DESIGN AND IMPLEMENTATION OF MICROSTRIP PATCH ANTENNA FOR BIOMEDICAL APPLICATIONS

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ABSTRACT

Antennas play a pivotal role in modern wireless communication, facilitating connections between devices through wireless mediums by transmitting and receiving radio waves. In healthcare and biomedicine, BCWC as gained prominence due to advancements in miniaturized sensors, wearable electronics, and biomedical technologies. This has revolutionized the field by enabling continuous disease monitoring and treatment. The study focuses on modelling and characterizing microstrip patch antennas to identify dilated tissues, Heart Beat, Temperature Of the human body. Using antenna modelling instead of traditional biomedical sensors, the researchers achieved high directivity, gain, VSWR as 7.63dB, 2.9dB and 1.53. These results are attained in the frequency range of 2 to 2.5 GHz at a resonant frequency of 2.4 GHz. By using Defective Ground Surface and By Changing Geometric Values of Strip.

KEYWORDS

Biomedical, HFSS (High-Frequency Structure Simulator), BCWC (Body-Centric Wireless Communication), VSWR (Voltage Standing Wave Ratio), Directivity, Gain, DGS (Defective Ground Surface).

1.INTRODUCTION

A microstrip patch antenna is a planar antenna comprising a thin metallic patch on a dielectric substrate, backed by a ground plane. It operates at microwave frequencies, offering a compelling blend of performance, compactness, and ease of integration. This planar configuration, typically fabricated using printed circuit board (PCB) technology, allows for cost-effective mass production and seamless integration into various electronic devices. The fundamental principle of operation involves the excitation of electromagnetic fields within the dielectric substrate when an RF signal is applied to the patch. These fields, constrained by the patch's dimensions and the ground plane, establish resonant modes within the structure. By carefully designing the patch dimensions and selecting appropriate substrate materials, engineers can tailor the antenna's resonant frequency and radiation characteristics to meet specific application requirements. The versatility of microstrip patch antennas is evident in the variety of configurations available. Rectangular patch antennas, the most common type, offer a simple and straightforward design with well-understood characteristics. Circular patch antennas are particularly useful for applications requiring circular polarization, such as satellite communication, where the polarization of the transmitted or received wave rotates continuously. Square patch antennas strike a balance between performance and ease of fabrication, finding applications in various wireless systems. Elliptical patch antennas offer greater flexibility in shaping the radiation pattern by adjusting the eccentricity of the ellipse. Slot antennas, where a slot is cut into the ground plane, exhibit altered radiation characteristics and impedance characteristics. Microstrip array antennas, comprising multiple patch elements arranged in specific patterns, enhance gain, directivity, and enable beam steering. Efficiently delivering RF energy to the radiating patch is crucial for optimal antenna performance. Common feeding mechanisms include microstrip line feeds, probe feeds, aperture-coupled feeds, and coplanar waveguide feeds, each with its own advantages and limitations in terms of impedance matching, ease of implementation, and impact on the radiation pattern. Microstrip patch antennas offer several significant advantages, including low profile, ease of fabrication, versatility, and conformal design capabilities. These attributes make them highly suitable for a wide

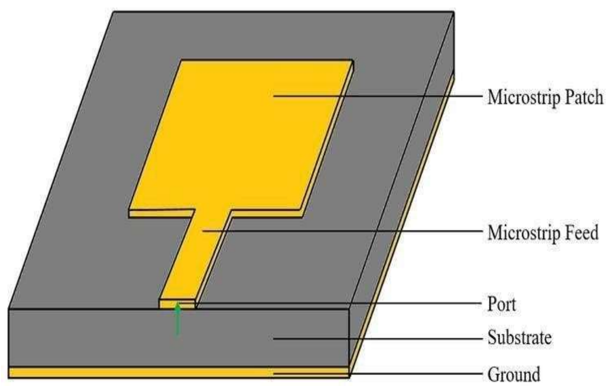


Figure 1. Microstrip Patch Antenna.

range of applications, from mobile phones and Wi-Fi routers to satellite communication systems, radar systems, remote sensing, automotive technologies, and biomedical applications.Common types of patch antennas include rectangular, circular, square, elliptical, slot, and microstrip array antennas, each offering unique radiation characteristics and suitable for different applications.

