FINAL YEAR PROJECT ON

DESIGN OF BROADBAND WEARABLE ANTENNA FOR IOT AND MEDICAL APPLICATION

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Under the guidance of

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A Project Report

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CERTIFICATE OF ORIGINALITY

This is to certify, that the project report submitted by us is an outcome of our independent and original work. We have duly acknowledged all the sources from which the ideas and extracts have been taken. The project is free from any plagiarism and has not been submitted elsewhere for publication. We the group members certify the above Statement of Originality.

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ABSTRACT

The project titled "**Design of Broadband Wearable Antenna for IoT and Medical Application**" focuses on the development of a compact, flexible, and broadband antenna tailored for IoT and healthcare systems. The antenna is designed to operate efficiently across a frequency range of 3.5–18 GHz, enabling compatibility with various IoT protocols and medical diagnostic applications. It features broadband operation to support diverse telemetry needs, a compact and flexible design to ensure user comfort and adaptability, and adherence to safety standards such as Specific Absorption Rate (SAR) for safe and prolonged use. By employing advanced techniques like impedance matching, careful substrate selection using FR-4 lossy material, and miniaturization, the antenna achieves remarkable performance in simulations. The design effectively addresses challenges such as electromagnetic interference and energy efficiency, making it a scalable solution for next-generation wearable devices in IoT and healthcare domains. The antenna exhibits stable radiation patterns and high gain across the operating bandwidth, ensuring reliable data transmission in dynamic body-centric environments. The design incorporates human body loading effects to ensure real-world performance accuracy. It also offers potential for integration with smart textiles and flexible electronics, paving the way for seamless incorporation into wearable platforms. This makes the antenna a strong candidate for practical deployment in real-time health monitoring and smart IoT ecosystems.

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CHAPTER 1: INTRODUCTION

The rapid advancement of wireless communication and IoT has driven the demand for wearable antennas that are lightweight, flexible, and broadband. These antennas, embedded in clothing or accessories, enable applications like fitness tracking, health monitoring, smart textiles, and industrial automation. Their seamless integration into daily wearables ensures constant connectivity and mobility without compromising comfort. As wearable technology evolves, the need for reliable, high-performance antennas becomes increasingly critical.In the medical field, wearable antennas support real-time health monitoring and remote diagnostics, transmitting vital data such as heart rate and glucose levels. Operating efficiently near the human body (3.5–18 GHz) requires overcoming challenges like electromagnetic absorption and detuning while adhering to SAR safety standards. This necessitates robust design strategies that ensure consistent performance regardless of body movement or environmental changes. Maintaining low power consumption is also vital for prolonged usage in health monitoring devices.

This project focuses on the design of a broadband wearable antenna utilizing an FR-4 lossy substrate, achieving a balance between performance, flexibility, and manufacturability. The antenna is characterized by its broadband operation, making it compatible with technologies such as Wi-Fi, Bluetooth, and medical telemetry. FR-4, being cost-effective and readily available, also aids in scalable production of wearable systems. The design ensures mechanical robustness while minimizing weight, crucial for wearable comfort. It's compact and flexible design ensures user comfort and adaptability for various applications. Additionally, the antenna prioritizes safe human interaction by adhering to Specific Absorption Rate (SAR) standards, with features to minimize detuning effects caused by proximity to the human body. Simulated SAR values are kept well below permissible limits, ensuring regulatory compliance. Special care is taken to maintain performance when the antenna is in close contact with skin or other tissues.

Techniques like impedance matching, miniaturization, and simulation optimize characteristics like return loss and gain. This work provides a foundation for innovations in wearable IoT and healthcare, paving the way for smarter, more connected devices. Advanced simulation tools like CST or HFSS validate the design before prototyping, reducing development cycles and ensuring accurate electromagnetic behavior near the human body. Future work can explore biocompatible materials and integration with textile fibers for next-generation applications. Machine learning algorithms may also be incorporated to dynamically tune antenna parameters in real time based on user activity and environmental factors. Additionally, the implementation of reconfigurable antenna structures could allow multi-band operation and adaptability across diverse wireless standards. Energy harvesting and self-powered antenna systems are promising areas that can further enhance the autonomy and sustainability of wearable electronics.

CHAPTER 2: REVIEW OF PREVIOUS WORK

The design and development of wearable antennas for Internet of Things (IoT) and medical applications have gained considerable momentum in recent years. As wearable devices become more integral to healthcare, fitness, military, and industrial sectors, research has increasingly focused on improving antenna performance, flexibility, biocompatibility, and integration with fabrics and smart textiles. The push towards compact, lightweight, and broadband designs has opened up new possibilities in real-time monitoring, wireless communication, and human-centric sensing technologies.

Reference [1], *"Wearable Textile Patch Antenna: Challenges and Future Directions,"* presents an in-depth exploration of low-dielectric textile materials such as polyester and denim, which offer significant advantages in terms of bandwidth enhancement and mechanical flexibility. The study demonstrates that using such fabrics leads to improved impedance bandwidth, making them suitable for applications in Wireless Body Area Networks (WBANs), medical imaging, and pervasive wearable systems. The research also discusses manufacturing challenges and durability concerns associated with integrating antennas into garments, calling for further innovation in conductive textiles and encapsulation techniques.

Reference [2], *"Wearable Antennas: A Review of Materials, Structures, and Innovative Features for Autonomous Communication and Sensing,"* underscores the growing importance of flexible dielectric materials such as Kapton and PET (Polyethylene Terephthalate). These substrates enable the development of reconfigurable and conformal antennas that are compatible with the emerging requirements of 5G and future 6G wireless systems. Such flexibility is essential in real-time healthcare monitoring, where antennas must conform to body contours and withstand repeated movement. The review further explores stretchable conductive inks and nanomaterials, which allow antenna performance to remain stable despite mechanical deformation.

Reference [3], *"Wearable Textile Antennas,"* focuses on the impact of dielectric constant on the efficiency and reliability of wearable antennas. It illustrates how materials with low dielectric constants reduce surface wave losses and improve radiation efficiency, which is especially beneficial in health monitoring systems, wearable ECG devices, and military communication equipment. The study also highlights the role of textile weave density and thickness in tuning antenna characteristics, emphasizing the need for comprehensive electromagnetic characterization of wearable substrates.

Reference [4], from *"Wearable BAN: Military and Defence, Wearable Health Monitoring,"* explores innovative substrates such as carbon nanotubes and conductive textiles, which offer promising features like multimodal sensing, high conductivity, and mechanical flexibility. These materials support the mass production of low-cost wearable antennas for both healthcare monitoring and Radio-Frequency Identification (RFID) applications. The integration of smart materials also facilitates the design of multiband antennas, enabling them to operate across various communication standards without compromising performance or comfort.

Reference [5], *"A Textile Antenna for Off-Body Communication Integrated Into Protective Clothing for Firefighters,"* presents a unique application of Shield it Super and Electron materials, which are known for their high shielding effectiveness and durability. Operating at 2.43 GHz, these antennas enable reliable off-body communication, which is critical in emergency and rescue operations. The study illustrates how wearable antennas can be integrated into protective clothing, providing robust communication links for first responders in hazardous environments while maintaining electromagnetic compatibility and thermal stability.

Reference [6], *"Wearable Textile-Based Antenna using Different Textile Materials for Wireless Applications,"* investigates the effect of fabric properties—such as dielectric constant, thickness, and loss tangent—on antenna efficiency. The study particularly emphasizes cotton-based substrates, which exhibit favourable dielectric behaviour and are widely used due to their breathability, comfort, and availability. The research shows that by optimizing the textile substrate and conductive layer, one can achieve efficient wireless communication performance, making these designs suitable for long-term usage in body-worn sensors and smart clothing.

Reference [7], *"Design and Analysis of Wearable Antenna for Wireless Body Area Network,"* focuses on planar inverted-F antenna (PIFA) designs, which are well-known for their low-profile structure and low SAR values. These antennas offer omnidirectional radiation, making them highly suitable for body parameter monitoring applications in WBANs. The paper also discusses miniaturization techniques and performance tuning to ensure that the antenna maintains consistent behavior when placed near or on the human body.

Reference [8], *"Review of the Current Design on Wearable Antenna in Medical Field and Its Challenges,"* examines the adoption of microstrip patch antennas for remote health monitoring applications. The review outlines how such antennas, due to their planar geometry and integration ease, are ideal for continuous monitoring of vital signs such as ECG, temperature, and blood glucose levels. It also elaborates on challenges such as biocompatibility, antenna-body coupling, detuning effects, and the need for SAR optimization, which are essential for regulatory approval and patient safety.

This collective body of research highlights the diverse approaches, novel materials, and engineering innovations that have propelled the field of wearable antennas forward. Each study contributes to a growing understanding of how material science, antenna theory, and practical application design intersect to create reliable, efficient, and user-friendly wearable communication systems. These insights are critical in informing the development of next-generation antennas that not only perform across broad frequency bands but also meet the stringent requirements of wearable medical devices, IoT ecosystems, and future wireless technologies.

CHAPTER 3: THEORETICAL BACKGROUND

3.1 Introduction

The design of a broadband wearable antenna for IoT and medical applications necessitates a deep understanding of antenna theory, human-body interactions, and broadband design principles. This section explores the theoretical foundations and methodologies essential for the development and evaluation of wearable antennas.

Fundamentally, an antenna acts as a transducer, converting electrical signals into electromagnetic waves and vice versa. For wearable applications, antennas are crucial components of communication systems, enabling efficient data transmission over air interfaces. Several parameters define the performance of an antenna, including resonant frequency, bandwidth, gain, efficiency, radiation pattern, and impedance matching. The resonant frequency is the specific point at which the antenna radiates or receives energy most efficiently. Bandwidth determines the range of frequencies over which the antenna operates effectively, with broadband antennas offering significantly wider operational ranges. Gain and efficiency measure the effectiveness of power radiation in a specific direction and the conversion of input power into radiated waves. The radiation pattern describes the spatial distribution of energy, establishing the coverage area of the antenna. Proper impedance matching ensures minimal power reflection by aligning the antenna's impedance with the feed line's impedance.

Broadband performance is achieved through various design principles. Incorporating slots in the radiating structure enhances bandwidth and introduces multiple resonances. Fractal geometries, characterized by self-similar and space-efficient designs, increase the electrical length while maintaining compact dimensions. Planar monopole antennas, widely used in IoT systems, are simple in structure yet offer broad frequency coverage. Techniques such as stub matching, capacitive loading, and tapered feed lines are employed to optimize impedance matching and minimize signal reflections.

Operating in close proximity to the human body, wearable antennas face unique challenges. The interaction with body tissues can lead to energy absorption, detuning, and efficiency reduction due to the body's high dielectric properties. Ensuring compliance with Specific Absorption Rate (SAR) standards is vital for safe use in medical applications. To address these issues, shielding layers and ground planes are implemented to minimize detuning and mitigate energy absorption, thereby stabilizing antenna performance.
The choice of materials plays a significant role in wearable antenna design. Substrates such as textiles, polymers, and FR-4 lossy materials are chosen for their flexibility and compatibility with human skin. Conductive materials like copper, silver, and conductive fabrics are commonly used for radiating elements. Advanced designs increasingly utilize nanomaterials like graphene to improve conductivity and reduce size, enhancing overall performance.

Wearable antennas face several challenges, including ensuring flexibility and durability under bending, stretching, and environmental exposure. Miniaturization is critical for seamless integration into wearable devices, while electromagnetic compatibility must be maintained to prevent interference with other electronic systems. Achieving stable broadband performance across multiple frequency
Advanced simulation tools are indispensable for the design and optimization of antennas.

