Design and Analysis of Meander Line Antenna using Various Textile Substrates for WBAN Applications

Report submitted to the SASTRA Deemed to be University
as the requirement for the course

ECE300: MINI PROJECT

Submitted by

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SCHOOL OF ELECTRICAL & ELECTRONICS ENGINEERING
THANJAVUR, TAMIL NADU, INDIA – 613 401

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This is to certify that the report titled "**Design and Analysis of Meander Line Antenna using Various Textile Substrates for WBAN Applications**" submitted as a requirement for the course, **ECE300: MINI PROJECT** for B.Tech. ELECTRONICS & COMMUNICATION ENGINEERING programme, is a bonafide record of the work done by **Karri Sirisha Reddy (124004175**), **Mangina Lalitha Madhavi (124004175), and Manne Yaswanth(124004182)** during the academic year 2022-23, in the School of ELECTRICAL & ELECTRONICS ENGINEERING, under my supervision.

Signature of Project Supervisor:

Name with Affiliation: Dr G Rajkumar /AP-III / SEEE / SASTRA

Date:

Project *Vivavoc*e held on ________________

Examiner 1 **Examiner 2**

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Declaration

We declare that the report titled "**Design and Analysis of Meander Line Antenna using Various Textile Substrates for WBAN Applications**" submitted by us is an original work done by us under the guidance of **Dr. G Rajkumar, Associate Professor - III, School of Electrical and Electronics Engineering, SASTRA Deemed to be University** during the sixth semester of the academic year 2022-23, in the **School of Electrical & Electronics Engineering**. The work is original and wherever We have used materials from other sources, We have given due credit and cited them in the text of the report. This report has not formed the basis for the award of any degree, diploma, associate ship, fellowship, or other similar title to any candidate of any University.

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Name of the candidate(s):

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We would like to express our gratitude to all the professors who have supported us in our project, either directly or indirectly. Additionally, we extend our thanks to the teaching and non-teaching staff, as well as all others who have offered us support, encouragement, and assistance throughout our academic journey at SASTRA Deemed University, enabling us to successfully complete all of our courses. The guidance and mentorship we received from all these individuals will undoubtedly prove invaluable to us as we move forward in our professional careers.

ABSTRACT

Wireless Body Area Networks (WBANs) are an emerging technology that have the potential to revolutionize many fields which includes health monitoring systems, sports monitoring, personal communication systems etc. Antennas are a crucial component in WBANs, as they are responsible for the transmission and reception of data. The design of WBAN antennas is particularly challenging due to the complex nature of the human body and the need for the antennas to be compact, low-power, and operate at high frequencies.

The proposed MLA has a compact size of 55 mm x 22 mm and is fabricated on flexible denim substrate with a relative permittivity of 1.72 and a thickness of 1.16 mm. The designed antenna exhibits good radiation characteristics at a frequency of 900 MHz and with a reflection coefficient of -34 dB. A comparative study of the MLA's performance on different substrates is presented based on gain, directivity, radiation efficiency, and VSWR. The results show that the denim substrate provides the best performance in terms of gain, directivity, and Radiation efficiency.

Keywords: WBAN, ISM band, Textile Substrates, Meander Line Antenna.

Specific Contribution:

- Literature Survey, study of different research papers for better understanding of Antenna design and WBAN Applications.
- Study of Base paper, Documentation, working with Origin Pro software for better presentation of simulation results
- Designing and Simulating of antenna for required antenna parameters with the help of ADS software

Specific Learning:

- Evaluating the effect of substrate material on the antenna performance and selecting the most suitable substrate for WBAN application.
- Measuring and analyzing the antenna performance parameters such as VSWR, radiation efficiency, gain, and directivity

- Study of ADS Software simulation tool, designing and simulating Meander Line Antenna using ADS software

Signature of the Guide:

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CHAPTER 1
INTRODUCTION

1.1 Significance of WBAN:

Wireless Body Area Networks (WBANs) are an emerging technology that have the potential to revolutionize many fields which includes health monitoring systems, sports monitoring, personal communication systems etc. Antennas are a crucial component in WBANs, as they are responsible for the transmission and reception of data. The design of WBAN antennas is particularly challenging due to the complex nature of the human body and the need for the antennas to be compact, low-power, and operate at high frequencies.

The use of Wireless Body Area Networks (WBANs) for monitoring vital signs, tracking physical activity, and managing chronic diseases has increased significantly in recent years. These WBAN applications require wearable and flexible antennas that can be comfortably worn on the human body.

