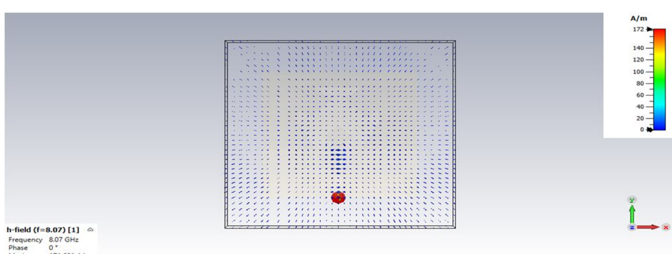

Fig.29. H-Field at 8.07 GHz.

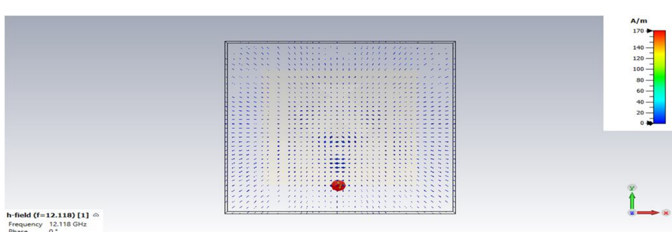

Fig.30. H-Field at 12.118 GHz.

5) *H Field:* The H-field across an antenna refers to the magnetic field intensity or magnetic field strength in the vicinity of the antenna. It's an essential parameter in antenna analysis and represents the magnetic field generated by the antenna's current flow.

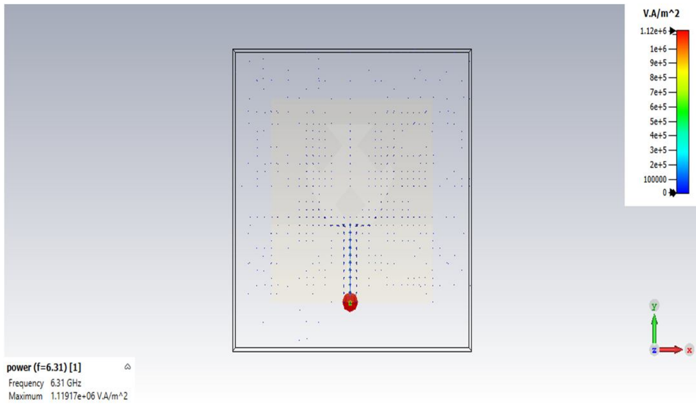

Fig.31. Power flow at frequency 6.31 GHz.

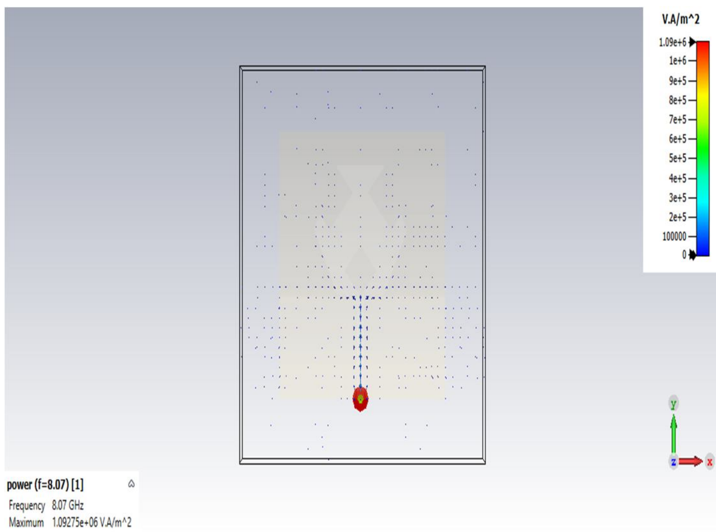

Fig.32. Power flow at frequency 8.07 GHz.

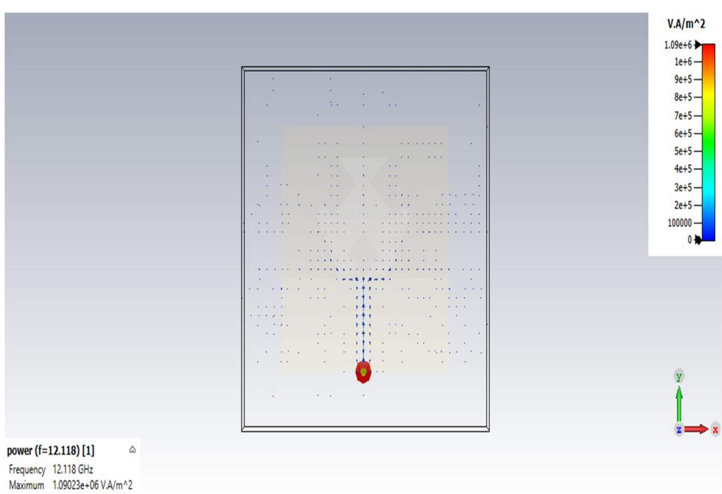

Fig.33. Power flow at frequency 12.118 GHz.