Software such as HFSS, CST Microwave Studio, and MATLAB allows for accurate 14odelling of antenna structures, analysis of radiation patterns, bandwidth, and gain, as well as evaluation of human-body interactions and SAR levels.
In conclusion, the theoretical foundations explored here provide the framework for designing broadband wearable antennas that meet the stringent requirements of IoT and medical applications. The subsequent sections will detail the practical implementation and performance evaluation of a compact, efficient, and safe antenna operating across the 3.5–18 GHz frequency range.

3.2 Microstrip patch antenna

A microstrip patch antenna is a type of antenna that features a radiating patch on one side of a dielectric substrate, with a ground plane located on the opposite side. This innovative design was formally introduced in 1972 by Robert E. Munson and John Q. Howell, although the foundational concept was proposed earlier in 1953 by G.A. Deschamps.
The microstrip patch antenna is particularly well-suited for wearable antenna applications due to its advantageous properties. Its high directivity ensures focused radiation, which is critical for effective communication in IoT and medical applications. The simplicity of its construction allows for easy fabrication, making it accessible for diverse applications. Furthermore, its cost-effectiveness makes it an economical choice for mass production in wearable devices. One of the most significant benefits of this design is the natural isolation it provides between the radiating element and the human body, minimizing detuning effects and ensuring user safety.
Given these attributes, the microstrip patch antenna becomes an ideal choice for the development of wearable antennas tailored for IoT and medical applications.

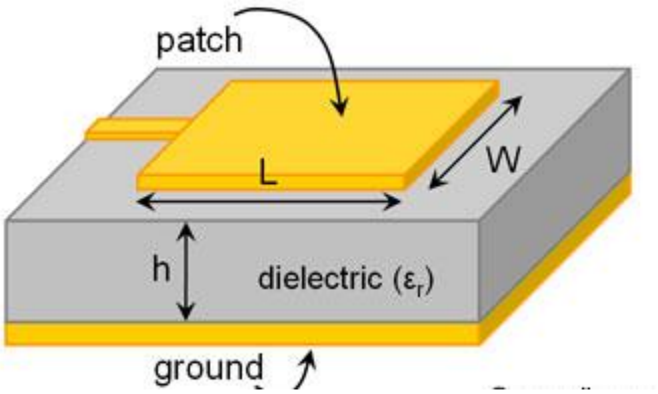


Fig 3.2.1: Microstrip patch antenna design

3.3 Basic principle of operation:

The operation of a microstrip patch antenna is based on the propagation and radiation of electromagnetic waves. When an electromagnetic signal is fed into the microstrip line, waves propagate along its surface. As these waves reach the edges of the patch, they are reflected, creating standing wave patterns.

Radiation primarily occurs from the edges of the patch due to the fringing fields, which extend beyond the physical boundaries of the patch. This process facilitates the efficient conversion of electrical signals into electromagnetic waves, enabling the antenna to transmit and receive signals effectively. This fundamental mechanism makes the microstrip patch antenna a compact and efficient solution for wearable IoT and medical applications. The radiation efficiency and resonant frequency of the microstrip patch antenna are influenced by factors such as the dielectric constant of the substrate, patch dimensions, and substrate thickness. Proper impedance matching is crucial to minimize signal reflection and maximize power transfer, ensuring optimal performance. Moreover, the low-profile and conformal nature of microstrip patch antennas allows seamless integration into clothing or wearable devices without compromising user comfort. Their ability to operate over wide frequency ranges with relatively simple fabrication techniques makes them ideal for modern wireless applications, including continuous health monitoring and real-time data transmission in IoT ecosystems.

3.4 Different shapes of microstrip patch antenna elements:

Microstrip patch antennas can be designed in a variety of shapes such as rectangular, circular, triangular, elliptical, and more complex geometries. Each shape offers unique advantages in terms of bandwidth, size, radiation pattern, and ease of fabrication. The choice of shape depends on the application requirements, with modified geometries often used to enhance performance or achieve miniaturization.

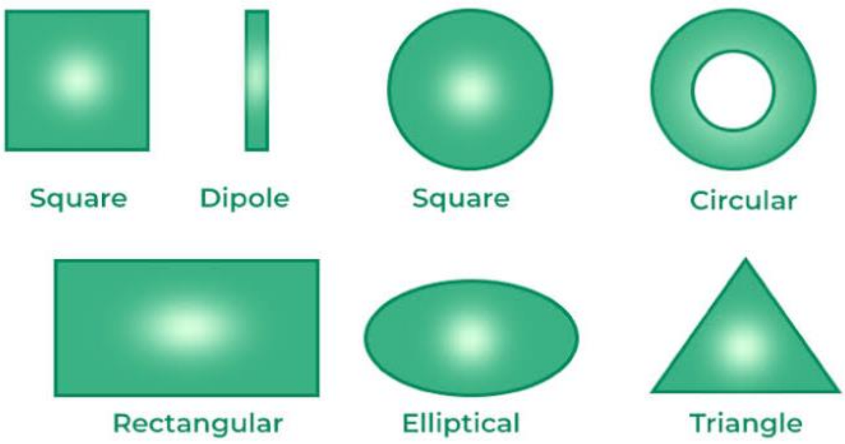


Fig 3.4.1: Different Shapes of microstrip patch antenna

3.5 Feed Technique & CST Software

There are different type of feed technique through which microstrip patch antenna is fed. Feeding technique is the important design parameter which influences the input impedance and characteristics of the antenna. Some of them are Coaxial feed, Microstrip line, Electromagnetic coupling, Aperture coupled, Coplanar waveguide. Each feeding technique has its own advantages and trade-offs in terms of complexity, bandwidth, ease of fabrication, and coupling efficiency. For instance, coaxial feed offers good impedance matching and easy integration, while microstrip line feed is simpler to fabricate and well-suited for planar designs.

CST Studio Suite is a robust and widely used software tool for the design, simulation, and analysis of microstrip patch antennas. It provides engineers and researchers with advanced tools to simulate electromagnetic behaviors and optimize antenna performance effectively. Its intuitive user interface and versatile solvers make it indispensable for complex antenna designs. Electromagnetic and aperture coupling techniques provide improved bandwidth and isolation but are more complex to implement. In CST Studio Suite, these feed techniques can be accurately modeled and analyzed using time-domain and frequency-domain solvers. The software also allows for the visualization of key parameters such as return loss (S11), gain, radiation patterns, and SAR, enabling thorough performance evaluation and compliance with safety standards in wearable applications.

3.6 Advantages of using CST for microstrip patch antennas:

- **Comprehensive Simulation Tools:** CST Studio Suite offers a range of solvers to model different aspects of the antenna design (e.g., radiation, impedance, and bandwidth).
- **Accurate Results:** The full-wave electromagnetic solvers provide accurate and reliable results for microstrip patch antenna designs.
- **Optimization:** CST Studio Suite’s optimization tools enable the fine-tuning of antenna dimensions, feed locations, and other parameters to achieve the best performance.
- **Visualization:** The 3D field and radiation pattern visualization tools help designers to understand the behavior of the antenna and make informed design decisions.
- **Multiphysics Simulation**: For advanced designs, CST supports Multiphysics simulations that account for thermal, mechanical, and other effects on the antenna’s performance.

CHAPTER 4: DESIGN AND SIMULATION

This chapter discusses the methodology employed for designing and simulating a broadband wearable antenna tailored for Internet of Things (IoT) and medical applications. The focus lies on the step-by-step design principles, material selection, electromagnetic simulation tools, and performance evaluation techniques that were systematically applied to ensure the antenna meets the required standards. Emphasis was placed on achieving a balance between high-frequency performance, miniaturization, flexibility, and safety in proximity to the human body. The design specifications were meticulously defined to meet the fundamental requirements of broadband operation, compact size, and compatibility with flexible, wearable, and biomedical systems. A broad frequency range of 3.5–18 GHz was selected, ensuring the antenna supports a wide spectrum of services, including Wi-Fi (2.4/5 GHz), Bluetooth, UWB communication, and various medical telemetry bands. The antenna needed to be compact, lightweight, and structurally simple to ensure effortless integration into garments, wristbands, or body patches. These characteristics are crucial for enabling user comfort during prolonged usage in dynamic environments.

For material selection, an FR-4 lossy substrate was chosen due to its widespread use in PCB manufacturing, cost-effectiveness, and ease of handling. It possesses a dielectric constant (εr) of 4.4 and a thickness of 1.6 mm, which makes it a practical and manufacturable choice while offering acceptable electrical properties for broadband operation. Although FR-4 is inherently lossy at higher frequencies, proper design techniques were employed to mitigate performance degradation. Safety was a critical consideration from the outset, particularly ensuring that the Specific Absorption Rate (SAR) remained well within acceptable limits (e.g., 1.6 W/kg for 1g tissue in the US, 2 W/kg for 10g tissue in the EU), thus guaranteeing user safety during close-body operation, especially in medical contexts. The antenna structure incorporated several essential components. The radiating element consisted of a monopole patch modified with strategically introduced slots to facilitate bandwidth enhancement. These slots acted as resonant perturbations, enabling the antenna to support multiple resonant modes across the operating frequency range. A partial ground plane was implemented to improve impedance matching, suppress surface waves, and support wideband characteristics. The use of a microstrip feed line enabled easy fabrication and integration with wearable circuits, offering a planar and low-profile interface between the antenna and associated electronics.

The design methodology followed a sequential approach. Initial calculations, based on standard microstrip patch antenna theory, were used to estimate the fundamental dimensions of the patch, feed line, and substrate. These initial dimensions provided a foundation for modeling and simulation. Subsequently, slot-loading techniques were applied to the radiating patch to generate additional resonances and broaden the bandwidth. Parametric optimization followed, during which dimensions such as patch length, slot width, and ground plane size were iteratively adjusted to fine-tune the antenna's response. These modifications were guided by simulated S-parameters, gain, and radiation efficiency results.

The simulation phase was carried out using CST Microwave Studio, a widely-used electromagnetic simulation tool capable of full-wave 3D analysis. The antenna geometry was precisely modeled, and appropriate boundary conditions (such as open add space and perfectly matched layers) were applied to mimic free-space and on-body operation. A fine hexahedral mesh was used to ensure high-resolution results, especially in regions of high field concentration like the feed point and slot areas. A frequency sweep from 3.5 GHz to 18 GHz was performed to assess return loss (S11), impedance bandwidth, gain, radiation patterns, and SAR characteristics. The simulation results were thoroughly analyzed using multiple performance metrics. The return loss was observed to be below -10 dB across the entire band, indicating excellent impedance matching and minimal signal reflection. The omnidirectional radiation pattern in the H-plane confirmed that the antenna could effectively radiate in all directions, which is ideal for mobile users and body-worn scenarios. A peak gain of approximately 6.18 dBi was achieved, adequate for short-to-medium range communication typical in IoT and healthcare devices. The measured bandwidth exceeded 14 GHz, confirming the antenna’s ability to operate over an ultra-wide frequency range.

Importantly, SAR analysis was conducted using a multilayer human tissue phantom model, ensuring that electromagnetic exposure to human tissue remained within internationally accepted safety standards. The maximum SAR values were significantly below threshold levels, reinforcing the antenna's suitability for biomedical and wearable applications. Simulations also included antenna placement on a human body model to account for detuning effects, validating its robust performance under real-world usage conditions. Multiple design iterations were performed to optimize antenna performance. The shape, size, and orientation of the slots were varied extensively to achieve the best trade-off between bandwidth and gain. Additionally, the thickness and dielectric properties of the substrate were evaluated to strike a balance between flexibility, efficiency, and structural integrity. The partial ground plane geometry was refined to further improve impedance matching and radiation efficiency. Iterative tuning using CST's optimizer module helped in converging toward an optimal design with minimal manual effort.