1.2 Meander Line Antenna:

Meander Line Antennas (MLAs) are a popular choice for WBAN applications due to their compact size, low profile, and wide impedance bandwidth. To achieve a lower frequency of range MHz, the length of the antenna should be very high. Meander line Antenna is nothing but a long wire having multiple bends. Hence these bends make the size of the antenna compact and suitable for Wearable Applications at a comparatively low frequency.

1.3 Type of substrate:

The MLA's design and performance are highly dependent on the substrate used for fabrication. The middle layer of the antenna is loaded with a dielectric material and treated as a substrate. The length of the antenna decreases as the relative dielectric constant of the substrate increases. Wearable antennas are preferred more for WBAN applications especially due to their high flexibility to be worn on the body. The use of textile substrates for MLA design offers several advantages over conventional substrates, such as flexibility, light weight, and conformability to the human body's curved surfaces.

1.4 Methodology:

This project presents the design and analysis of a Meander Line Antenna operating at 908.2 MHz using a textile substrate for WBAN applications. The proposed MLA's design is optimized for wearable and flexible applications, with a compact size and a low profile. Hence the antenna uses a textile substrate for being feasible for wearable applications.

The antenna has been designed and its performance is evaluated using an Advanced Design System(ADS) Software simulation tool. Then a comparative analysis has been done to verify different parameters of various textile substrates and an optimal substrate has been figured out. The proposed MLA's lightweight and flexible nature make it suitable for WBAN applications, enabling comfortable wearability and improved patient compliance. This project’s contribution is the proposed MLA design's improved performance at a relatively lower frequency, analyzing the optimal substrate for WBAN Applications and making it a promising solution for future wearable antenna designs.

1.5 Motivation:

The motivation for this project is the increasing demand for wearable devices for healthcare and sports applications. These devices require a reliable and efficient wireless communication system to transmit data, which is achieved through the use of antennas. Traditional antenna designs may not be suitable for wearable applications due to their bulkiness and rigidity. Therefore, the motivation for this project is to design and develop a compact, flexible, and efficient antenna that can be integrated into wearable devices for wireless communication. The ultimate goal is to improve the performance and reliability of wearable devices for healthcare and sports applications, leading to better monitoring and management of personal health and fitness.

CHAPTER-2

LITERATURE SURVEY

[1] Dhupkariya, S., Singh, V.K. and Shukla, A., 2015. A review of textile materials for wearable antenna. J. Microw. Eng. Technol, 1, pp.1-8.

Link:https://www.researchgate.net/profile/V-Singh-10/publication/271514332_A_Review_of_Textile_Materials_for_Wearable_Antenna/links/54e02b960cf24d184b0aa142/A-Review-of-Textile-Materials-for-Wearable-Antenna.pdf

In this paper, it has been concluded that wearable antenna is useful for off body communication in personal area network. The substrate dielectric constant and its thickness affect the bandwidth and efficiency of the microstrip antenna. From the review, it is studied that the dielectric constant, moisture, temperature, loss tangents, thickness, conductivity and deformation influence the performance and the characteristics of the textile wearable antenna. In this paper we also reviewed different techniques to fabricate the wearable textile antenna.

[2] Janapala, D.K., Nesasudha, M., Mary Neebha, T. and Kumar, R., 2022. Design and development of flexible PDMS antenna for UWB-WBAN applications. *Wireless Personal Communications*, pp.1-17.

Link: https://link.springer.com/article/10.1007/s11277-021-09095-7

Design and development of a flexible Ultra Wide Antenna using polydimethylsiloxane as a substrate.A flexible, low-weight wideband antenna of size 67mm x 44mm x 1.866mm with maximum peak gain measured 6.76 dB and maximum SAR of 1.482 W/Kg which doesn't exceed FCC value

[3] Sreemathy, R., Hake, S., Gaikwad, S., Saw, S.K. and Behera, S., 2022. Design, Analysis and Fabrication of Dual Frequency Distinct Bandwidth Slot Loaded Wash Cotton Flexible Textile Antenna for ISM Band Applications. *Progress in Electromagnetics Research M*, *109*.