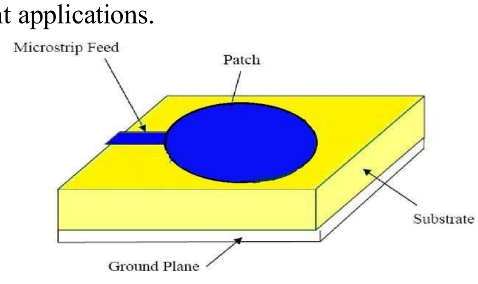


Figure 2: Circular Patch Antenna

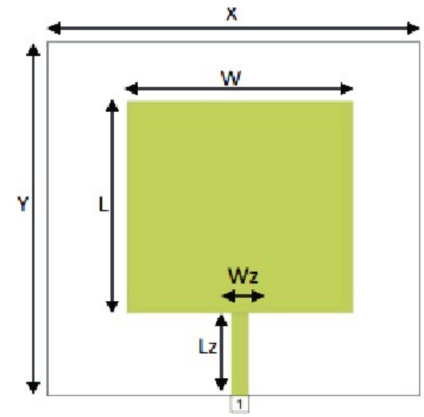


Figure 3: Square Patch Antenna

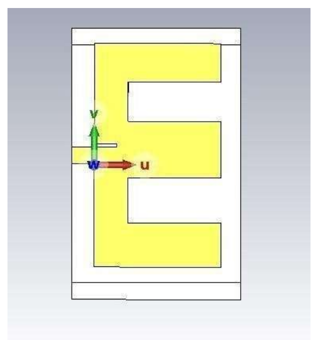


Figure 4: E-slot Patch Antenna

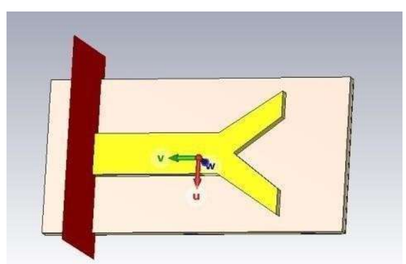


Figure 5: Y-slot Patch Antenna

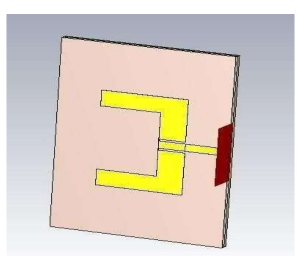


Figure 6: U-slot Patch Antenna

This study focuses on testing various microstrip patch configurations against software-based models of muscle and skin elements. The primary target audience for this research includes biomedical professionals and researchers interested in advancing tissue detection technologies. The sensor-based methods for detecting dilated tissues face challenges related to high costs and complex designs, especially for small-scale applications. To address these challenges, the proposed antenna-based detection system offers a simpler and more cost-effective alternative to traditional sensor designs, making it more accessible for biomedical applications. Additionally, this method allows for the identification of tissue types, which can aid in estimating cancer development and tumor stages, enhancing early diagnosis and treatment strategies.

2. Literature Survey

[1] The study by Younes Siraj, Kaoutar S. Alaoui, and Jaouad Foshi presents a dual-band patch antenna designed for biomedical applications, operating at 2.4 GHz and 3.33 GHz. This compact and efficient antenna is suitable for wearable and implantable medical devices, utilizing a lightweight and semi-flexible Taconic TLX™ substrate with a dielectric constant of 2.55, a low loss tangent of 0.0019, and a thickness of 0.7 mm. The design features a rectangular patch with an L-shaped slot and a partial ground plane, optimized using HFSS software. Key modifications improved impedance matching and enabled dual-band performance. The final design achieved reflection coefficients of -31.67 dB at 2.4 GHz and -20.25 dB at 3.33 GHz, with a peak gain of 5.09 dB at 2.4 GHz, ensuring efficient signal transmission.