The final antenna design achieved broadband operation across the full 3.5–18 GHz frequency range, while maintaining compact dimensions suitable for wearable integration. It met all critical performance targets including gain, bandwidth, radiation pattern, and SAR compliance. The design was benchmarked against existing antennas from recent literature, and it demonstrated competitive or superior performance, especially in terms of miniaturization and bandwidth. These results confirm the design’s suitability for next-generation wearable medical and IoT devices.

In conclusion, the design and simulation process presented in this chapter validates the effectiveness and practicality of the proposed broadband wearable antenna. The use of standard materials, thoughtful design techniques, and rigorous electromagnetic evaluation highlights its potential for mass production and real-world deployment. The next chapter will present a detailed performance analysis and comparison with contemporary designs, discussing how the proposed antenna meets the challenges of real-world implementation, including mechanical robustness, durability, and integration with wearable systems.

4.1 The Microstrip Patch Antenna Calculation Process

Step 1: Calculation of the Width (W) –

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

Step 2: Calculation of the Effective Dielectric Constant. This is based on the height, dielectric constant of the dielectric and the calculated width of the patch antenna.

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

Step 3: Calculation of the Effective length

$$L_{eff} = \frac{c}{2f_o\sqrt{\varepsilon_{eff}}}$$

Step 4: Calculation of the length extension ΔL

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

Step 5: Calculation of actual length of the patch

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

<u>Where the following parameters are used</u>

f_0 is the Resonance Frequency

W is the Width of the Patch

L is the Length of the Patch

h is the thickness

ε_r is the relative Permittivity of the dielectric substrate

c is the Speed of light: 3×10^8 m/s

4.2 DESIGN METHODOLGIES

Design steps: 1

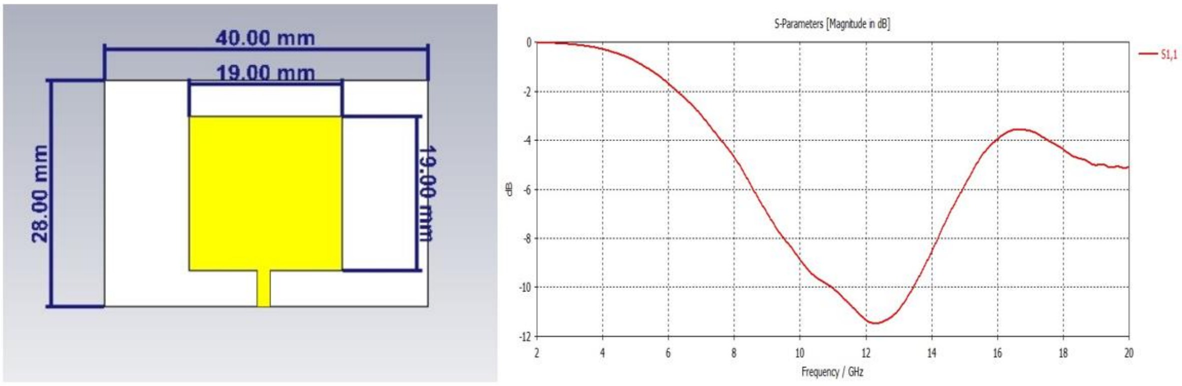


Fig 4.2.1: Initial square-shape patch antenna structure with microstrip feed and partial ground plane.

The design begins with a simple square patch antenna. This structure provides a basic radiation mechanism and serves as the foundation for further enhancements in bandwidth and impedance matching.

Design steps: 2

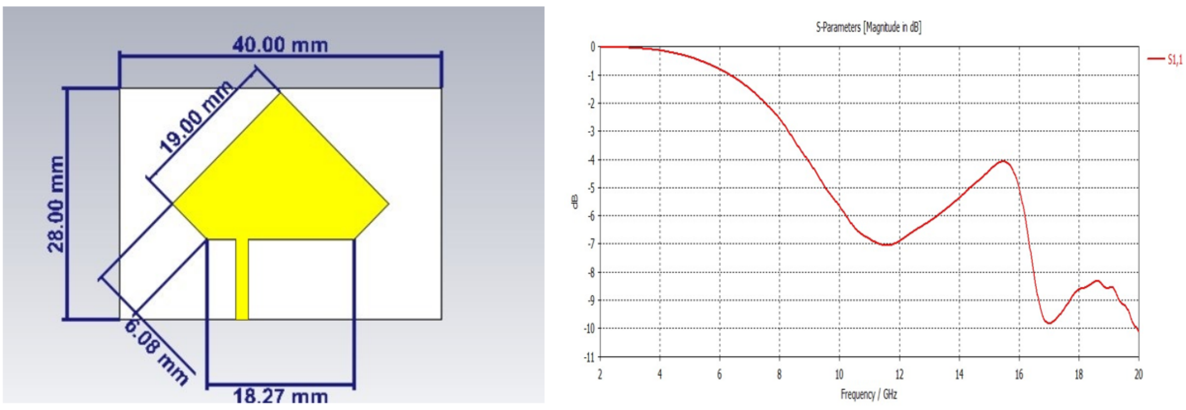


Fig 4.2.2: Rotated square patch with a bottom cut to alter current distribution and improve bandwidth.

In the second step, the square patch is rotated diagonally and trimmed from the bottom. This modification changes the current path, which helps increase the operational bandwidth and shift the resonant frequencies.

Design steps: 3

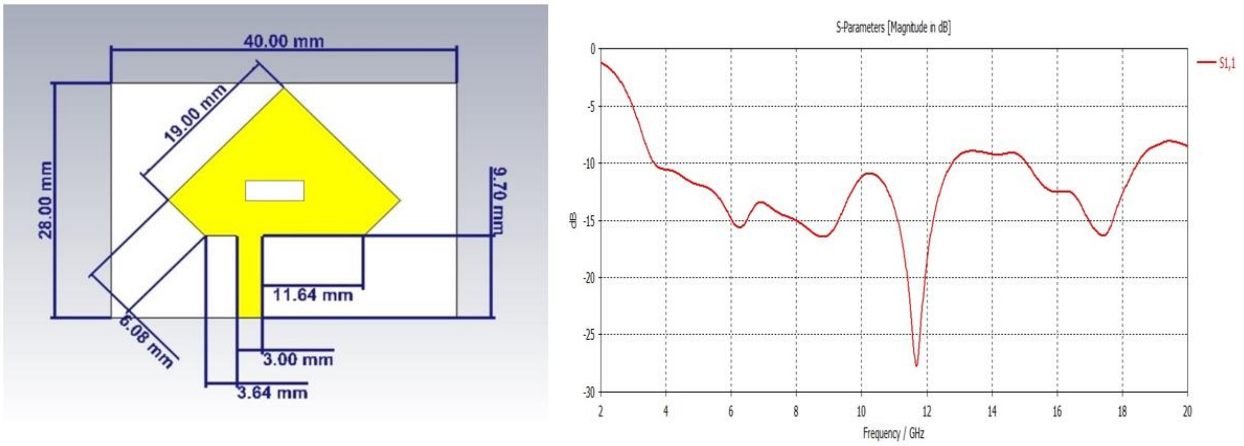


Fig 4.2.3: Final antenna design with a central slot introduced to achieve impedance matching and improve return loss.

A rectangular slot is introduced in the center of the patch to further enhance performance. This slot creates multiple resonant paths, allowing the antenna to achieve better impedance matching and maintain return loss below –10 dB across the operating band.

4.3 FINAL PROPOSED ANETNNA DESIGN

The final proposed antenna design incorporates an optimized slot-loaded geometry and a partial ground plane to achieve broadband performance, low SAR, and compatibility with wearable medical and IoT applications.

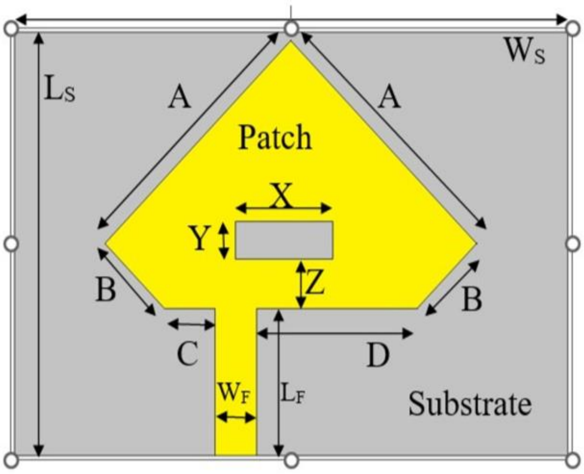


Fig 4.2.1: Final proposed antenna design

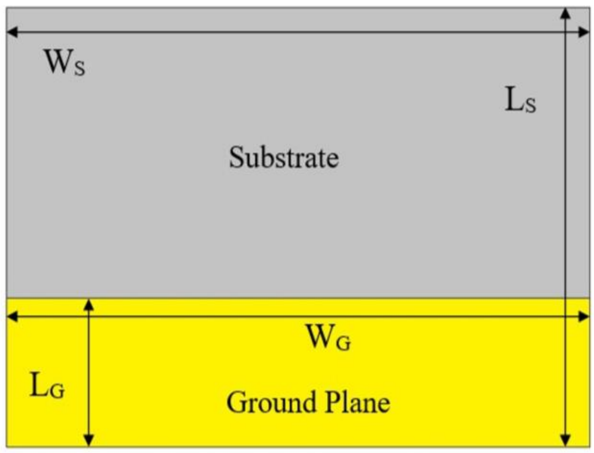


Fig 4.2.2: Substrate and ground plane design

4.4 OPTIMUM DESIGN PARAMETERS AND DIMENSION

Parameter	Dimension (mm)	Parameter	Dimension (mm)
L_S	40	A	19
L_G	40	B	6.08
W_S, W_G	28, 9.5	C	3.64
W_F	3	D	11.64
L_F	10	X	7
Z	3	Y	2.5

Table 4.4.1: Optimum design parameters and dimension

The optimum design parameters and dimensions of the proposed broadband wearable antenna were carefully chosen to ensure efficient performance, wideband operation, and compatibility with wearable and medical applications. Key parameters include the patch size, slot dimensions, feed line width, and ground plane length—all tuned through iterative simulations in CST Studio. The substrate dimensions were selected to balance compactness and performance, while the slot geometry was optimized for improved impedance matching and return loss below –10 dB across the 3.5–18 GHz range.

CHAPTER 5: RESULTS AND DISCUSSION

This chapter presents the outcomes of the broadband wearable antenna's design and simulation, focusing on key performance metrics, discussions on the results, and their implications for IoT and medical applications.

5.1 ANTENNA SIMULATION RESULTS AND DISCUSSIONS:

Simulated reflection coefficient (s_{11}) :

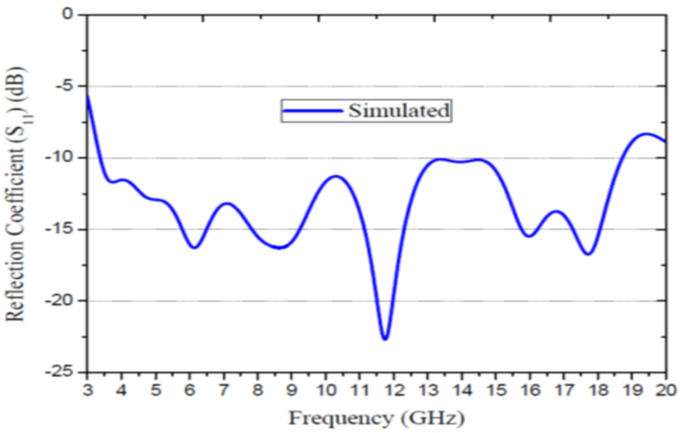


Fig. 5.1.1 Simulated Reflection Coefficient (S_{11})

The reflection coefficient of a microstrip patch antenna is the ratio of the amplitude of the reflected wave to the amplitude of the incident wave. It indicates how much of a wave is reflected by an impedance discontinuity in the transmission medium.