Link: https://www.jpier.org/ac_api/preview.php?t=ab&id=22011203

Dual band microstrip antenna is designed using textile material as a substrate with a circular

and a rectangular patch and is simulated using HFSS software.Return loss,VSWR,gain and directivity of rectangular patch are better than circular patch..Textile microstrip patch antennas are used for military and biomedical applications due to their compact size, simpler planar configuration, low weight, flexibility, low SAR, and ease at installation

[4] Rajinikanth, V., Chandru, S., Kaviyarasu, M., Chandu, K. and Sudhakar, N., 2021. Certain Investigation of Wearable Antenna with Linear Polarization for WBAN Application. Link:https://www.researchgate.net/profile/Rajinikanth-Vinayagam/publication/355171909_CERTAIN_INVESTIGATION_OF_WEARABLE_ANTENNA_WITH_LINEAR_POLARIZATION_FOR_WBAN_APPLICATION/links/61668b4f3851f95994f76a35/CERTAIN-INVESTIGATION-OF-WEARABLE-ANTENNA-WITH-LINEAR-POLARIZATION-FOR-WBAN-APPLICATION.pdf

Wearable antenna design strategy through CST simulation software has been presented. Simplest possible patch Meandered fork-shaped with partial ground has been chosen along with easily available semi-flexible substrate as a dielectric material in to design the proposed antenna.Antenna is simulated in different tissues of the human body such as skin, fat, and muscle. The total volume of the designed antenna is (19.5*18*0.75) mm3, and is operated at the ISM band , achieving maximum gain is -4.41 dB, and the achieved bandwidth is 483 MHz

[5] Dhivya, K. and Arulaalan, M., Design of Textile Wearable Antenna for WBAN Applications. Link:https://web.archive.org/web/20220802032116id_/https://www.mjaret.com/uploads/Files/1658389108MJARET-0722-0010.pdf

A wearable Microstrip patch antenna for biomedical purposes that operates at a 2.45 GHz frequency range in the ISM Band is shown. The dielectric constant of textiles is typically between 1 and 2. Under the frequency of 2.45GHz, the antenna shown has obtained 3.1 dB gain and 0.2 Watt/kg of SAR. The developed antenna also satisfied other antenna criteria with a 77.5 percent efficiency, making it appropriate for WBAN applications.

[6] Gao, G.P., Zhang, B.K., Dong, J.H., Dou, Z.H., Yu, Z.Q. and Hu, B., 2022. A Compact Dual-mode Pattern-Reconfigurable Wearable Antenna for the 2.4 GHz WBAN Applications. *IEEE Transactions on Antennas and Propagation*. Link:https://ieeexplore.ieee.org/abstract/document/9970518

A novel reconfigurable antenna operating at both ON- and OFF-body modes is proposed. The analysis showed that the measured results both in free space and on different parts of the human body were agreed well with simulated results, which indicates that the antenna has good wearable performance.

[7] Mirhadi, S., 2021. Single-Layer, Dual-Port, and Dual-Mode Antenna With High Isolation for WBAN Communications. *IEEE Antennas and Wireless Propagation Letters*, *21*(3), pp.531-535.

Link: https://ieeexplore.ieee.org/abstract/document/9662219

In this letter, a single-layer, dual-port, and dual-mode antenna with high isolation between the ports is suggested. This antenna consists of a short-circuited ring patch antenna. The mutual coupling between the two ports was about 26.5 dB. This antenna had a thin profile for having a single-layer and can be installed on the body more conveniently than multilayer antennas.

[8] Wang, S. and Gao, H., 2022. A dual-band wearable conformal antenna based on artificial magnetic conductor. *International Journal of Antennas and Propagation*, *2022*.
Link:https://www.hindawi.com/journals/ijap/2022/9970477/

In order to improve the effectiveness of the antenna performance of wearable devices, a dual-band flexible monopole antenna with a 3 × 3 artificial magnetic conductor using meander technology. The gain is significantly improved to 5.67 dBi and 6.89 dBi and the maximum SAR is 0.35 and 0.39 W/kg which is far below the FCC standard of less than 1.6 W/kg for 1 g of tissue in 2.45 GHz and 5.8 GHz, respectively

[9] Kumkhet, B., Rakluea, P., Wongsin, N., Sangmahamad, P., Thaiwirot, W., Mahatthanajatuphat, C. and Chudpooti, N., 2023. SAR Reduction Using Dual Band EBG Method Based on MIMO Wearable Antenna for WBAN Applications. *AEU-International Journal of Electronics and Communications*, p.154525.
Link:https://www.sciencedirect.com/science/article/pii/S1434841122003958

A wearable ultra-wideband MIMO antenna using conductor and polyester fiber fabrics is proposed in this paper. The antenna's total dimension is 115 × 70 mm2. As a result, the antenna can be installed on curved or bent surfaces due to its flexibility. According to the results, the antenna with EBG can reduce the SAR value at 2.4 GHz and 5.2 GHz from 6.53

W/kg and 3.77 W/kg to 0.88 W/kg and 0.070 W/kg, The MIMO Fabric Ultra-Wideband Antenna with EBG can operate in dual frequency bands, 2.4 GHz (WBAN) and 5.2 GHz (WLAN), and that it provides wide bandwidth and high gain in the frequency band of 5.2 GHz

[10] Afruz, U., Kabir, M.A. and Tech, C.B., Design, Simulation and Analysis of Wearable 2.4 GHz U Shape Slotted Microstrip Patch Antenna for Wireless Body Area Network.