[2] The study by Kenwin Patrick A, Kishore Kumar T, and Mukesh Kumar focuses on designing a miniaturized microstrip patch antenna for biomedical applications, specifically operating in the frequency range of 5.725 GHz to 5.825 GHz. This wearable antenna is suitable for stroke imaging and tumour detection in breast cancer and is fabricated using flexible substrates like jeans, cotton, and neoprene rubber. The compact design includes a ground plane and patch element, optimized for narrow bandwidth and minimal size. Designed using CST Studio Suite, the antenna achieved a simulated gain of 8.17 dB at 5.8 GHz, a minimum VSWR of 1.1912, and a return loss of -21.062 dB, indicating good impedance matching. The analysis of directivity and radiation patterns further confirms its suitability for high-performance biomedical applications.

[3] The study "Miniaturized and Energy Enhanced Microstrip Patch Antenna for Biomedical Applications" by Gautam Bhandari, Subhadeep Chatterjee, Dr. Bimal Raj Dutta, Safeer Ahmad, and Mayank Singh from Chandigarh University focuses on designing microstrip patch antennas for detecting dilated tissues in the human body. Operating in the 2 to 2.4 GHz frequency range with a resonant frequency of 2.11 GHz, the antenna achieves a directivity of 6.3339 dB, gain of 2.757 dB, VSWR of 1.012, S-parameters of -43.89 dB, and SAR of 1.4572 W/Kg. The research emphasizes the advantages of antenna modeling over traditional sensor-based methods, aiming to provide a simpler, cost-effective solution for tissue detection and potential applications in cancer monitoring.

[4] The study by Rishika S, M. Alagirisamy, N. Udhaya Kamali, Jenyfal Sampson, Dr. P. Sivakumar, and P. Uma Maheshwari focuses on designing a T-shaped patch antenna for medical applications, specifically operating at 2.483 GHz. The antenna, simulated using CST Microwave Studio, is chosen for its efficiency in tumour detection and remote health monitoring. It features a three-layer structure comprising a conducting substrate, ground plane, and patch layer, with dimensions optimized for the target frequency. A microstrip

feeding technique is utilized for ease of fabrication and minimal spurious radiation. The final design includes a patch thickness of 0.035 mm, a substrate height of 1.6 mm, and a dielectric constant of 4.7 (FR-4 material). Simulation results indicate a return loss of -10 dB, demonstrating effective impedance matching and efficient signal transmission, confirming its suitability for medical applications.

[5] The study by Naw Khu Say Wah and Hla MyoTun focuses on designing a microstrip patch antenna for S-band applications, targeting a resonant frequency of 2.42 GHz within the 2 GHz to 4 GHz range. The antenna features a stacked nearly square patch configuration on an FR-4 substrate with a dielectric constant of 4.4 and a thickness of1.6 mm. Using a coaxial probe feeding technique, simulation results from CST Microwave Studio indicate a return loss of -16.207 dB, a VSWR of 1.5, and a directivity of 5.57 db. The antenna achieves a bandwidth of 160.24 MHz (6.67%) and an efficiency of 96.34%. Although the design includes truncated corners for circular polarization, further optimization is required. The antenna is suitable for Wi-Fi applications (2.40-2.48 GHz) and CubeSat missions, with potential for enhancements to increase bandwidth and improve axial ratio performance.

