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Design and Simulation of Elliptical Shaped Microstrip Patch Antenna Using HFSS

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Abstract: The elliptical patch antenna presents a comprehensive study on the design, fabrication, and performance analysis of an operating at 2.4 GHz, employing FR4 substrate material. The elliptical shape is chosen for its unique radiation characteristics and compact form factor, making it suitable for integration into modern wireless communication systems. The design process involves careful consideration of key parameters, including patch dimensions, feedline structure, and ground plane geometry. Advanced simulation tools, such as electromagnetic simulators, are employed to optimize the antenna's performance, achieving desirable characteristics such as low return loss and enhanced bandwidth. Utilizing FR4 as the substrate material offers several advantages, including costeffectiveness, ease of procurement, and compatibility with standard PCB manufacturing processes. The dielectric properties of FR4 are thoroughly analyzed and incorporated into the antenna design process to ensure accurate simulation results. The proposed elliptical patch antenna has promising applications in various wireless communication systems, including Wi-Fi, Bluetooth, and IoT devices, operating in the 2.4 GHz frequency band. Its compact size and robust performance make it a compelling choice for space-constrained and high-performance wireless communication applications. This contributes valuable insights into the design and optimization of patch antennas, particularly those using FR4 substrates, and serves as a foundation for the development of efficient and cost-effective wireless communication solutions in the 2.4 GHz spectrum.
Keywords: FR4 substrate, Elliptical patch antenna, Radiation pattern, Antenna optimization, Dielectric properties, Frequency band, Return loss.

I. INTRODUCTION

An elliptical patch antenna is a specialized type of microstrip or printed antenna that features a radiating element in the shape of an ellipse.

This radiating element is typically made from a conductive material, such as copper, etched onto a dielectric substrate. The distinctive elliptical shape sets it apart from other planar antenna geometries, such as rectangular or circular patches. The geometry and dimensions of the elliptical patch antenna are carefully designed to resonate at specific frequencies, making it a valuable component in wireless communication systems and other applications where compact, planar antennas are needed.

Introducing the concept of an elliptical antenna is an intriguing exploration into the world of electromagnetic wave propagation. Unlike traditional antennas with circular or rectangular shapes, an elliptical antenna takes on an elliptical form. This unique geometry gives it distinct radiation characteristics and is employed in various applications where precise control over the electromagnetic field is required.

The elliptical shape of the antenna allows for customization of its radiation pattern. Engineers can design elliptical antennas to emit and receive electromagnetic waves in specific directions, making them valuable tools in applications like satellite communication, radar systems, and wireless networking. By manipulating the dimensions and orientation of the elliptical antenna, engineers can steer the radiation pattern to suit their needs, optimizing signal strength and coverage.

One notable application of elliptical antennas is in satellite communications. They are commonly used in satellite ground stations to establish high-gain, directional links with orbiting satellites. The elliptical shape allows for fine-tuning of the antenna's focus on a specific satellite in orbit, ensuring reliable data transmission over vast distances.

Moreover, the unique properties of elliptical antennas have also found utility in radar systems. Radar relies on precise beam forming to detect and track objects accurately. The ability to tailor the radiation pattern of an elliptical antenna makes it ideal for such applications, enabling radar systems to detect targets with exceptional precision, whether in military surveillance, weather forecasting, or air traffic control. In essence, elliptical antennas exemplify the versatility and adaptability of electromagnetic wave technology, providing engineers with a valuable tool for addressing a wide array of complex communication and sensing challenges.