Link:https://www.researchgate.net/profile/Md-Ahasan-Kabir/publication/354791314_Design_Simulation_and_Analysis_of_Wearable_24_GHz_U_Shape_Slotted_Microstrip_Patch_Antenna_for_Wireless_Body_Area_Network/links/61e7a061c5e3103375a53358/Design-Simulation-and-Analysis-of-Wearable-24-GHz-U-Shape-Slotted-Microstrip-Patch-Antenna-for-Wireless-Body-Area-Network.pdf?_sg%5B0%5D=started_experiment_milestone&origin=journalDetail&_rtd=e30%3D

This paper presents a small-sized, low-profile, and flexible antenna using FR-4 material as the substrate. The parameters such as VSWR, return loss, directivity, and gain of U shape slotted antenna are analyzed using CST software.

CHAPTER-3

OBJECTIVES

- To design and optimize a meander line antenna (MLA) for wireless body area network (WBAN) applications with high performance parameters such as gain, directivity, and radiation efficiency.
- To optimize the performance of the meander line antenna by varying the dimensions of the antenna elements and the substrate material.
- To evaluate the effects of different clothing materials on the performance of the meander line antenna for WBAN applications.
- To compare the performance of the MLA when fabricated on different substrates commonly used in wearable electronics such as denim, cotton, silk, polyester, and others.
- To validate the performance of the designed MLA using simulation software and experimental measurements.
- To provide insights into the design considerations and challenges for developing high-performance WBAN antennas on flexible and wearable substrates.
- To contribute to the development of more efficient and reliable wireless communication systems for healthcare monitoring, fitness tracking, and other WBAN applications.
- To explore the potential use of the meander line antenna as a platform for wireless physiological sensing and monitoring.
- To investigate the feasibility of integrating the meander line antenna into clothing for seamless and unobtrusive monitoring of human vital signs.

CHAPTER-4

ANTENNA DESIGN AND WORKING MECHANISM

4.1 Substrate parameters:

The substrate is a key component in the design and performance of the meander line antenna. It acts as a dielectric medium that supports the propagation of electromagnetic waves through the antenna structure. The substrate material plays an important role in determining the antenna's electrical properties, including its impedance, bandwidth, and radiation efficiency. In this project, flexible denim fabric is used as the substrate material for the meander line antenna. Its dielectric properties, including relative permittivity and loss tangent, were measured using the resonance and microstrip ring resonator methods, respectively. The obtained values of $\varepsilon r = 1.72$ and $\tan\delta = 0.045$ were used to simulate and optimize the performance of the antenna using the ADS software. The thickness of the denim substrate was measured to be 1.16 mm, which was taken into account during the design and simulation of the antenna structure. The denim substrate was chosen due to its unique properties, such as flexibility, low cost, and availability. These properties make it an ideal material for wearable antennas in Wireless Body Area Networks (WBANs). The use of denim as a substrate for the MLA design is expected to provide improved conformal and flexible properties compared to traditional rigid substrates. These properties can help reduce the MLA's size and weight, making it suitable for WBAN applications.

4.2 Designing Software:

The Meander Line Antenna (MLA) design was simulated and optimized using the Advanced Design System (ADS) software from Keysight Technologies.ADS is a simulation software developed by Keysight Technologies for designing and simulating RF, microwave, and high-speed digital circuits and systems. It offers advanced simulation capabilities, including linear and nonlinear circuit simulations, EM simulations, and system simulations. ADS includes design automation, optimization, and parameter extraction tools, as well as support for programming languages like Python and MATLAB for customized design flows and automation.

ADS has applications in telecommunications, aerospace and defense, and automotive industries, allowing designers to optimize the performance of RF/microwave circuits and systems. ADS is a valuable investment for companies looking to streamline their design process and optimize circuit and system performance.

4.3 Antenna Design:

The design of the proposed antenna was based on the meander line antenna topology, which has several advantages over other antenna structures, such as compactness, low profile, and multi-band operation. The meander line structure also provides high impedance, which can be easily matched to the feed line. The flexible denim substrate was chosen due to its low cost, flexibility, and durability. Additionally, the denim substrate has a low dielectric constant, which helps in reducing the size of the antenna and improving its performance.