[6] The study by Xie ZhenYun focuses on designing a microstrip antenna for medical applications, specifically for detecting various types of breast tissue, including tumors. The research leverages the differing electrical properties of tissues, such as conductivity and permittivity. Four antenna designs were simulated using HFSS, with the rectangular microstrip antenna with a gap demonstrating the best performance at a resonant frequency of 2.45 GHz and dimensions of 37.26 mm × 28.83 mm. Testing with a Vector Network Analyzer (VNA) on various biological tissues revealed that the S21 parameter varied with different tissue sizes and quantities. The results indicate the antenna's capability to differentiate between normal and tumor tissues, highlighting its potential for breast cancer diagnostics. Further validation in vivo is necessary to confirm its effectiveness.

[7] This study by S. Parasuraman, S. Logeswaran, and G.P. Ramesh presents a contour shape reconfigurable microstrip patch antenna for biomedical applications, operating between 8 GHz and 12 GHz. The lightweight and cost-effective design, built on a 1.6 mm thick FR4 substrate, features a contour shape that enhances performance. It utilizes four PIN diodes for switching between linear and circular polarization states. With a ground plane size of 100× 100 mm^2 and a 50 Ω microstrip line for feeding, the antenna achieved significant area reductions of 77% and 64% for its first and second resonant frequencies, respectively. The prototype demonstrated excellent return loss and a crosspolar level better than -10 dB, confirming its effectiveness for biomedical communication. Future work will focus on fabrication and performance analysis with ±45° polarization orientation.

3. Existing Work

The existing paper presents a comprehensive study on the design and testing of a microstrip patch antenna specifically tailored for medical applications, focusing on detecting dilated tissues within human body elements such as muscle and skin. This research thoroughly reviews the fundamental characteristics and operational principles of microstrip patch antennas, which have gained prominence in various fields due to their compact size, ease of fabrication, and versatility. The study delves into the design intricacies of four distinct types of microstrip patch antennas: the rectangular microstrip antenna, U-slot microstrip patch antenna, E-slot microstrip patch antenna, and Y-slot microstrip patch antenna. By strategically introducing slots into the geometries of these patch antennas, researchers have achieved significant improvements in key performance metrics, including gain, bandwidth, and Voltage Standing Wave Ratio (VSWR), making the antennas more suitable for specific applications, particularly in the biomedical field where precision and reliability are paramount. The design process was conducted using the CST Microwave Design Suite, a powerful simulation tool that allows for detailed analysis and optimization of antenna performance. For the substrate material, a cotton-based medium was selected, which is lightweight and biocompatible, making it an ideal choice for wearable medical devices. After designing and simulating all four types of microstrip patch antennas, the research team conducted a comparative analysis to evaluate their performance metrics, ultimately finding that the U-slot microstrip patch antenna demonstrated superior directivity and gain compared to the other configurations at a resonant frequency of 2.11 GHz. Following the selection of the U-slot design, the researchers meticulously calculated and analyzed various performance parameters, including S-parameters, VSWR, far-field gain, directivity, and Specific Absorption Rate (SAR) values, with results indicating notable enhancements over conventional designs, particularly in terms of increased bandwidth and reduced VSWR. The U- slot microstrip patch antenna achieved a bandwidth of 2 – 2.2 GHz and a gain of 2.757 dB, showcasing its versatility across a frequency range of 1 to 5 GHz, making it particularly applicable in biomedical technology and wearable devices, where the ability to operate effectively across multiple frequencies is crucial. The attributes of the U-slot microstrip patch antenna, including its safety, non-invasive nature, and high sensitivity, position it as a valuable tool for medical diagnosis and monitoring. The paper concludes that this antenna design is well-suited for a variety of biomedical applications, including continuous health monitoring, disease detection, and therapeutic interventions, and contributes significantly to the advancement of antenna technology, paving the way for innovative solutions across various sectors, including defense and healthcare, ultimately enhancing patient care and outcomes.