II. WHY ELLIPTICAL PATCH ANTENNA

Elliptical patch antennas are favored in various applications for several compelling reasons. Firstly, their unique shape allows for versatile polarization control, enabling the generation of linear and circular polarizations. This flexibility proves invaluable in fields such as satellite communication and radar systems where polarization alignment is essential. Another significant advantage of elliptical patch antennas is their ability to offer wider impedance bandwidths compared to certain other patch antenna shapes. This makes them well-suited for applications demanding broadband communication, especially those involving high-speed data transmission. Their compact form factor makes elliptical patch antennas ideal for use in spaceconstrained environments and devices, enhancing integration possibilities. Additionally, in wireless communication systems employing multiple-input, multiple-output (MIMO) or diversity techniques, these antennas can provide polarization diversity, reducing signal fading and enhancing overall system performance. Elliptical patch antennas are also adept at customizing radiation patterns, a feature particularly beneficial when specific coverage areas or beam shaping is required. They are often employed in applications requiring circular polarization or specialized radiation patterns, such as medical imaging. In certain scenarios, elliptical patch antennas are chosen for their aesthetic appeal, making them preferable in consumer electronics and industrial designs. They offer a visually appealing and streamlined appearance. Furthermore, these antennas can be designed to operate across various frequency bands, adding versatility for multi-band and multi-frequency applications. In research and innovation, elliptical patch antennas are frequently explored, pushing the boundaries of antenna technology for advanced performance and adaptability. Lastly, in radar systems, particularly those used for remote sensing and target recognition, elliptical patch antennas prove useful in transmitting and receiving polarimetric 7 radar signals. This capability provides valuable insights for characterizing objects and materials. Ultimately, the selection of an elliptical patch antenna, or any other antenna type, depends on the specific needs of the application. Factors such as frequency range, polarization, gain, beamwidth, size constraints, and performance characteristics play pivotal roles in choosing the most suitable antenna for a particular task. Elliptical patch antennas are just one of many antenna types available, each tailored to different applications and use cases.

III. SOFTWARE DESIGN

A. About ANSYS HFSS Software

Ansys HFSS (High-Frequency Structure Simulator) is a commercial electromagnetic (EM) structure solver developed by Ansys, offering a variety of advanced solver technologies. Each solver within ANSYS HFSS is an automated solution processor where users define the geometry, material properties, and the desired range of solution frequencies. Engineers primarily utilize Ansys HFSS for the design and simulation of high-speed, high-frequency electronic systems found in radar, communication systems, satellites, ADAS (Advanced Driver Assistance Systems), microchips, printed circuit boards, IoT devices, and other digital and RF (Radio Frequency) devices. Furthermore, this solver has been employed to simulate the electromagnetic characteristics of objects like automobiles and aircraft.

ANSYS HFSS enables system and circuit designers to simulate EM-related issues, such as losses due to attenuation, coupling, radiation, and reflection. The significant advantage of accurately simulating a circuit's high-frequency behavior on a computer is that it reduces the need for extensive final testing and system verification, as well as minimizing the costly construction of multiple prototypes. This results in both time and cost savings during product development. HFSS operates by capturing and simulating objects in three dimensions, taking into account their material composition and shapes or geometries.

HFSS is distinguished among electromagnetic simulators, particularly for antenna design, complex RF electronic circuit elements like filters, transmission lines, and packaging, because of its automation and guaranteed accuracy. When it comes to antenna design, achieving sustainable design necessitates an understanding of the variables affecting antenna performance in practical settings. With Ansys HFSS, designers can explore "what if" real-world scenarios through electromagnetic simulation, enabling them to examine antenna design within the context of the entire system.

Five key applications of Ansys HFSS software include:

1) Antenna Design and Simulation
2) Sensor Development
3) PCB Modeling and Simulation
4) Electromagnetic Interference and Compatibility
5) RF and Microwave Modeling

Engineers responsible for integrating antennas into platforms are primarily concerned with how the presence of the platform affects antenna performance. The performance of an antenna varies significantly when installed on actual vehicles and platforms, in contrast to a flat ground plane within an anechoic chamber. Furthermore, the coupling between pairs of antennas can vary substantially depending on their placement on the platform. Ansys HFSS offers a comprehensive suite of simulation tools and technologies for antenna design and placement simulations. It provides reliable results for assessing the performance of antennas as individual components and when integrated into real-world operational environments. Depending on the complexity of the problem and the desired results, users can choose from a range of solver technologies and high-performance computing enhancements available as add-ons.