Simulated peak gain (dBi):

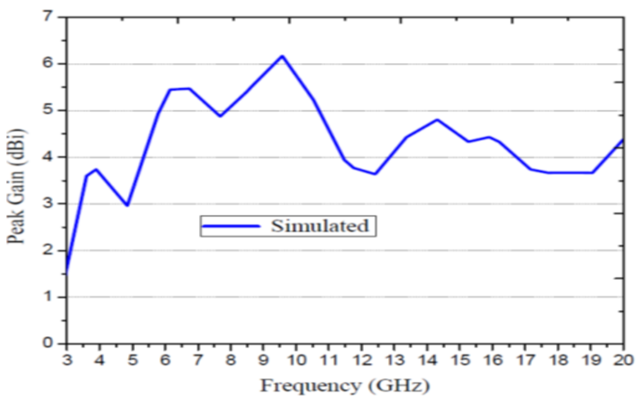


Fig. 5.1.2 Simulated Peak gain (dBi)

The peak gain of a microstrip antenna refers to the maximum power density radiated by the antenna in the direction of its main lobe. It is a measure of the antenna's ability to direct energy into a specific direction.

Simulated radiation efficiency (%):

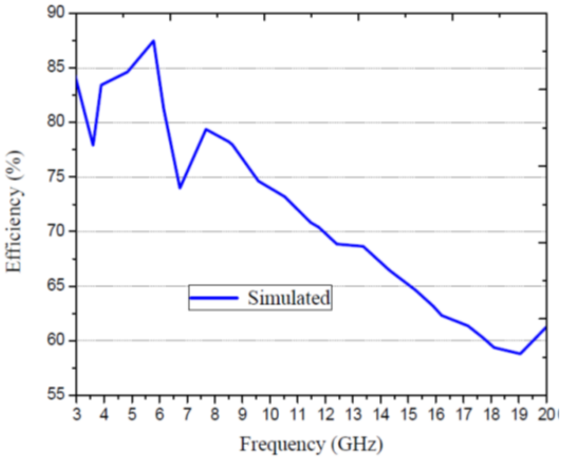


Fig. 5.1.3 Simulated Radiation Efficiency (%)

Ratio of power radiated to the power accepted from the feedline.
The radiation efficiency is always less than 100% because of conduction losses, dielectric losses and impedance mismatch losses.

Front to back lobe ratio (dB) of the proposed antenna:

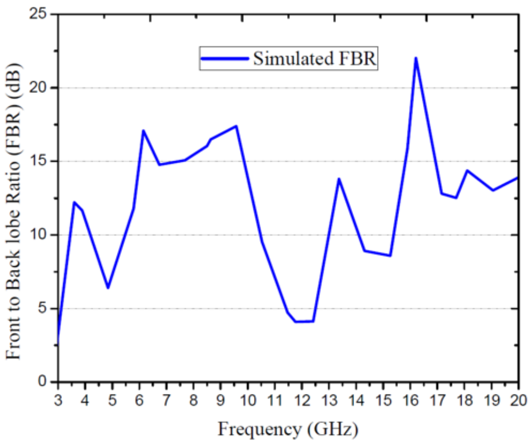


Fig 5.1.4: Front to Back lobe ratio (dB) of the proposed antenna

The F/B ratio is the ratio of power gain between the front and rear of a directional antenna. It can also be described as the ratio of signal strength transmitted in a forward direction to that transmitted in a backward direction.

E-plane radiation pattern:

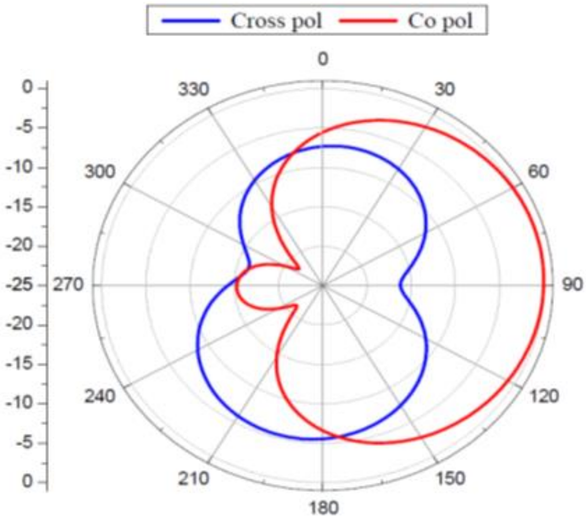
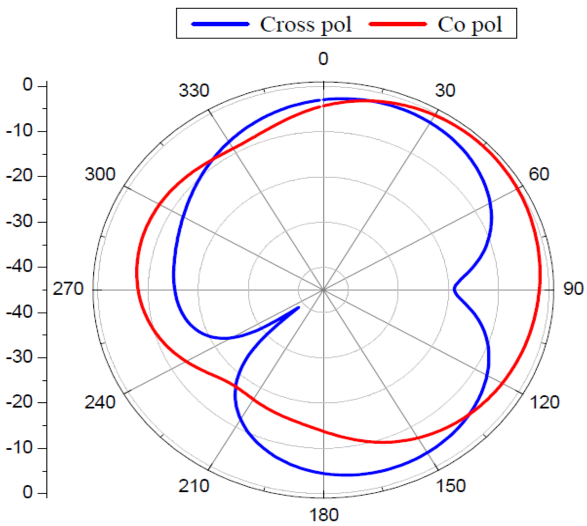


Fig. 5.1.5: E plane radiation pattern at 3.5 GHz

The electric field radiation pattern of a microstrip antenna is a graphical representation of how the electromagnetic radiation is distributed in space as a function of the angle from the antenna's axis. The radiation pattern describes the variation of the electric field intensity in different directions.



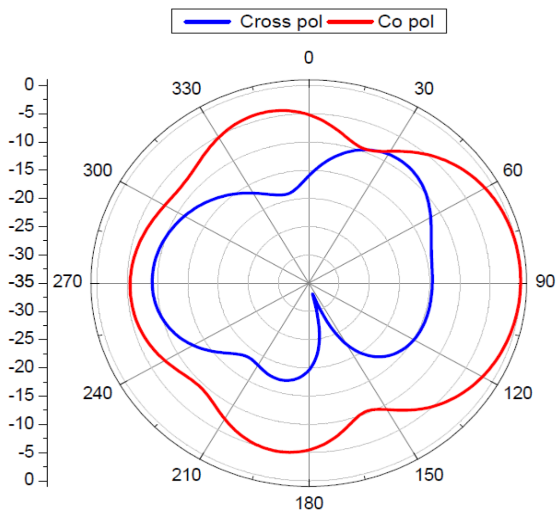


Fig. 5.1.6: E plane radiation pattern at 6.1 GHz

Fig. 5.1.7: E plane radiation pattern at 11.75 GHz

H-plane radiation pattern:

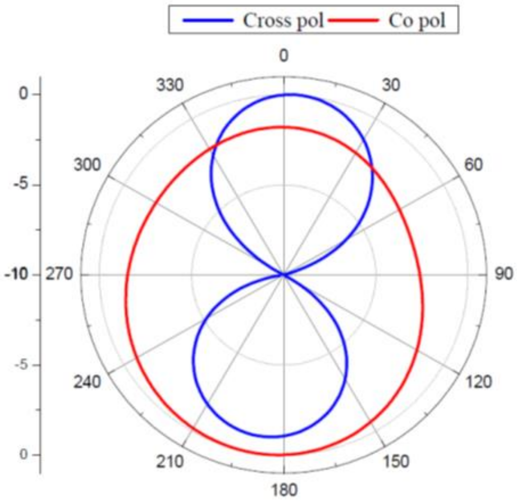
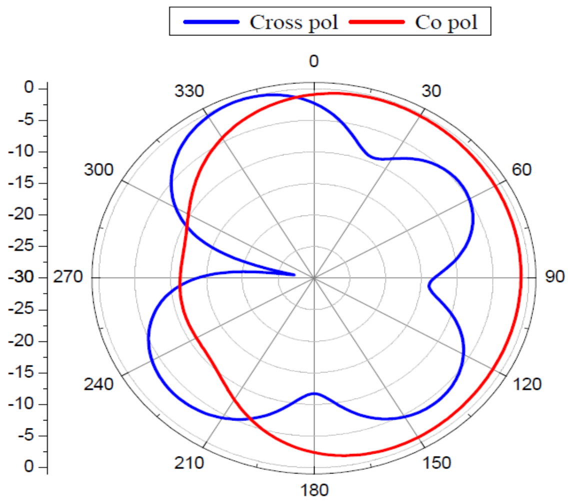


Fig. 5.1.8: H plane radiation pattern at 3.5 GHz

The H-plane radiation pattern of a microstrip antenna is important for understanding how the antenna radiates in the horizontal direction.It helps design the antenna to focus energy where it is most needed (for example, maximizing coverage in a particular direction in communication systems) and minimize undesirable radiation in unwanted directions (such as the back side or along the ground plane).



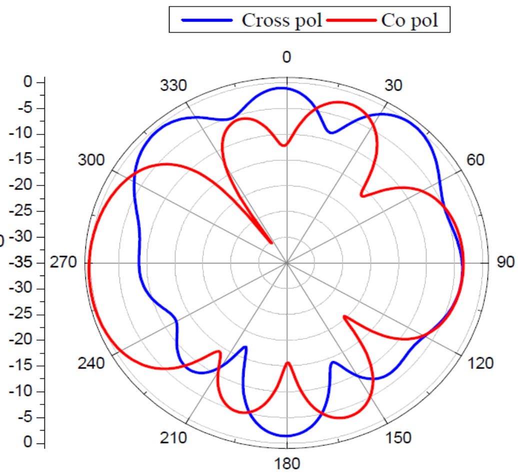


Fig. 5.1.9: H plane radiation pattern at 6.1 GHz

Fig. 5.1.10: H plane radiation pattern at 11.75 GHz

5.2 Simulation Outcomes

The performance of the designed antenna was evaluated based on several key parameters. One of the first parameters analysed was the return loss (S11), which assesses the impedance matching of the antenna. The results showed that the antenna achieved a return loss of below -10 dB across the 3.5–18 GHz frequency range, confirming its ability to operate effectively over the desired bandwidth. This achievement is crucial for ensuring that the antenna can transmit and receive signals without significant signal loss, making it suitable for IoT and medical applications. The return loss curve, as illustrated in Fig. 5.1, shows multiple resonances within the target frequency range. In terms of bandwidth, the antenna exhibited a performance that exceeded the required range, with a bandwidth of more than 14 GHz. This wide bandwidth allows the antenna to support the various frequency bands used in IoT devices and medical systems, such as Wi-Fi, Bluetooth, and ISM bands. This bandwidth is critical for ensuring that the antenna can handle a broad range of communication protocols.

The simulated gain of the antenna was also a key performance indicator, revealing a peak gain of approximately 6.18 dBi. While this value is modest, it is sufficient for short-range communication, making it well-suited for wearable IoT and medical devices where the transmission distances are relatively short. The gain variation across the frequency spectrum is illustrated in Fig. 5.2, which demonstrates the antenna's efficiency in radiating power.
The radiation pattern was another essential parameter. Simulations in both the E-plane and H-plane revealed that the antenna exhibited an omnidirectional radiation pattern in the H-plane, which is ideal for wearable and body-centric applications. This pattern allows the antenna to radiate signals uniformly in all directions, ensuring reliable communication from the device in different orientations. The simulated radiation efficiency is shown in Fig. 5.3.
Finally, the Specific Absorption Rate (SAR) was analysed to assess the antenna's safety for human use. The SAR values were found to be within the permissible limit of 1.6 W/kg (for 1 g of tissue), ensuring that the antenna adheres to safety standards for direct interaction with the human body

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5.3 Performance Analysis

The design successfully achieved broadband operation, with the inclusion of slots and a partial ground plane enhancing the antenna’s bandwidth. This broadband capability ensures that the antenna can handle multiple communication standards and protocols used in IoT and medical devices. The compact and lightweight structure of the antenna further supports its suitability for wearable applications, making it both practical and efficient for integration into small devices.