4. Design Methodology

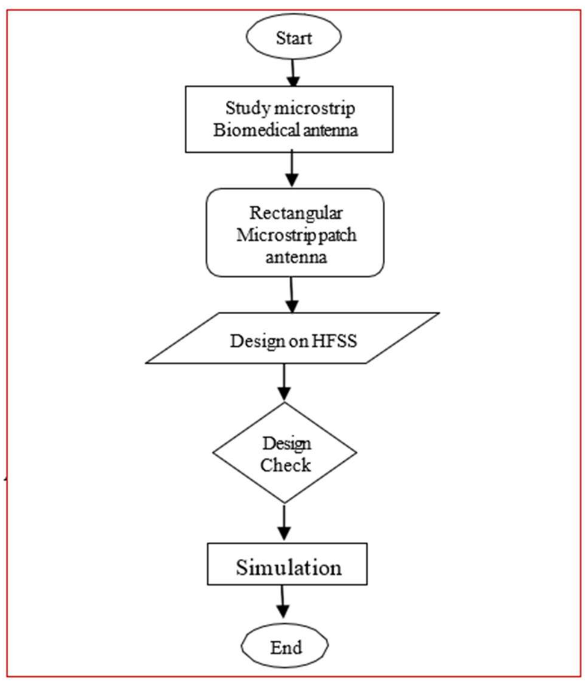


Figure 7: Methodology

The methodology for addressing the design of microstrip patch antennas begins with an extensive review of existing literature and studies pertinent to the problem statement, focusing on the principles and applications of microstrip patch antennas in biomedical contexts. Following this foundational research, the antenna designs are developed using the HFSS (High-Frequency Structure Simulator) microwave design suite, which provides a robust platform for simulation and analysis. Initially, a rectangular microstrip antenna is designed, after which a thorough design verification process is conducted to identify and rectify any errors encountered during the design phase. Corrections are made, and the revised design is re-simulated to ensure accuracy and performance. To enhance the realism of the simulations, phantom layers representing skin, fat, and tumor tissues are introduced, allowing for an assessment of the antenna's radiation effects on these biological layers. The results from three different design configurations are then compared based on various performance metrics and parameters, leading to the selection of the most suitable design. For the chosen configuration, critical performance indicators such as S-parameters, Voltage Standing Wave Ratio (VSWR), far-field gain, and directivity values are meticulously calculated, providing a comprehensive evaluation of the antenna's effectiveness for its intended biomedical applications.

The substrate used was FR-4(epoxy).FR-4 epoxy substrate is a widely used material in printed circuit board (PCB) fabrication, valued for its electrical insulation, mechanical strength, and thermal stability. With a dielectric constant of approximately 4.4, it is suitable for high- frequency applications in telecommunications, consumer electronics, and automotive industries. Its durability, resistance to environmental factors, cost-effectiveness, and ease of fabrication make FR-4 a preferred choice for various electronic devices. FR-4(epoxy)based material with specifications as shown in **Table 1.**

FR-4 EPOXY SUBSTRATE INFORMATION		
S.NO	PARAMETER	VALUE
1	Type	epoxy
2	Epsilon	4.4
3	Electric Conductance	0.001 S/m
4	Mu	1
5	Density	1850 kg/m^3
6	Thermal Conductivity	0.3 W/m-K

5. RESULT AND DISCUSSION

This paper discuss about the designed microstrip patch antenna for biomedical application using the HFSS Microwave Design Suite. As per the prescribed methodology in the previous portion the designing of the Rectangular microstrip patch antenna was completed and the result of the antenna was recorded.

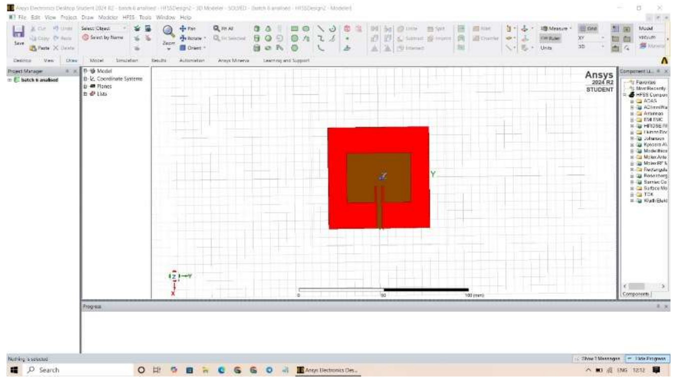


Figure 8: Rectangular Microstrip Patch Antenna

The rectangular microstrip patch antenna with FR-4 epoxy substrate as shown in the fig. 9.