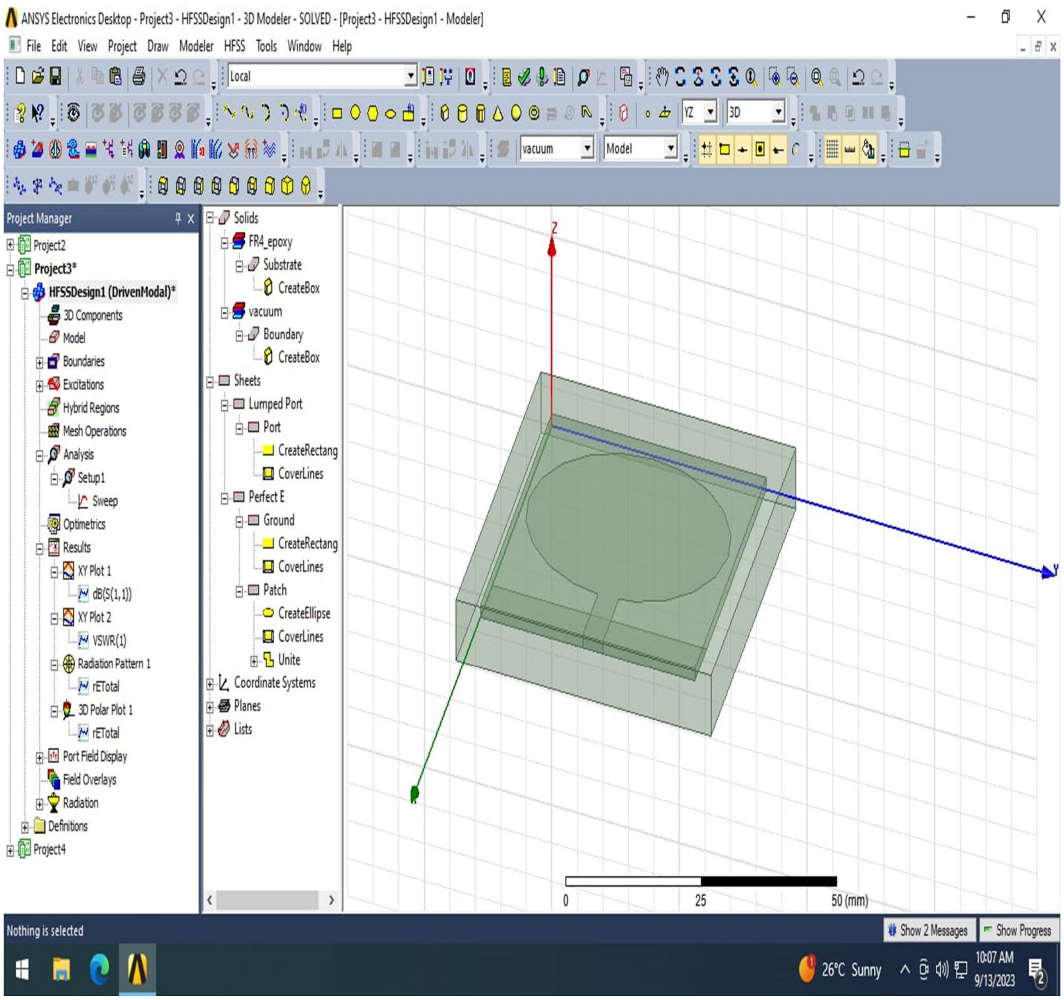

Fig 3.1.1 Existing model of elliptical patch antenna

IV. MATERIALS AND METHODOLOGY

The design of an elliptical patch antenna for skin cancer detection. The proposed antenna is designed based on a characteristic resonant frequency of 2.4 GHz and utilizes an FR4 epoxy substrate. The methodology shown in the image is a general approach to designing a patch antenna. Frequency range selection: It is used select frequency range for antenna which is 2.4 GHz. This frequency range will determine the size of the antenna and the material that can be used. Substrate material selection: It is used to select the material for the substrate of the antenna which is FR4 epoxy. The substrate material will affect the performance of the antenna, such as its bandwidth and gain. Substrate thickness selection: It is used to select the thickness of the substrate for the antenna. The substrate thickness will affect the resonance frequency of the antenna. Patch, Feed, & Ground dimension: This block is used to define the dimensions of the patch, feed, and ground plane of the antenna. The dimensions of these components will affect the performance of the antenna. Port assignment and excitation: It is used to assign ports to the antenna and to excite the antenna at a specific frequency. Results: It displays the results of the simulation, such as the return loss, gain, and radiation pattern of the antenna