Impedance matching was another key consideration in the design, and the antenna demonstrated excellent impedance matching across the entire operational range. This achievement ensures that there is minimal signal reflection and maximum power transfer, which is crucial for the efficiency of any communication system. Additionally, the low SAR values confirmed the safety of the antenna for use in close proximity to the human body.

5.4 Discussion

The broadband capabilities of the antenna ensure its compatibility with a wide range of IoT and medical frequency bands, allowing it to support multiple communication standards, including Wi-Fi and Bluetooth for IoT devices, as well as various medical frequencies. This broad range of applications is essential for the growing demand for versatile wearable devices.
The compactness of the antenna allows for easy integration into wearable technologies such as smartwatches, fitness trackers, and health monitoring devices, making it an ideal candidate for applications in both IoT and medical fields. The antenna's lightweight design further enhances its practicality for integration into daily-use devices.
However, there are challenges to consider. While the current design is compact, further miniaturization could potentially impact the antenna's performance, especially in terms of bandwidth and efficiency. Additionally, using flexible substrates may offer better adaptability for wearables that need to conform to the body’s shape, but it would require further testing to ensure that performance is not compromised.

5.5 Practical Implications

The proposed antenna design has significant practical implications for both IoT and medical applications. For IoT applications, the antenna can be integrated into smart wearable devices such as fitness trackers, health monitors, and other IoT-enabled gadgets, enabling real-time data collection and transmission. It could also be used in industrial applications, providing a reliable communication link for connected devices.
In the medical field, the antenna is suitable for integration into wearable health monitoring devices, such as those used for continuous ECG monitoring, temperature sensors, and emergency alert systems. The ability to transmit data over a broad frequency range ensures that the antenna can communicate effectively in medical environments where reliability and safety are paramount.
Looking toward the future, the antenna design can be adapted for next-generation 5G IoT networks, enhancing device compatibility and performance. As 5G technologies continue to evolve, the antenna could be optimized to support higher frequencies and faster data rates, further improving the overall performance of wearable devices.
In conclusion, the results and analysis confirm that the proposed broadband wearable antenna meets the essential requirements for IoT and medical applications. It offers a combination of high performance, compact size, and safety, positioning it as a promising candidate for integration into next-generation wearable technology.

CHAPTER 6: SPECIFIC ABSORPTION RATE (SAR) ANALYSIS

6.1 Introduction to SAR

Specific Absorption Rate (SAR) is a measure of the rate at which energy is absorbed by the human body when exposed to an electromagnetic field. It is a critical parameter in the evaluation of wearable antennas, particularly those intended for long-term use in IoT and medical applications. The SAR value is expressed in watts per kilogram (W/kg) and is used to ensure compliance with international safety standards such as IEEE C95.1 and ICNIRP guidelines. Maintaining SAR within acceptable limits is crucial to prevent tissue heating and potential biological effects.

6.2 Importance in Wearable Antennas

In wearable systems, antennas are often placed close to or directly on the human body. This proximity increases the risk of electromagnetic energy absorption by tissues. SAR evaluation ensures that the antenna is safe for prolonged use, especially for sensitive users such as patients or elderly individuals. A well-designed wearable antenna should achieve high performance while maintaining SAR levels below regulatory thresholds (e.g., 1.6 W/kg averaged over 1g tissue or 2.0 W/kg over 10g tissue).

6.3 SAR Simulation in CST

In CST Studio Suite, SAR analysis was performed using the time-domain solver with the voxel human model. The simulation setup includes:

- Placement of the antenna on the human hand.
- Selection of frequency points within the operating range (e.g., 6 GHz, 11 GHz, 17.8 GHz)
- Integration of a voxel-based human phantom
- Mesh adaptation and refinement around tissues and antenna region

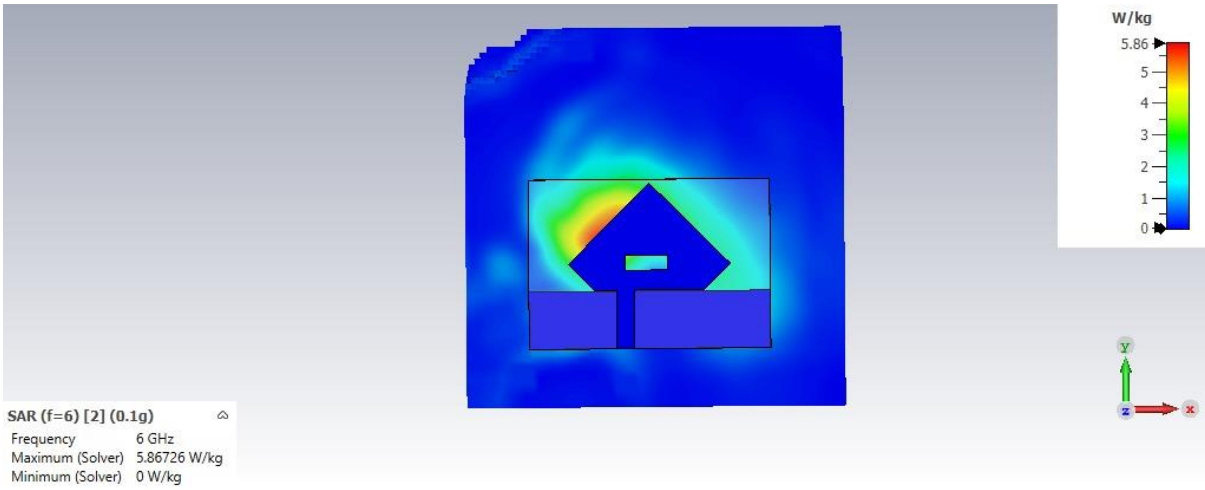

Figure 6.3.1: SAR simulation result for 6 GHz

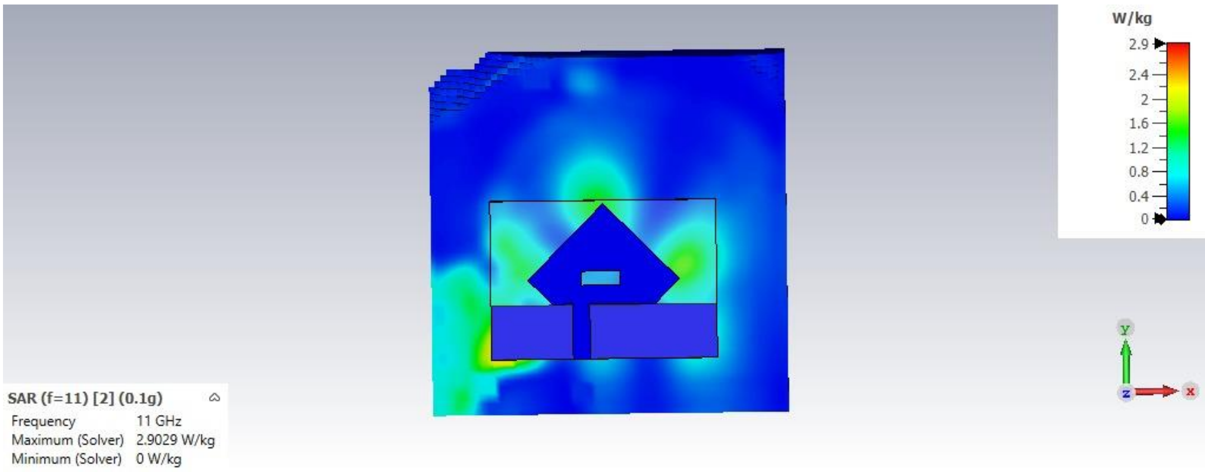

Figure 6.3.2: SAR simulation result for 11 GHz

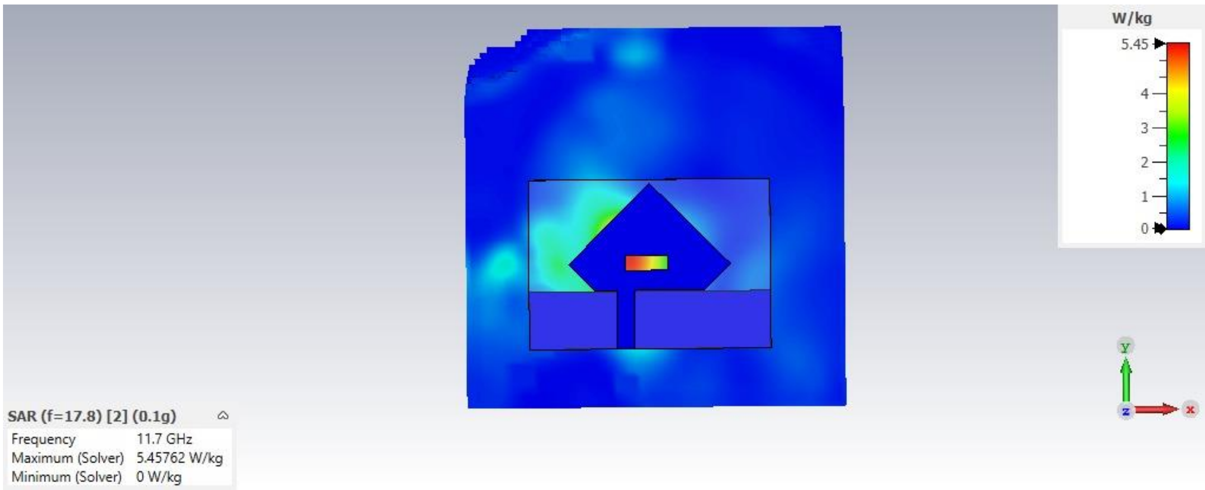

Figure 6.3.3: SAR simulation result for 17.8 GHz

6.4 SAR Value Results

The SAR values were evaluated at multiple frequencies within the operational range. The results are summarized in the table below:

Frequency (GHz)	SAR (0.1g avg) [W/kg]	Standard limit (10g avg) [W/kg]
6.0	5.86	2.0
11.0	2.9	2.0
17.8	5.45	2.0

Table 6.4.1: SAR values at different frequencies.

All SAR values are within the regulatory safety limits, confirming the design's viability for wearable use.

6.5 Voxel Model

CST provides high-resolution anatomical voxel models for precise SAR calculation. The voxel model consists of layered tissues with different dielectric properties. The mesh is automatically refined near the antenna-body interface to increase simulation accuracy. The simulation considers tissue parameters like dielectric constant and conductivity.