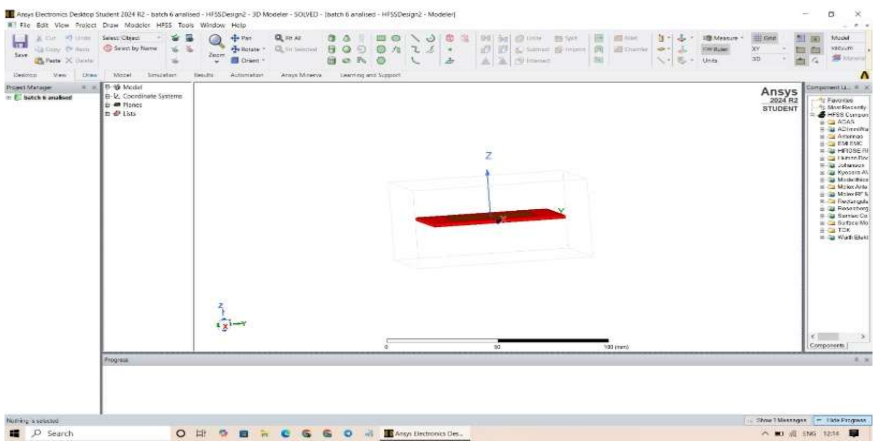


Figure 9: Rectangular Patch Antenna with FR-4 epoxy substrate

The S-parameter attained after the simulation valued -13.5620 at the resonant frequency of 2.4 GHz.

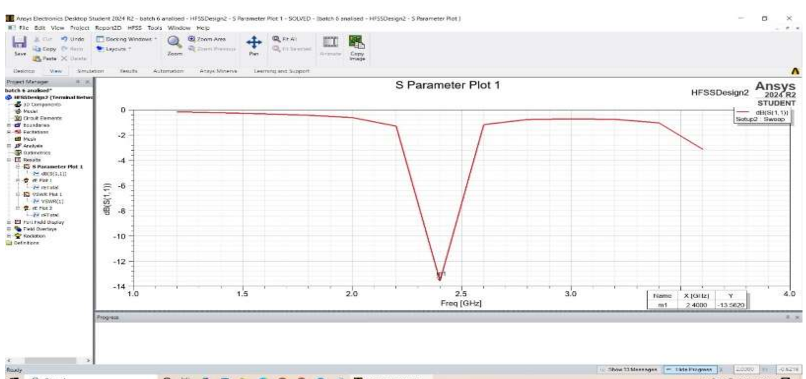


Figure 10: S-parameter at 2.4 GHz

The VSWR attained after the simulation valued 1.5312 at the resonant frequency of 2.4 GHz.