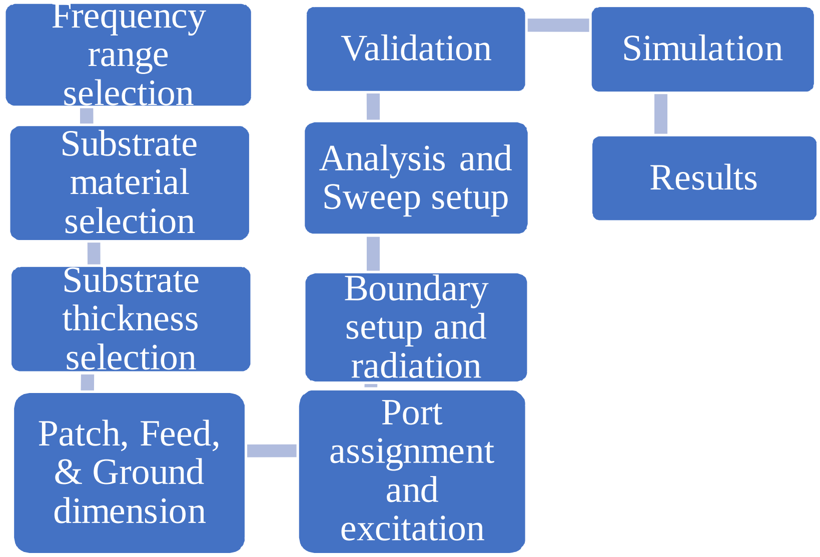

Fig 3.2.1 Flow Chart of Design Methodology

A. Procedure to Design a Elliptical Patch Antenna Using HFSS Software

Here are step-by-step instructions for setting up and simulating a project in Ansys Electronic Desktop using the HFSS module:

1) Launch the Ansys Electronic Desktop application on your computer.
2) Navigate to the "Project" tab and select "New HFSS Project."
3) In the project, click on the "Box" icon located in the toolbar. Name this box "Substrate" and specify the material as "FR-4 Epoxy" with a relative permittivity of 4.4. Set the transparency to 0.5, and then click "Apply" and "OK."
4) Create a box under the "Substrate" and position it at coordinates (0,0,0). Click "Apply" and "OK."
5) To create the "Patch," follow a similar procedure, but this time use a rectangle instead of a box. Set the transparency to 0.6 and name it "Patch." Create a rectangle under the "Patch" with position coordinates (18,21,1.6), and click "Apply" and "OK."
6) Under the "Feed," select the rectangle tool, name it "Feed," and provide a transparency of 0.6. Create a rectangle under "Feed" at coordinates (42,20,1.6). Click "Apply" and "OK."
7) For the "Boundary," choose the box, name it, and create another box under "Boundary" with position coordinates (-4,-3.5,-4). Click "Apply" and "OK."
8) Create the "Ground Plane" by using a rectangle, naming it "Ground," and setting the transparency to 0.55. Create a rectangle under the "Ground Plane" at coordinates (35,0,0). Click "Apply" and "OK."
9) Switch the axis orientation from XY to YZ in the toolbar above.
10) Add a rectangle for the "Port," name it, and set the transparency to 0.55. Create a rectangle under the "Port" with position coordinates (42,20,1.6). Click "Apply" and "OK."
11) Combine the "Patch" and "Feed" by using the "Unite" option in the toolbar. Click "Apply" and "OK."
12) To set up an excitation port, go to the "Project" section, select "HFSS Design," right-click on "Port," choose "Assign Excitation," and then "Lumped Port." Follow the prompts to define the port location and click "Finish."
13) For plotting purposes, right-click on "Patch," select "Assign Boundary," choose "Perfect E," and click "OK." Then, right-click on "Boundary" (under "Vacuum"), select "Assign Boundary," and choose "Radiation." Click "OK.
14) Right-click on "Radiation" and insert a "Far Field Setup." Select the "Infinite Sphere" option and click "OK." Now, right-click on "Analysis" and add a "Solution Setup." Specify the frequency as 2.4 GHz and click "OK."
15) Click the "+" icon near "Analysis," right-click on the setup, and add a "Frequency Sweep." Click "OK." To ensure correctness, go to the "HFSS" tab in the toolbar, click on "Validation Check," and confirm that green checkmarks are displayed.
16) Right-click on "Analysis," select "Analyze All," and save the project.
17) Right-click on the results and create a modal solution data report. Choose the rectangular plot and create a new report to display each plot.
18) For VSWR (Voltage Standing Wave Ratio), repeat the above steps in a new report window following the same procedure.

These steps outline the process of setting up and simulating an electromagnetic structure using Ansys HFSS in Ansys Electronic Desktop.

SHAPE	NAME ASSIGNED	POSITION	x, y, z PARAMETERS
Box	Substrate	0,0,0	x=42, y=42, z=1.6
Elliptical	Patch Radius =15	18,21,1.6	(z) x=15, y=20 Ratio=1.3
Rectangle	Feed	42,20,1.6	(z) x=-18, y=4
Box	Boundary	-4, -3.5, -4	x=50, y=50,z=8
Rectangle	Ground	35,0,0	(z) x=7, y=42
Rectangle	Port	42,20,1.6	(x) y=4, z=1.6

Table 1. Dimensions of Elliptical patch antenna

V. RESULTS

The "S11" parameter, often referred to as the return loss or reflection coefficient, is a measure of how well an antenna impedance matches the impedance of the transmission line or system it's connected to. It's typically expressed in decibels (dB) and represents the amount of power that is reflected back into the system.