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6) *Power Flow:* Power flow in an antenna is the transmission of electromagnetic energy in the type of radio waves or electromagnetic radiation.

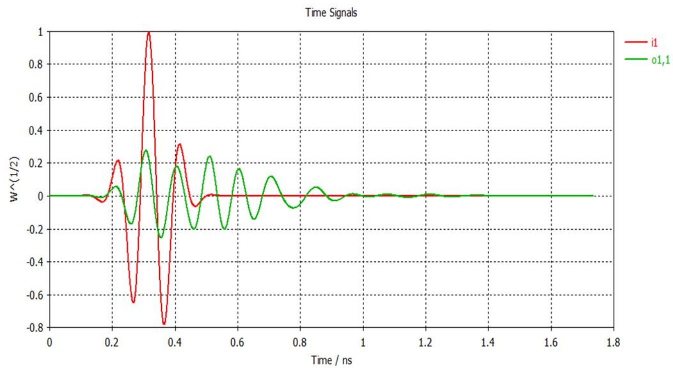

Fig.34. Port Signal.

7) *Port Signal:* A port signal in an antenna refers to the electrical or electromagnetic signal that is either transmitted into the antenna for broadcasting or received from the antenna for further processing. It represents the connection point where the antenna interacts with the electrical or electromagnetic system it is part of, whether for signal transmission or reception.

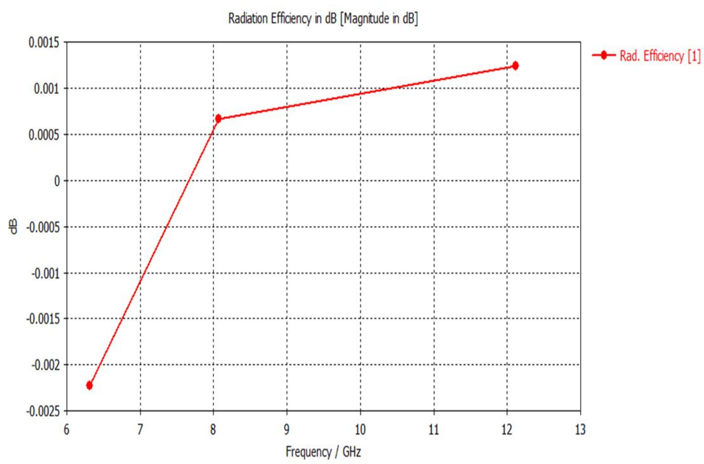

Fig. 34. Radiation Efficiency Graph.

8) *Radiation Efficiency:* Antenna radiation efficiency gauges the antenna's effectiveness in transforming electrical input power into emitted electromagnetic waves. It serves as a metric for the antenna's capacity to transmit or receive signals with minimal losses attributable to factors like resistive losses or impedance mismatches. Greater radiation efficiency signifies superior performance in converting input power into practical radiation.

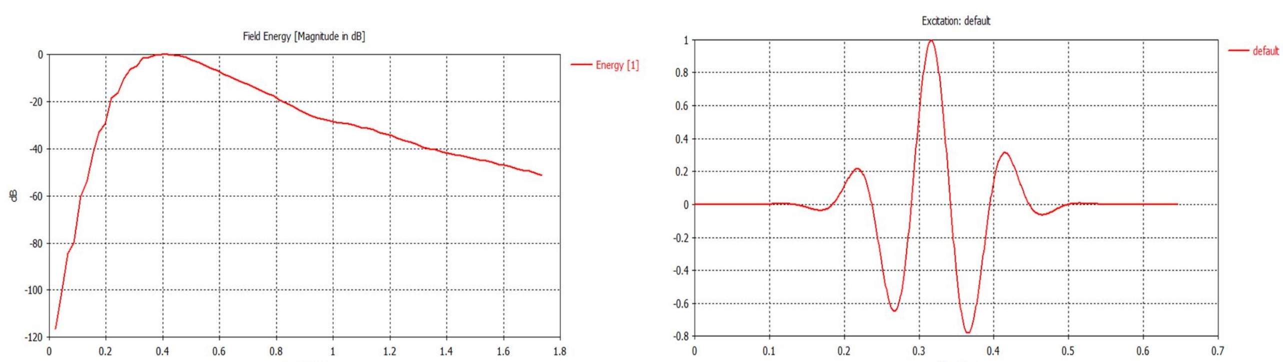

Fig 35. Energy Excitation Graph.