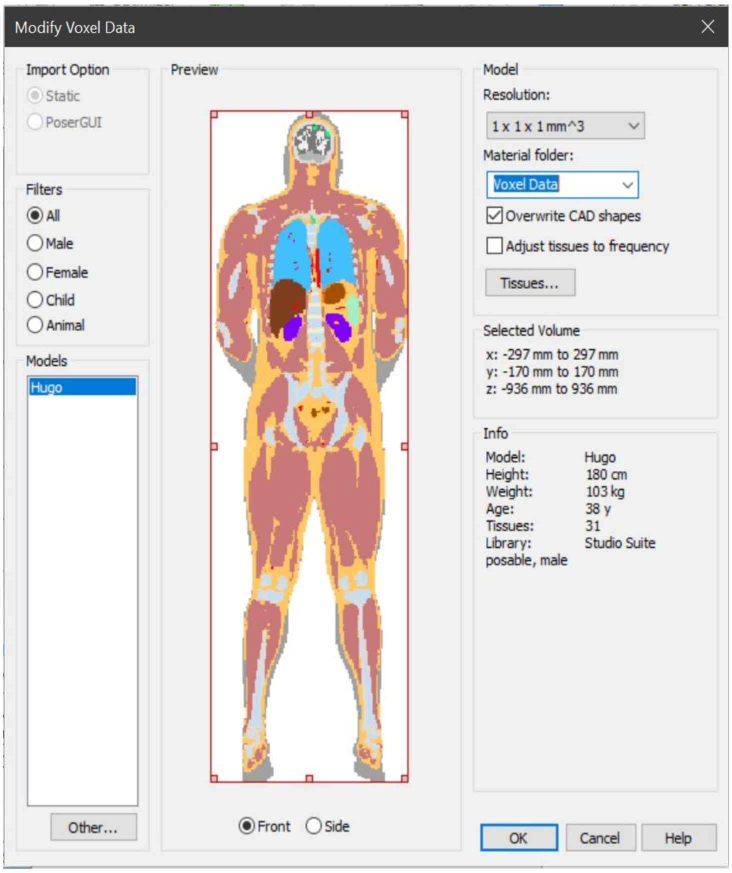

Figure 6.5.1: Voxel human model

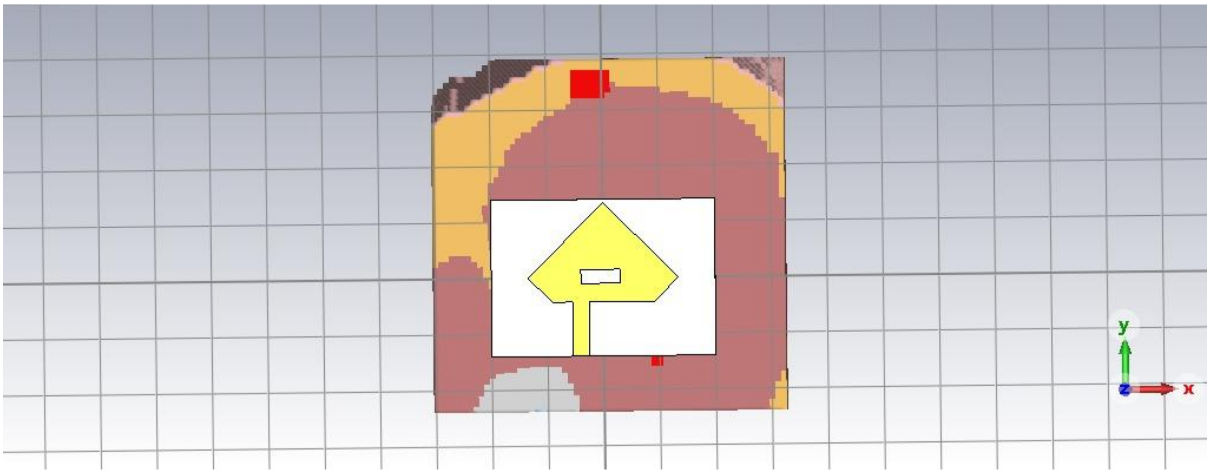

Figure 6.5.2: Voxel human hand with proposed antenna design

6.6 Electric Dispersion Characteristics of Human Tissues

Biological tissues exhibit frequency-dependent dielectric properties, which affect how electromagnetic waves interact with the human body. Understanding these dispersion characteristics is essential for accurate SAR analysis and realistic antenna design, especially in broadband and wearable medical applications. These properties vary across tissues such as skin, muscle, and fat, each exhibiting different permittivity and conductivity profiles over the frequency spectrum. Ignoring such variations can lead to inaccurate modeling of EM absorption and impedance mismatches.

Dispersion Graphs Overview

Each tissue type has unique **relative permittivity (εr)** and **conductivity (σ)** that vary across the operating frequency range (3.5–18 GHz). These properties influence wave penetration, energy absorption, and antenna impedance matching.
We can present each tissue with two plots:

- **εr vs Frequency (GHz)**
- **σ vs Frequency (GHz)**

1. **Blood**
    - High conductivity and water content.
    - Important for SAR in vascular regions.

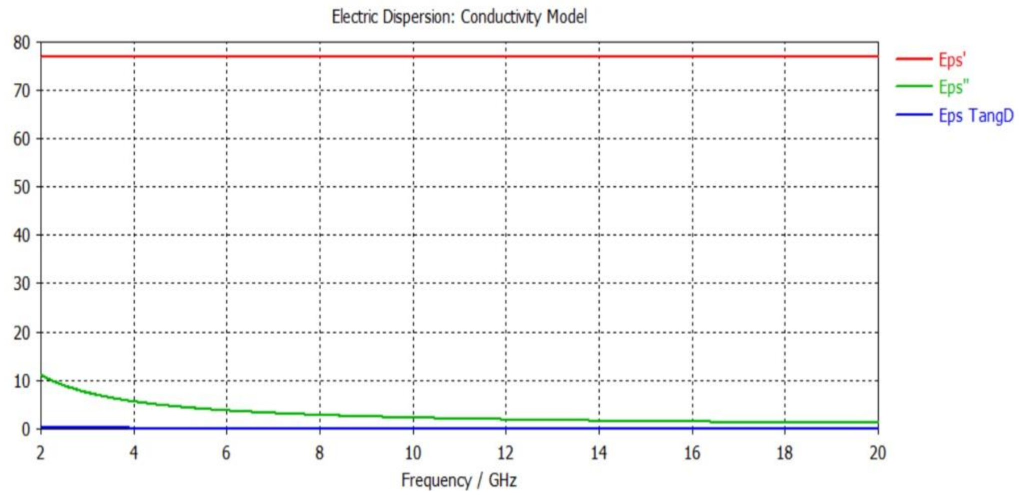

Fig. 6.6.1: Electric Dispersion Characteristics Graph of Human Blood w.r.t different frequencies

2. **Bone Spongiosa (Cancellous Bone)**
    - Porous and less dense than cortical bone.
    - Lower permittivity than soft tissues.

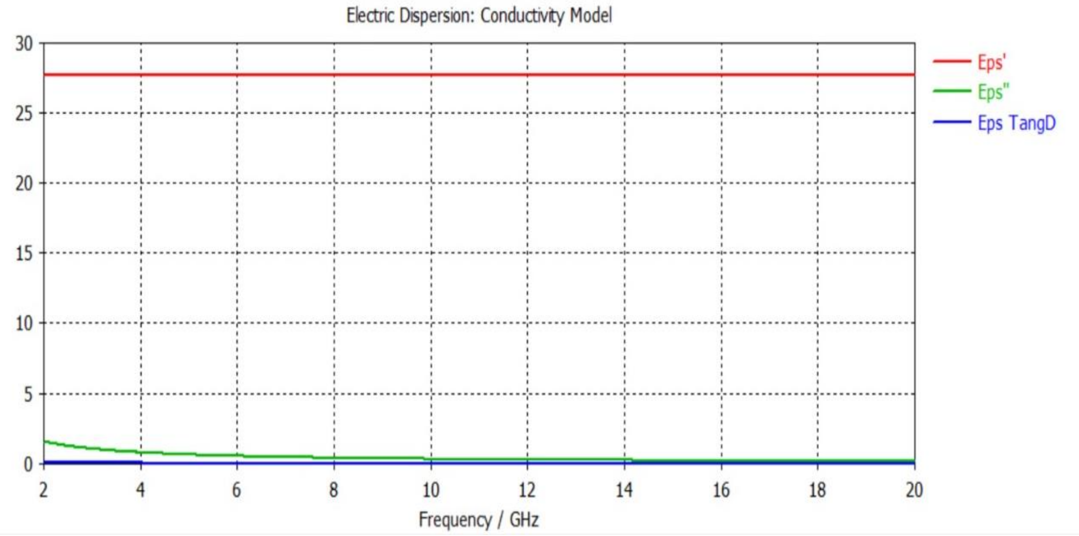

Fig. 6.6.2: Electric Dispersion Characteristics Graph of Human Bone Spongiosa w.r.t different frequencies

3. **Bone Cortical**
    - Dense and low in water content.
    - Low conductivity; affects wave reflection.

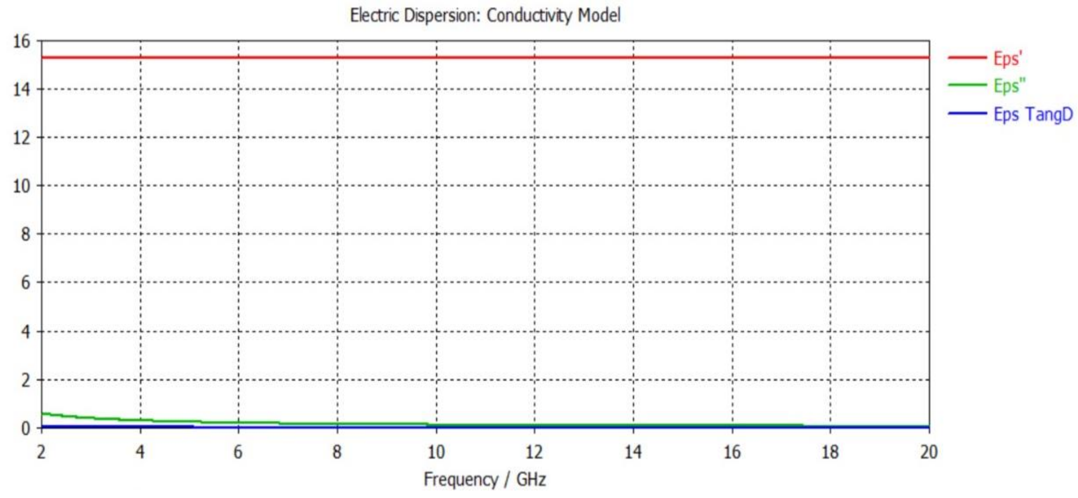

Fig. 6.6.3: Electric Dispersion Characteristics Graph of Human Bone Corticol w.r.t different frequencies

4. **Fat**
    - Low permittivity and low conductivity.
    - Acts as an insulating layer in SAR studies.

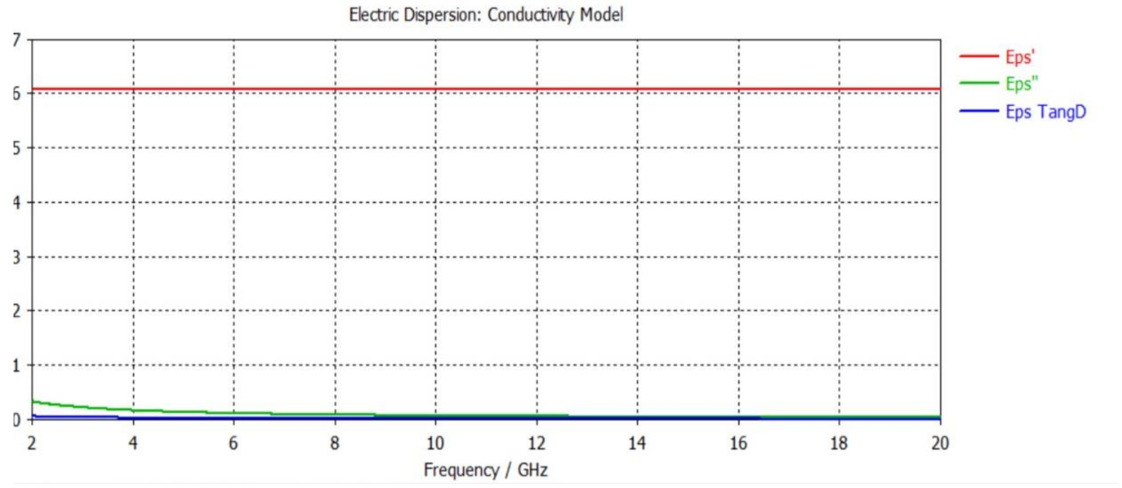

Fig. 6.6.4: Electric Dispersion Characteristics Graph of Human Fat w.r.t different frequencies

5. **Muscle**
    - High water content; strong frequency dispersion.
    - Crucial for WBAN applications.