When discussing an elliptical patch antenna, the S11 vs. frequency plot shows how the return loss changes with varying frequencies. This plot helps characterize the antenna's performance across a range of frequencies.

A typical S11 vs. frequency plot for an elliptical patch antenna should ideally show a low and stable return loss over the desired operating frequency range. This indicates good impedance matching and efficient power transfer between the antenna and the connected system.

The specific shape of the S11 vs. frequency plot can provide information about the bandwidth, resonant frequency, and impedance matching of the antenna. Engineers and designers use this information to optimize antenna performance for their specific application and frequency requirements.

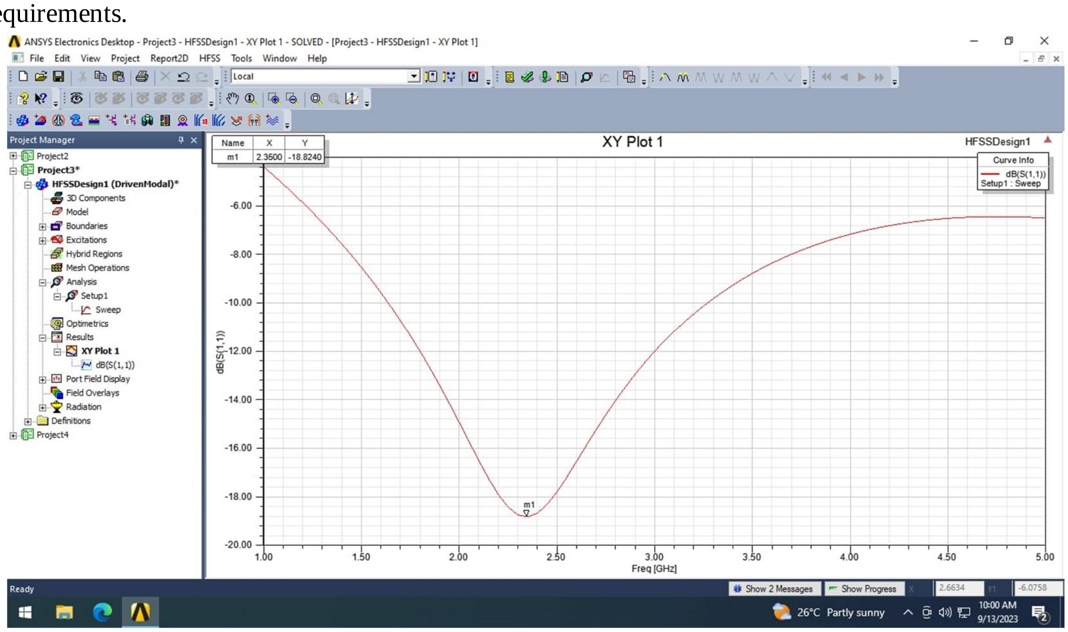

Fig 4.1 S11 Vs. Frequency plot of elliptical patch antenna

The radiation pattern of an elliptical patch antenna illustrates how it radiates or receives electromagnetic waves in three dimensions. It describes the antenna's efficiency in different directions relative to its physical orientation. This pattern characterizes the antenna's directionality, beamwidth, gain, side lobes, and polarization. The directionality can be omnidirectional or directional, indicating whether the antenna radiates uniformly in all directions or prefers certain directions. The beamwidth, which is the width of the main lobe or beam, reflects the antenna's level of directionality. Gain measures its efficiency in radiating energy in specific directions, and side lobes may appear in addition to the main lobe. Designers use radiation patterns to optimize elliptical patch antennas for various applications by adjusting the antenna's shape and dimensions to achieve the desired coverage, gain, and directionality.