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9) *Energy Excitation:* Energy excitation in an antenna refers to feeding energy into the antenna structure to create electromagnetic waves for transmission or to extract energy from incoming waves during reception.

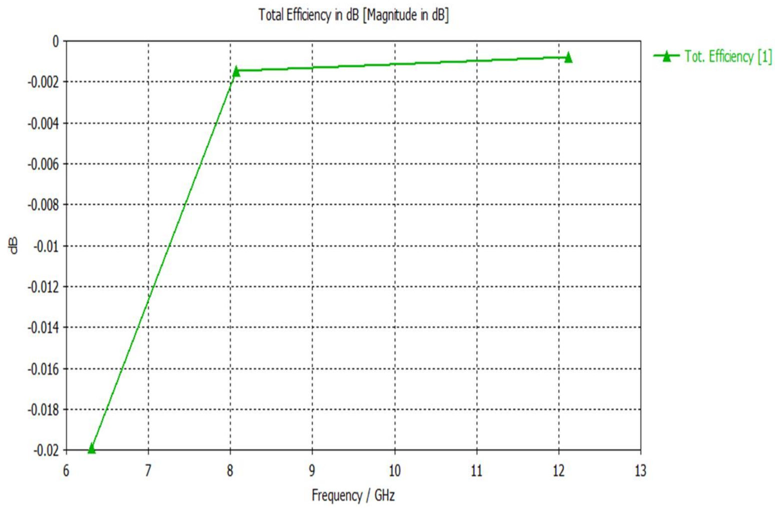

Fig.36. Total Efficiency Graph.

10) *Total Efficiency:* Total efficiency in an antenna measures how effectively it converts input electrical power into radiated electromagnetic waves while minimizing losses due to factors like radiation efficiency, dielectric losses, conductor losses, impedance mismatches, and losses in feed lines and baluns. It quantifies the antenna's ability to transmit or receive signals efficiently.

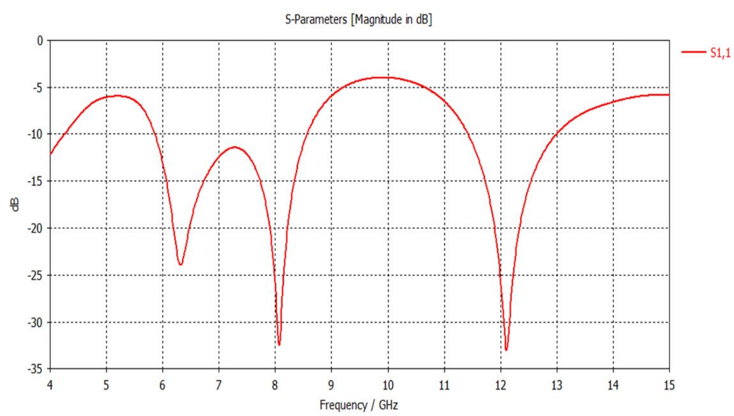

Fig.37.S Parameters.

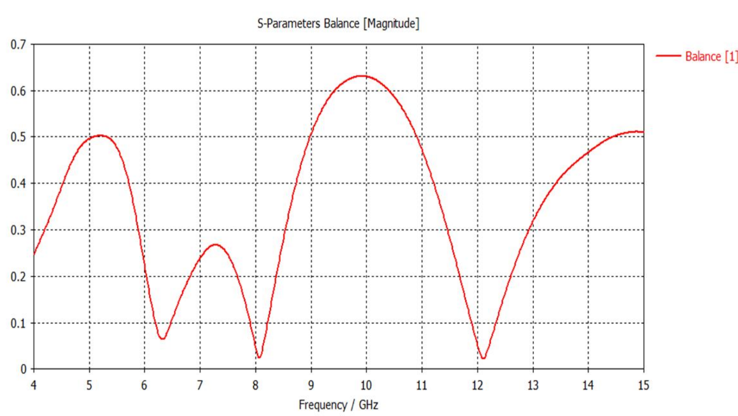

Fig.38.S Parameters Balance magnitude.