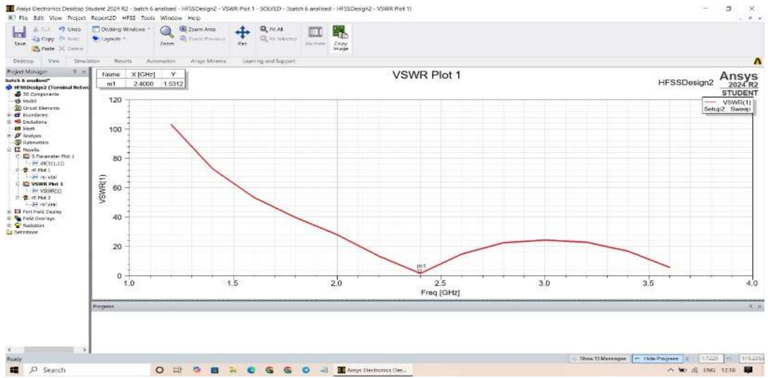
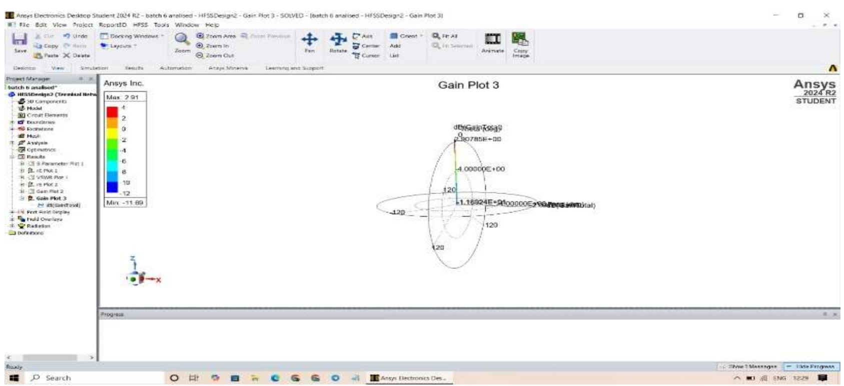
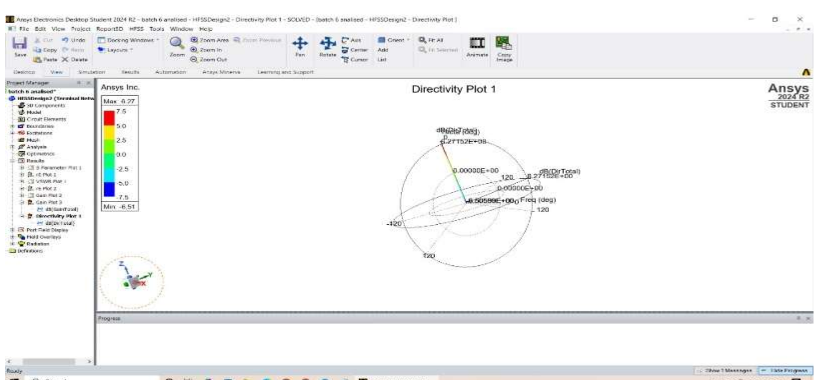


Figure 11: VSWR at 2.4 GHz

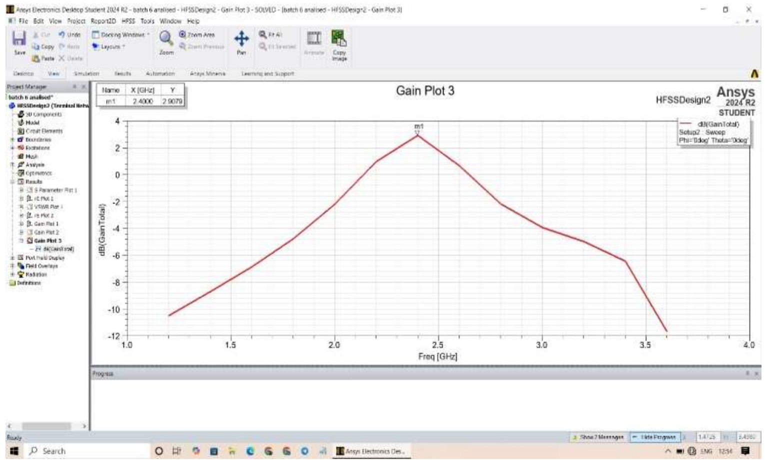
The farfield results that include the Directivity and Gain were calculated to the values of 7.62 dBi and 2.9 dBi respectively.