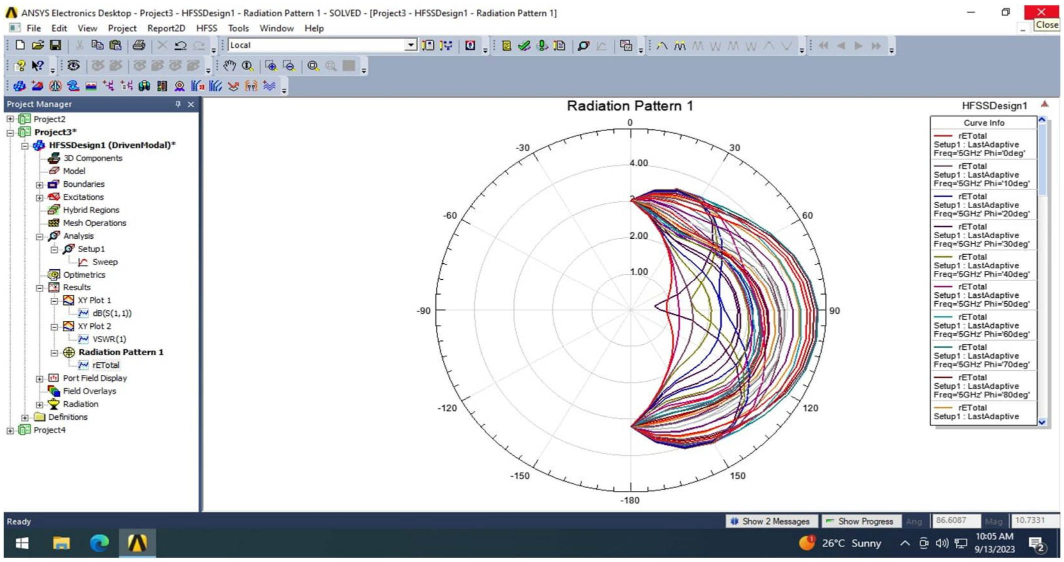

Fig 4.2 Radiation pattern

The Voltage Standing Wave Ratio (VSWR) is another important parameter used to assess the performance of antennas, including elliptical patch antennas. VSWR measures the ratio of the maximum voltage to the minimum voltage along a transmission line or at the input/output of an antenna. It's a measure of impedance matching and how efficiently an antenna transmits or receives power.For an elliptical patch antenna, the VSWR vs. frequency plot shows how the VSWR changes with varying frequencies. Ideally, you'd want a low and stable VSWR across the desired operating frequency range. A VSWR close to 1 (ideally 1:1) indicates that the antenna is well-matched to the transmission line and is efficiently transmitting or receiving power.A high VSWR indicates poor impedance matching, which can result in power being reflected back into the system, reducing the antenna's efficiency.Designers and engineers use VSWR vs. frequency plots to optimize antenna performance, ensure good impedance matching, and achieve the desired operating characteristics for specific applications and frequency requirements.