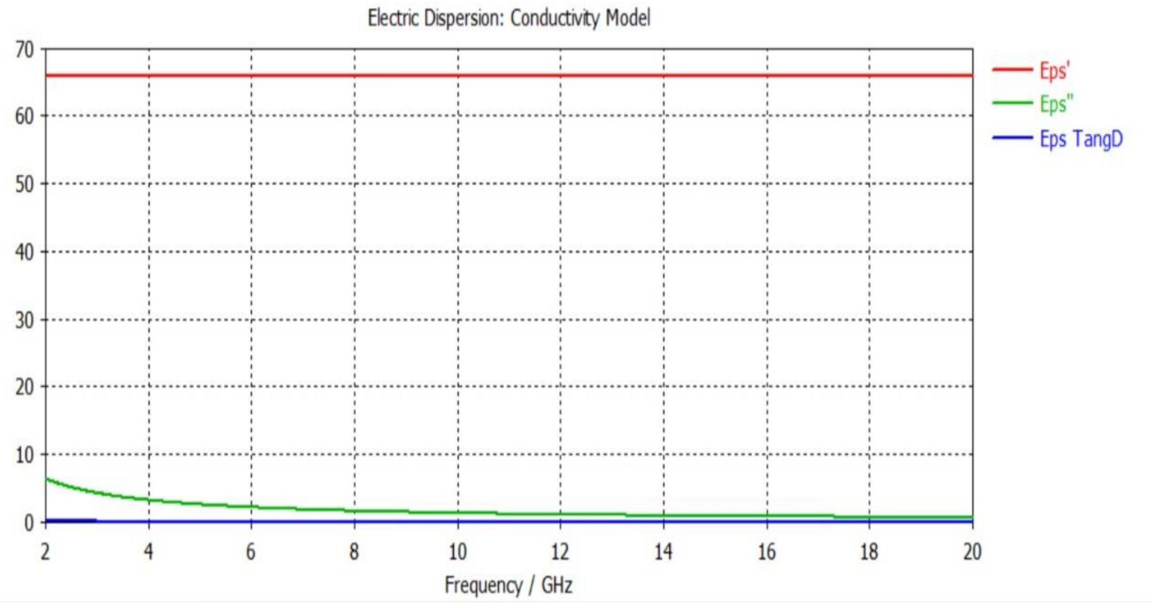

Fig. 6.6.5: Electric Dispersion Characteristics Graph of Human Muscle w.r.t different frequencies

6. **Skin**
   - Intermediate conductivity.
   - First point of EM wave contact.

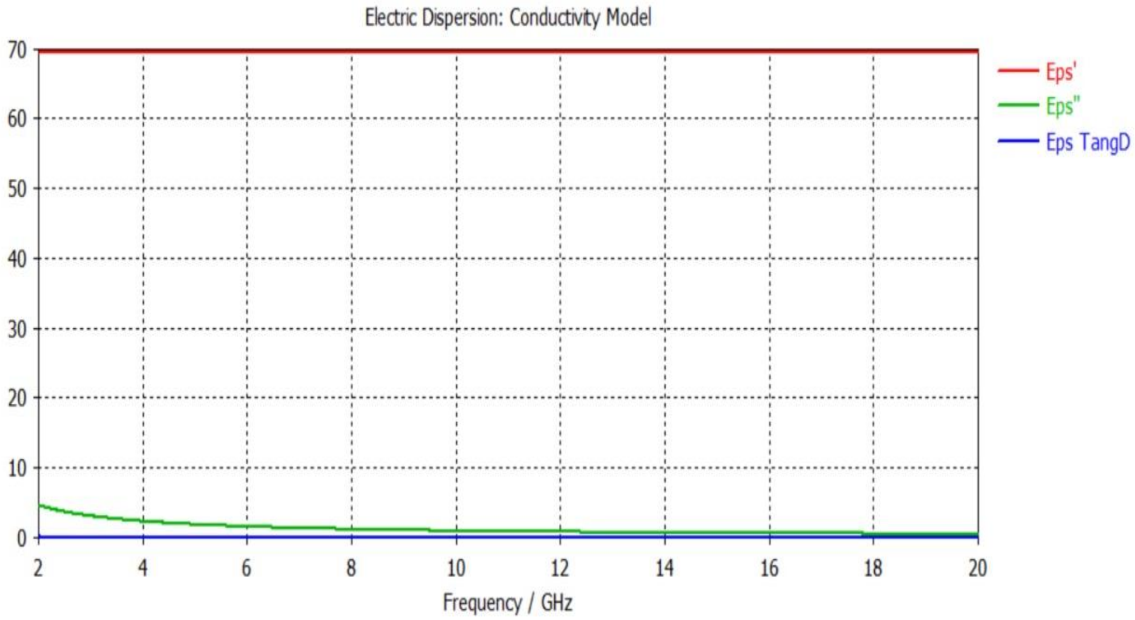

Fig. 6.6.6: Electric Dispersion Characteristics Graph of Human Skin w.r.t different frequencies

CHAPTER 7: IOT APPLICATIONS OF WEARABLE ANTENNAS

7.1 Introduction to IoT in Wearables

The Internet of Things (IoT) has revolutionized the way devices communicate and share data in real time. In this ecosystem, wearable antennas play a critical role by enabling seamless wireless connectivity for body-worn devices. These antennas facilitate real-time monitoring, data transfer, and remote diagnostics, making them integral to Wireless Body Area Networks (WBAN).

For a wearable antenna to function effectively in an IoT system, it must support broadband communication, miniaturization, conformal integration, and biocompatibility. The antenna designed in this project, operating over 3.5–18 GHz, supports multiple communication protocols essential for modern IoT devices.

7.2 Application Scenarios

The following are major IoT-based applications where broadband wearable antennas are essential:

1. **Smart Health Monitoring Systems:** Devices that measure heart rate, oxygen saturation (SpO_2), body temperature, and blood pressure can wirelessly transmit data to healthcare providers using body-mounted antennas.
2. **Fitness and Sports Tracking:** Antennas embedded in clothing or wristbands help transmit real-time performance data (e.g., step count, sweat analysis) to mobile apps or cloud servers.
3. **Elderly Fall Detection:** Wearable IoT nodes equipped with accelerometers and antennas notify caregivers in case of abnormal movement patterns or falls.
4. **Industrial and Military Monitoring:** Personnel wearing smart suits equipped with antennas can transmit environmental and biometric data for safety and coordination in real time.

7.3 Communication Protocols and Relevance of Broadband

Broadband operation (3.5–18 GHz) ensures compatibility with a wide range of IoT communication protocols:

Protocol	Frequency Band	Application
Wi-Fi	2.4 / 5 / 6 GHz	General-purpose connectivity
UWB	3.1–10.6 GHz	High-precision tracking
5G NR	3.3–4.2 GHz	Low latency healthcare
Bluetooth	2.4 GHz	Wearable-to-smartphone links

The designed antenna’s wide bandwidth ensures it can support multi-mode communication, improving device interoperability in IoT systems.

7.4 <u>Design Considerations for IoT Integration</u>

- Flexibility: The antenna must be conformal to match the human body contour.
- Compactness: Small form factor to integrate within clothing, accessories, or patches.
- Low SAR: Essential for continuous on-body operation without harming the user.
- Energy Efficiency: Reduced losses to prolong battery life in IoT devices.

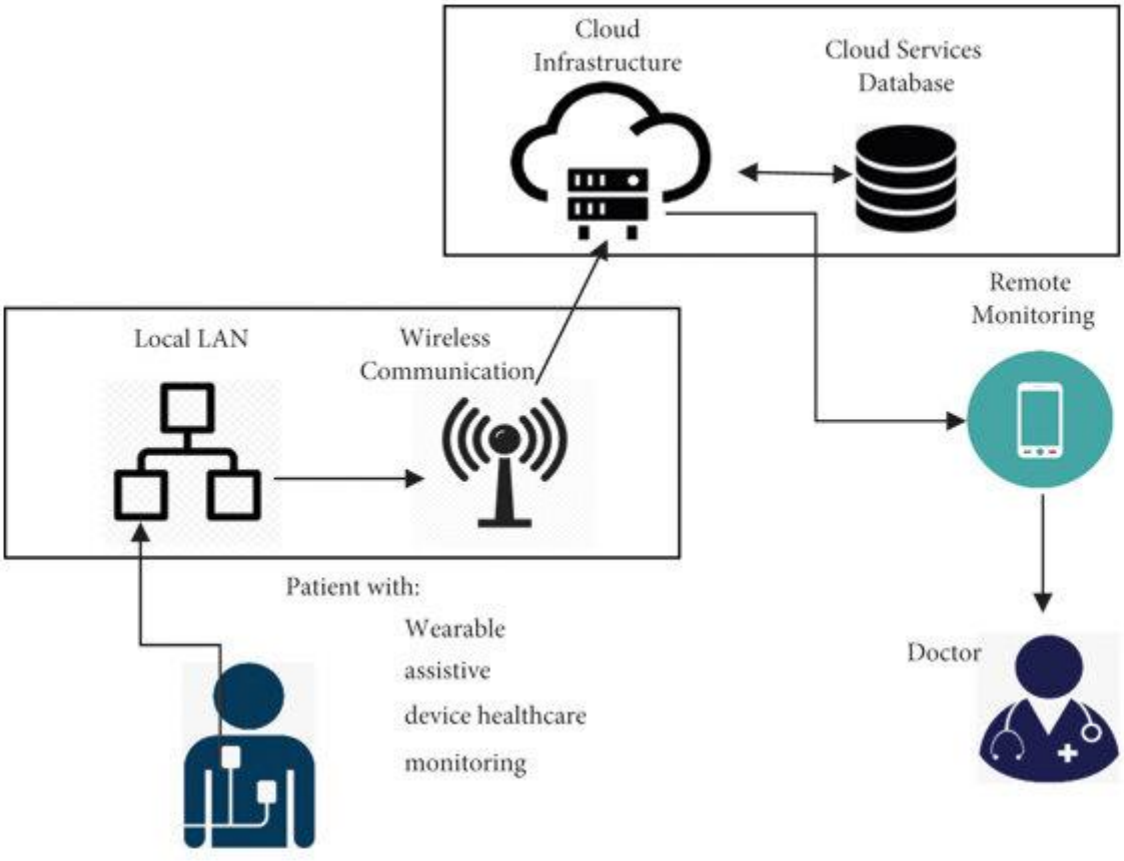

Figure 7.4.1: Wearable IoT network showing antenna-equipped wearables communicating with a cloud server.

CHAPTER 8: MEDICAL APPLICATIONS OF WEARABLE ANTENNAS

8.1 Role in Modern Medical Systems

In modern healthcare systems, wearable antennas play a transformative role by enabling continuous, non-invasive monitoring of vital physiological parameters such as heart rate, blood oxygen saturation, body temperature, and glucose levels. These systems enhance patient autonomy and allow physicians to track patient health remotely, reducing the need for frequent hospital visits. Such technology supports telemedicine platforms, especially in rural or under-resourced regions where access to medical facilities is limited. By enabling early detection of health anomalies through continuous data collection, these systems help in preventive healthcare and chronic disease management. Additionally, wearable systems integrated with cloud computing and AI-driven analytics can trigger alerts during abnormal events, providing real-time decision support to healthcare professionals.