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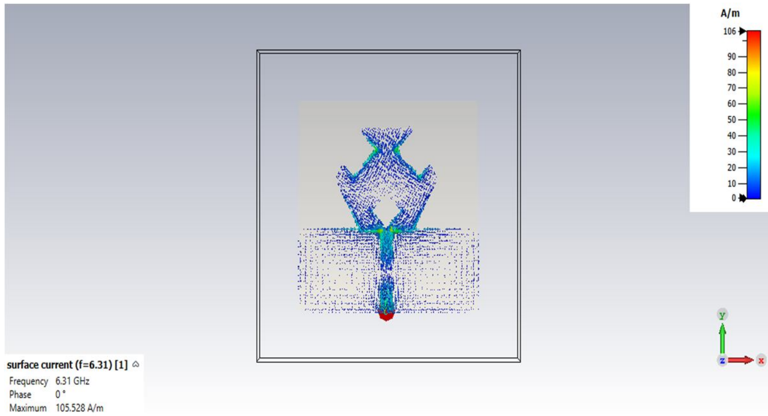

Fig.39.Surface current at 6.31 GHz.

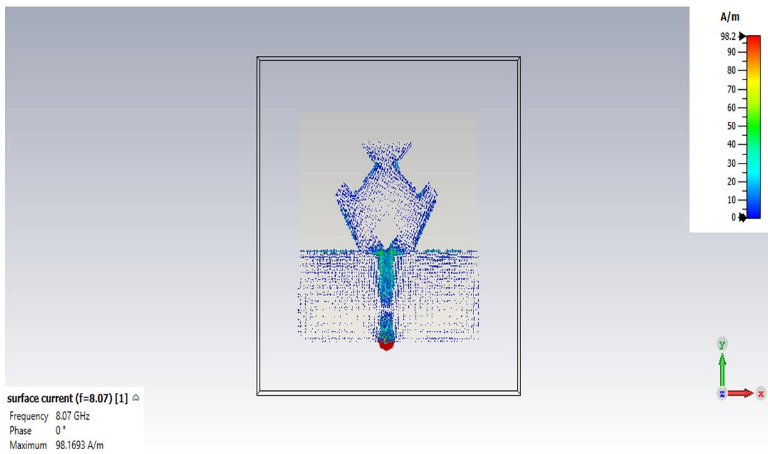

Fig.40.Surface current at 8.07 GHz.

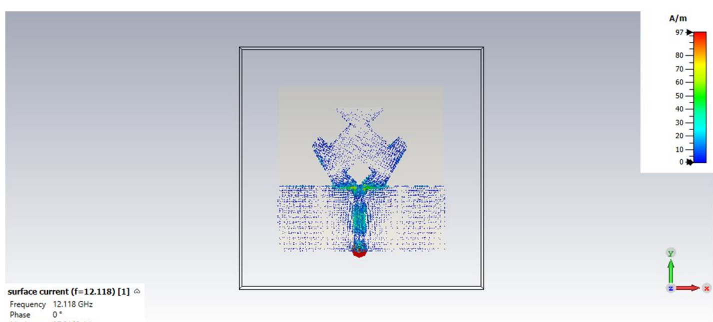

Fig.41.Surface current at 12.118 GHz.

Surface current: Surface current in an antenna refers to the flow of electric current along the conductive surface of the antenna structure. It plays a crucial role in the generation and radiation of electromagnetic waves. Surface currents are responsible for the emission of electromagnetic radiation, allowing the antenna to transmit or receive signals effectively.

VII. CONCLUSION

This study proposes a tri-band microstrip antenna with Dual band frequencies operating in 6.31 GHz, 8.07 GHz, and 12.118 GHz. this research has presented a dual-band wearable antenna designed for X and Ku frequency bands, with an extended tri-band capability operating at 6.31 GHz, 8.07 GHz, and 12.118 GHz. The antenna's performance enhancements include significantly improved bandwidths at 37.58% and 12.85%, crucial for reliable and high-data-rate satellite communications.

VIII. FUTURE SCOPE

The design considerations incorporated into this dual-band wearable antenna have made it a versatile and practical solution for many satellite communication applications. Its compact form factor, flexible substrate, and dual-band functionality allow seamless integration into wearable devices while maintaining wearer comfort and mobility.

The improved bandwidths achieved in this design are significant, as they directly contribute to the antenna's efficiency and reliability in satellite communication networks. This expanded bandwidth ensures that the antenna can support various communication protocols, data transmission rates, and satellite services, making it a valuable asset for users across different sectors.