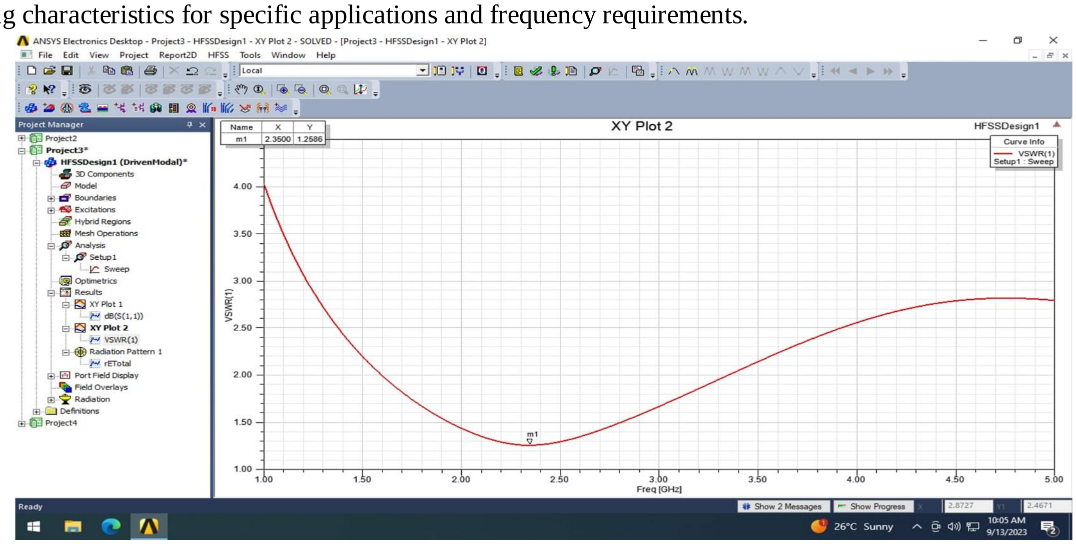

Fig 4.3 VSWR Vs. Frequency plot of elliptical patch antenna

A 3D polar plot for an elliptical patch antenna offers a detailed visual representation of how the antenna radiates or receives electromagnetic waves in three dimensions. This plot showcases the antenna's radiation pattern concerning both azimuth (horizontal) and elevation (vertical) angles, essentially creating a spherical view of its performance. The azimuth angle reveals how the antenna directs energy in various horizontal directions, providing insights into its directional characteristics. The elevation angle illustrates the antenna's behavior in the vertical plane. By examining the gain variation across different angles, the plot helps assess the antenna's coverage and directionality. Additionally, it can indicate the presence of side lobes, which are smaller radiation lobes in directions other than the main lobe. This comprehensive 3D polar plot is a valuable tool for antenna designers and engineers, enabling them to fine-tune elliptical patch antennas to meet specific application requirements and optimize their performance.

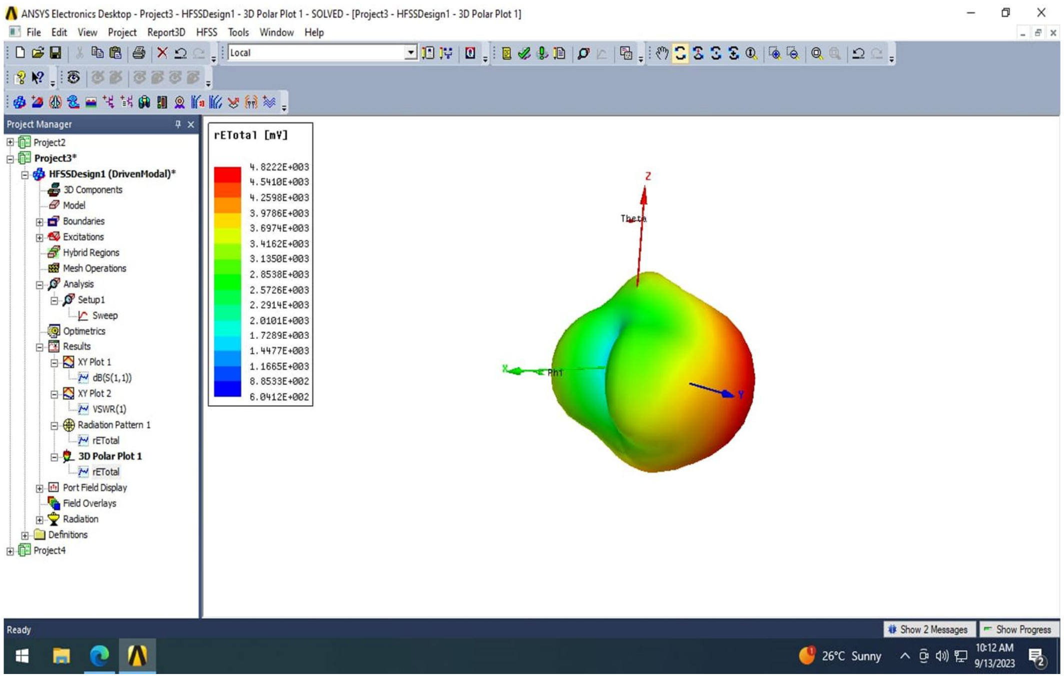

Fig 4.4 3D Polar Plot

VI. CONCLUSION AND FUTURE SCOPE

The elliptical patch antenna designed with an FR4 substrate and intended for operation at 2.4 GHz has been subject to comprehensive evaluation. At its core, the antenna's performance at 2.4 GHz has been rigorously examined, taking into account factors such as return loss, bandwidth, and radiation pattern to ensure it aligns with the original design specifications. An assessment has provided insights into how efficiently the antenna directs RF energy within the 2.4 GHz frequency range, including parameters like gain, s-parameter and VSWR. Additionally, the antenna's bandwidth, a crucial aspect for compatibility with applications like Wi-Fi, medical diagnosis has been scrutinized. The evaluation also considered practical factors such as manufacturability, size constraints, and ease of fabrication when employing FR4 as a substrate. Furthermore, a comparative analysis with other antenna types may provide context for its advantages and disadvantages. The overall conclusion underscores the antenna's performance, highlighting its strengths and areas for potential enhancement or optimization to better meet specific application requirements in the future.