(a) Gain Plot



(b) Directivity Plot



(c) Gain at 2.4 GHz

Required Formulas:

To Calculate Resonant Frequency:

$f_r = (c/2L)*\text{sqrt}(\varepsilon_{eff})$

Where

f_r = resonant frequency (in Hz)

c = speed of the light (approximately 3 * 10^8 m/s)

L= length of the patch (in meters)

ε_{eff} = effective dielectric constant

The effective dielectric constant can be calculated by:

$\varepsilon_{eff} = (\varepsilon_r+1)/2+(\varepsilon_r - 1)/ 2* (1/ \text{sqrt}(1+ 12\ h/w))$

Where

ε_r = relative dielectric constant of the substrate

h = thickness of the substrate (in meters)

w= width of the patch (in meters)

TABLE II. COMPARISION OF RESULTS AND VALUES

Parameters	Values (Asper base paper)	Parameters	Values (As per our result)
S- Parameter (in dB at 2.11 GHz) i Substrate ii Skin iii Fat iv Tumor	i. -43.89 ii. -28.53 iii. -24.54 iv. -23.28	S-Parameter (in dB at 2.4 GHz)	Less than -14
VSWR	1.012	VSWR	1.5312
Farfield Directivity (in dBi)	6.333	Farfield Directivity (in dBi)	7.62
Farfield Gain (in dBi)	2.755	Farfield Gain (in dBi)	2.907
SAR (in W/Kg at 2.11GHz)	1.4572	SAR (in W/Kg at 2.11GHz)	Not mentioned

6. CONCLUSION

In conclusion, antenna design has emerged as a rapidly evolving technology, demonstrating substantial potential in facilitating wireless connectivity for body sensor networks, which are crucial for modern medical applications. The inherent characteristics of antennas, such as being safe, non- invasive, and highly sensitive, position them as invaluable tools for medical diagnostics, enabling real-time monitoring of various health parameters. Additionally, the simplicity, cost-effectiveness, and minimally invasive nature of antenna-based techniques make them particularly promising for applications like thermal ablation, where precision and safety are paramount. This project underscores the transformative role of antenna design in advancing medical technologies, offering innovative and accessible solutions that can significantly enhance healthcare practices. A comprehensive investigation has been conducted, identifying critical design challenges while presenting effective and meticulously crafted solutions that leverage the capabilities of advanced antenna technologies. This theoretical research delves into the intricacies of microstrip patch antennas, with a specific focus on mitigating inherent limitations that may affect performance. By strategically incorporating slots into the geometries of the patch antennas, significant improvements in gain, bandwidth, and Voltage Standing Wave Ratio (VSWR) have been achieved, rendering the antennas more suitable for specific applications. The developed rectangular microstrip patch antenna, thoroughly analyzed using the High-Frequency Structure Simulator, exhibits notable enhancements over conventional microstrip antennas. The simulation results indicate a substantial increase in bandwidth, coupled with a reduction in VSWR, which collectively contribute to an overall improvement in antenna efficiency. With a bandwidth ranging from 2.2 to 2.8 GHz and impressive metrics for return loss, directivity, and gain, the antenna's versatility is further underscored by its applicability across a frequency range of 1 to 6 GHz. The achieved gain of 2.9 dB highlights its effectiveness in practical applications, particularly in the fields of biomedical technology and wearable devices, where it holds promise for various adaptations in defense, healthcare, and other diverse sectors. Furthermore, the substrate utilized for the antenna design is FR-4 epoxy, a material renowned for its excellent electrical insulation, mechanical strength, and thermal stability, making it particularly suitable for high-frequency applications. The findings of this project not only contribute to the advancement of antenna technology but also pave the way for innovative solutions across multiple domains, ultimately enhancing the landscape of modern healthcare and technology integration.

7. Acknowledgements

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B. Tech in Electronics and Communication Engineering, Final Year Student Godavari Global University, Rajahmundry, Andhra Pradesh, India. My goal is to contribute to the development of more efficient, high-performance antennas that will drive the next generation of wireless communication systems, especially in the context of 5G, IoT, and autonomous systems.