Furthermore, the dual-band capability, which includes an extended frequency of 12.118 GHz, positions this wearable antenna for even more diverse satellite communication applications, including emerging technologies and services that demand connectivity in higher frequency bands. In the future, this design has the potential to undergo fabrication and testing using a human phantom to assess its Specific Absorption Rate (SAR) and its impact on the human body. This evaluation will enable its utilization in wearable applications and various other use cases. Furthermore, the design can be extended to enable data exchange among diverse devices through cloud networks, facilitating satellite connectivity for purposes like tracking, navigation, data retrieval, and communication.

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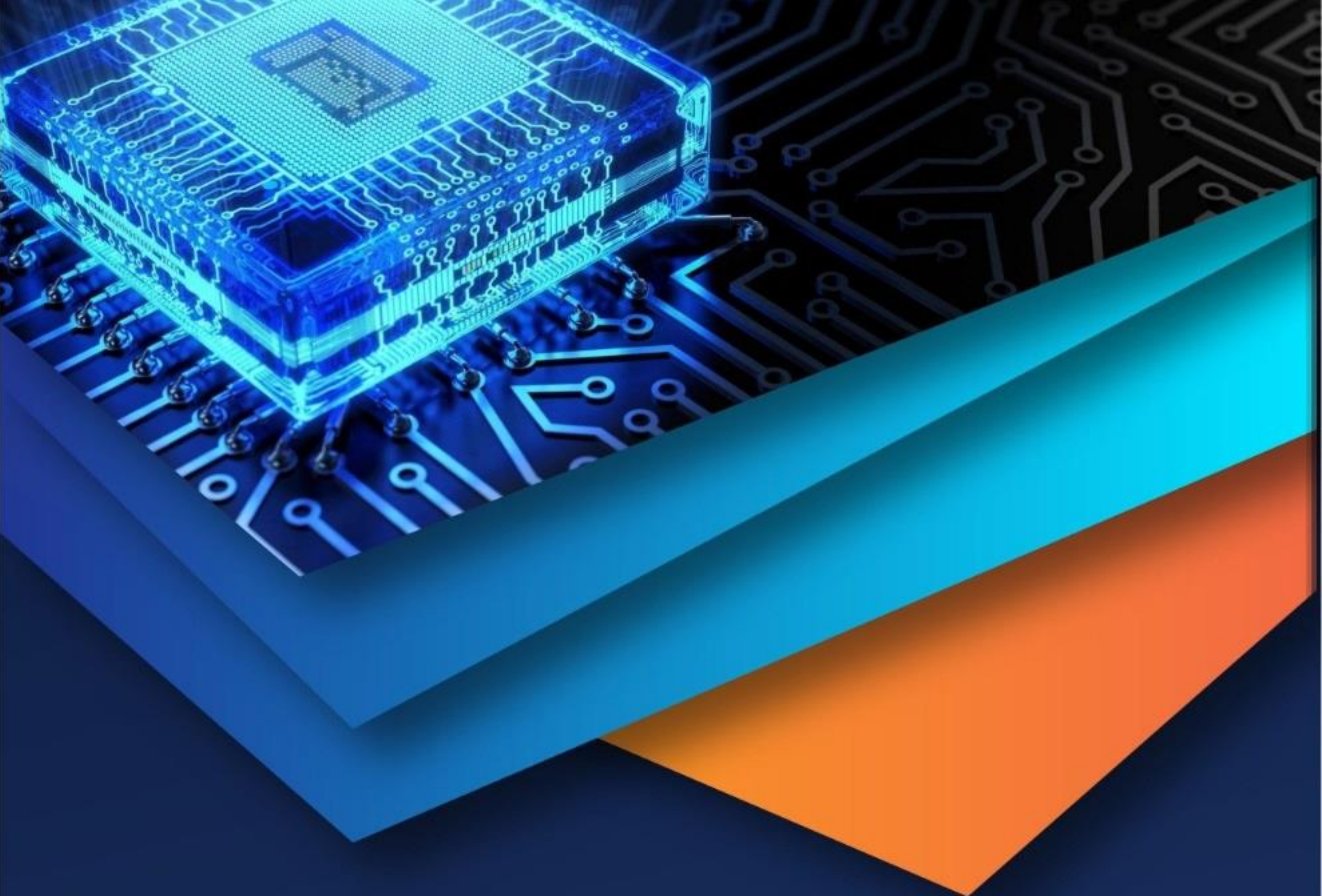

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