Researchers are advancing skin cancer detection by improving elliptical antenna-based imaging techniques. They aim to optimize antenna designs, signal processing, and imaging systems for higher resolution and accuracy in identifying skin cancer. Additionally, integrating this technology with ultrasound, MRI, or optical imaging can provide a more comprehensive diagnosis. Quantitative analysis methods can extract tissue property data for better differentiation of skin conditions and treatment assessment. Machine learning and AI integration enhance accuracy and enable automated diagnosis. Advancements may lead to real-time imaging, aiding treatment monitoring. Portable devices could bring skin cancer detection to primary care settings, improving accessibility. Clinical trials are crucial for validation and comparison with established methods. Customized antenna arrays can increase sensitivity, and detailed imaging may enable personalized treatment planning. Telemedicine applications could allow remote consultations, particularly in underserved areas. Educational integration can train future healthcare professionals. Lastly, regulatory approvals and commercial partnerships are vital for market entry and ensuring safe and effective solutions.

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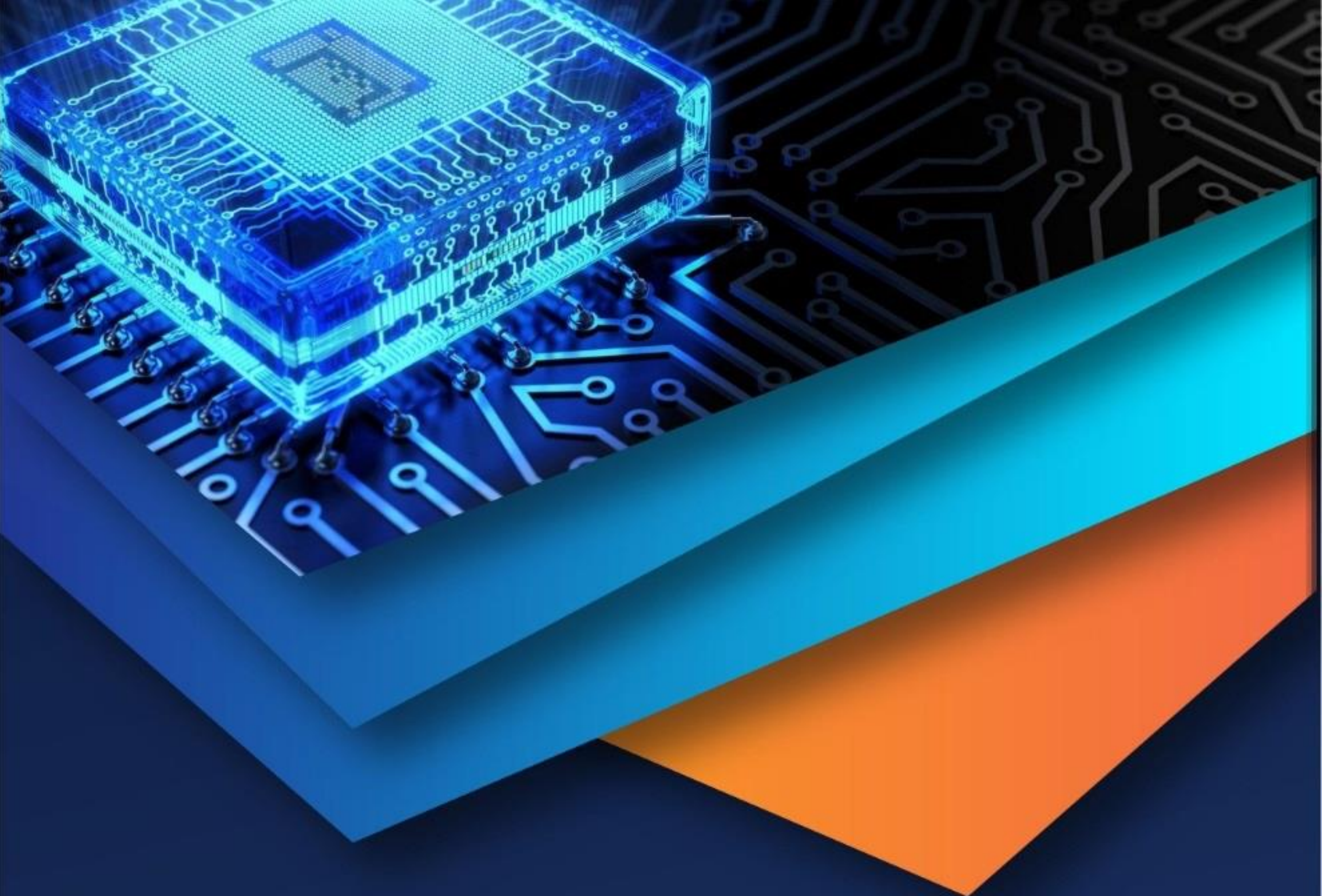

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