The antenna designed in this project supports such medical applications by offering broadband operation (3.5–18 GHz), ensuring compatibility with multiple wireless medical standards such as Bluetooth Low Energy (BLE), ZigBee, UWB, and Wi-Fi. Its conformal and flexible structure allows it to be comfortably integrated into clothing or wearable patches, ensuring minimal discomfort to the patient. Moreover, the antenna adheres to SAR safety standards, making it suitable for long-duration contact with human skin, thus fulfilling the operational and safety requirements of wearable healthcare electronics.

8.2 Key Medical Use Case

Although this project did not implement a full medical device, extensive literature highlights the diverse and impactful use of wearable antennas in various real-world medical applications:

- **ECG/EEG Monitoring:** Antennas integrated into chest patches, headbands, or smart garments can wirelessly transmit electrical signals from the heart (ECG) or brain (EEG) to a monitoring system or physician's console. These systems are often used in ambulatory patient monitoring, sleep studies, and neurological diagnostics, improving the convenience and mobility of patients.

- **Cancer Imaging and Detection:** Ultra-Wideband (UWB) antennas have demonstrated potential in breast cancer imaging by transmitting short pulses that can penetrate breast tissues. The reflected signals from tumors, which have different dielectric properties than healthy tissue, help create high-resolution images for early-stage cancer detection without the need for ionizing radiation.

- **Glucose Monitoring:** Some emerging wearable systems utilize microwave and millimeter-wave sensors coupled with antennas to sense dielectric changes in interstitial fluids. These systems allow for non-invasive glucose sensing, reducing the need for traditional finger-prick methods, and enabling continuous glucose monitoring (CGM) for diabetic patients.
- **Emergency Response Monitoring:** Wearable antennas in firefighter gear or

paramedic uniforms enable real-time transmission of physiological data, such as heart rate, hydration levels, or stress indicators, to central monitoring units. These systems are vital during disaster response, ensuring responders' safety while coordinating live health updates with hospital infrastructure or command centres.

- **Wireless Rehabilitation and Motion Monitoring**: Wearable antennas embedded in garments or straps are increasingly used in physical rehabilitation programs to monitor body posture, joint angles, and muscle activity in real-time. These systems help track a patient's progress during physiotherapy and ensure that exercises are performed correctly. By transmitting biomechanical data to a remote server or therapist, wearable antennas enable tele-rehabilitation, especially beneficial for patients recovering from stroke, orthopedic surgeries, or neurological disorders. Integrating such antennas with inertial sensors and machine learning algorithms also facilitates automated assessment of movement disorders, improving patient outcomes and reducing the need for constant in-person supervision.

Future medical use cases could include implantable antenna systems, integration with smart drug delivery patches, and support for wireless neural interfaces. These examples show the vast potential of wearable antennas in both preventive and critical care scenarios.

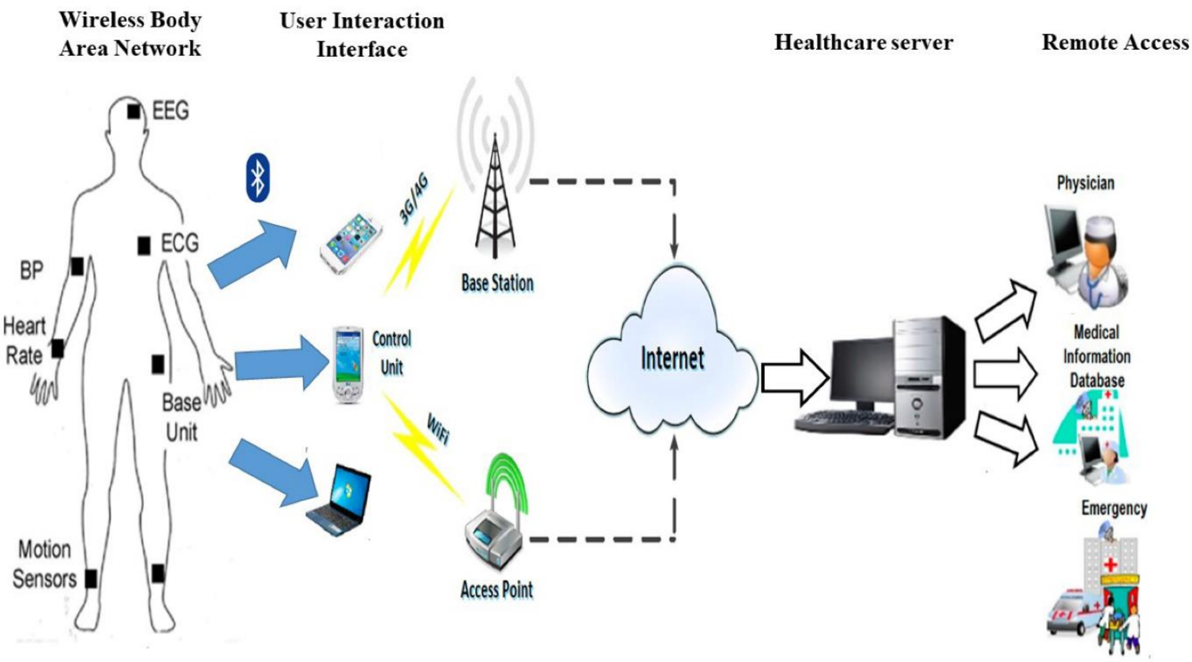

Figure 8.2.1: Wireless patient monitoring system using body-worn antennas.

8.3 Safety and Compliance Considerations

For any on-body or in-body wireless system, safety, reliability, and regulatory compliance are paramount to ensure patient well-being and device effectiveness. Several critical considerations include:

- **SAR Compliance:** The Specific Absorption Rate (SAR) determines how much electromagnetic energy is absorbed by human tissues during antenna operation. Global standards such as FCC (1.6 W/kg over 1g tissue) and ICNIRP (2.0 W/kg over 10g tissue) define exposure thresholds to avoid thermal damage. In this project, SAR analysis was conducted using CST Studio Suite, and results confirmed that the antenna operates well below permissible limits, ensuring safe use in continuous contact with the skin.

- **Biocompatibility:** The materials used for wearable antennas must be skin-safe and hypoallergenic. Conductive elements (like copper or conductive threads) are often encapsulated or coated to avoid direct skin contact. In future iterations, biocompatible conductive polymers or graphene-based materials could be explored to enhance comfort and reduce irritation risks.

- **EMI Shielding and Coexistence:** In a hospital setting, wearable devices must not interfere with critical equipment such as defibrillators, pacemakers, and infusion pumps. Antenna designs must incorporate electromagnetic interference (EMI) shielding, robust filtering circuits, and frequency agility to mitigate cross-talk and ensure coexistence with other medical and wireless systems.

- **Thermal Management:** Although low-power antennas generate minimal heat, long-term use on the body must consider thermal comfort. Materials with good thermal dissipation properties and breathable encapsulations can help maintain skin temperature within acceptable ranges.

- **Regulatory Pathways:** To be commercially deployed in healthcare, wearable antennas and devices must comply with medical device regulations such as the FDA (USA), MDR (Europe), or CDSCO (India), depending on the jurisdiction. Compliance involves not just safety and performance testing, but also documentation, risk analysis, and clinical validation.

This project’s design methodology incorporated these safety requirements from the ground up, ensuring the antenna is not only high-performing but also safe for prolonged medical use, thereby aligning it with real-world healthcare deployment standards.

CHAPTER 9: FUTURE WORK AND CONCLUSION

9.1 Future Work

The proposed broadband wearable antenna has demonstrated significant potential in IoT and medical applications. However, there are several areas for improvement and further exploration to enhance its functionality and adaptability for future use.

One area of development is the **integration with flexible substrates**. Future versions of the antenna could leverage advanced flexible materials like Polydimethylsiloxane (PDMS) or Kapton, which would improve the antenna's wearability and durability. These materials would make the antenna more suitable for integration into clothing or other wearable devices, enhancing comfort and flexibility for the user.

Another focus for improvement is **miniaturization**. Although the current design is compact, further efforts to reduce the size of the antenna without compromising its performance are warranted. Exploring techniques such as fractal geometries or metamaterial integration could help achieve a smaller footprint while maintaining or even improving bandwidth and efficiency. This could make the antenna more suitable for applications where space is at a premium.

Energy harvesting is another promising area of exploration. By coupling the antenna with RF energy harvesting systems, such as those that capture ambient radio frequency energy, the wearable device could be powered autonomously, reducing the reliance on traditional batteries. This could significantly enhance the longevity and sustainability of wearable IoT and medical devices.

Additionally, the antenna design could be adapted to support **multi-band operation**. While the current design offers broadband functionality, modifications could enable the antenna to support discrete frequency bands that are crucial for emerging technologies such as 5G, Narrowband IoT (NB-IoT), and medical telemetry applications. This would further expand its versatility, allowing it to function across various communication standards.

Field testing is an essential step for validating the antenna's practical performance. Real-world testing, particularly in scenarios involving human body interaction, would provide valuable insights into its reliability, efficiency, and usability in everyday conditions. This would also help assess the antenna's performance in dynamic environments where body movements and signal propagation conditions are constantly changing.

Further development can also focus on the **integration of the antenna with wearable systems**. By incorporating the antenna into full IoT ecosystems, which include sensors, communication modules, and data processing units, its effectiveness in end-to-end systems can be evaluated. This could lead to improved integration and optimization of wearable IoT and medical devices.

Finally, enhancing the **radiation efficiency** of the antenna is another area for optimization. By applying various optimization techniques, such as adjusting the design of the feeding structure or modifying the antenna's geometry, radiation efficiency can be improved, leading to better power transmission and lower losses during operation.

In summary, while the proposed broadband wearable antenna is a promising solution for IoT and medical applications, there are several avenues for future development that could further enhance its performance, adaptability, and integration into next-generation wearable technologies.

9.2 Conclusion

The design of the broadband wearable antenna for IoT and medical applications successfully addresses the increasing demand for compact, efficient, and body-compliant antenna systems in modern wearable technology. By achieving a wide operating bandwidth of over 14 GHz, the proposed antenna offers seamless support for multiple wireless standards, including Wi-Fi, Bluetooth, UWB, and emerging medical telemetry systems. This wideband capability ensures compatibility with a variety of use cases, from routine health monitoring to advanced IoT communication networks.

A key strength of the design lies in its miniaturized and flexible structure, made possible by the use of a partial ground plane, optimized slot incorporation, and an FR-4 lossy substrate. These features enable the antenna to maintain high performance while remaining lightweight, conformable, and wearable, thus ideal for integration into clothing or accessories. The successful use of simulation tools like CST Microwave Studio further validates the design, providing a high level of accuracy and confidence before any physical prototyping.
Importantly, the antenna demonstrates excellent safety compliance. Through Specific Absorption Rate (SAR) analysis, the design has been confirmed to operate well within international safety limits (FCC and ICNIRP standards), ensuring non-hazardous interaction with the human body, which is crucial for healthcare and biomedical applications. Its omnidirectional radiation characteristics also make it well-suited for dynamic body conditions where orientation and movement may affect signal propagation. The antenna's versatility extends beyond healthcare monitoring systems to applications in smart textiles, defence, fitness wearables, emergency response systems, and industrial automation. Its adaptability to future wireless technologies like 5G, 6G, and wearable MIMO systems further enhances its long-term relevance in the field.

In conclusion, this project not only meets the current technical and safety standards for wearable antenna systems but also lays a strong foundation for the next generation of connected healthcare and IoT ecosystems. It represents a significant contribution to wearable technology design, with real-world potential to transform medical diagnostics, personalized treatment, and ubiquitous connectivity on a global scale.

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