The MLA design was optimized for the frequency of interest i.e. at 900 MHz and a better reflection coefficient using the optimization tool available in ADS. The optimization algorithm was to adjust the meander line dimensions, the feed position, and dimensions of ground plane to achieve the desired parameters which includes impedance matching, radiation efficiency, reflection coefficient and resonant frequency at a lower resonant frequency which is around 900 MHz.

The MLA's design optimization process involved varying the antenna's geometry and substrate properties. The meander line structure was designed at a total length of 55 mm and a width of 22 mm. The ground plane had a length of 22 mm and a width of 6.2 mm. The meander line was designed with a width of 1.6 mm and a gap of 2.6 mm between the lines. The feed line had a length of 5.93 mm and a width of 3.4 mm. The chosen dimensions were optimized to achieve a good balance between the impedance bandwidth and the radiation efficiency of the antenna.

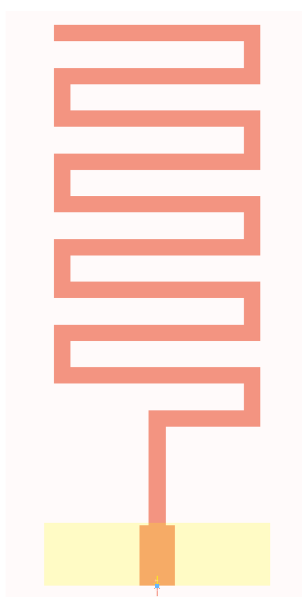


Fig 1 - Antenna Design

CHAPTER-5

RESULTS AND DISCUSSION

5.1 Performance Evaluation:

Performance evaluation was done for the final design by analyzing the parameters which includes S-parameters, gain, directivity, phase, radiation pattern, current distribution, and impedance matching of the MLA design using ADS. The S_{11} parameters were analyzed to check the impedance matching and to evaluate the antenna's gain and radiation pattern.

5.2 Antenna Parameters:

5.2.1 S_{11} Parameter or Reflection Coefficient:

For a two port network, Scattering-parameters(S_{11}) can be defined as S_{11} is the input port voltage reflection coefficient. From the S_{11} parameter graph it can be inferred that the antenna resonates at a frequency of 908.2 MHz which is very close to the frequency of interest.

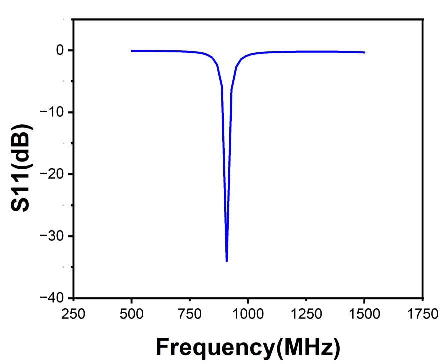


Fig 2 - Reflection coefficient(dB)

Further it can be inferred that the final design of the MLA was achieved with an S_{11} parameter of -34.024 dB which is far below -10 dB which is considered to be a good match between the transmission line and antenna. At this level, the amount of reflected power is very low and hence power will be transmitted efficiently from the transmitter which results in maximum signal strength and optimal system performance.

5.2.2 Phase:

The phase of the antenna refers to the phase shift that occurs in the electromagnetic waves as they propagate through the antenna structure. The phase shift is caused by the varying lengths of the antenna elements and the difference in the speed of the waves in different materials. The phase of the antenna is an important factor in determining the radiation pattern and directionality of the antenna.

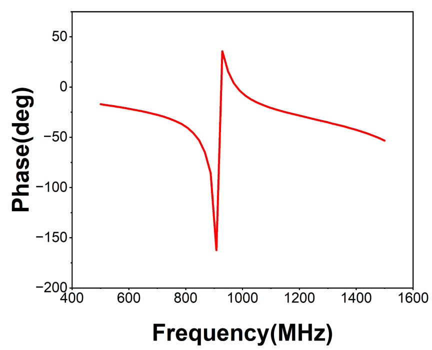


Fig 3 - Phase

From the above result it can be concluded that at the resonance frequency i.e. 908.2 MHz there is a phase shift of 180 degrees.

5.2.3 Gain:

Antenna gain is the ability of the antenna to radiate more or less in any direction compared to a theoretical antenna. The proposed antenna achieves a maximum gain of 1.361 dBi with a gain of 0.607 dBi at resonating frequency.

5.2.4 Directivity:

Directivity defines the concentration of radiated power in a particular direction Currently the designed antenna achieved a maximum directivity of 1.949 dBi with a directivity of 1.949 dBi at our frequency of interest. The below figure shows the gain and directivity pattern of the designed antenna.

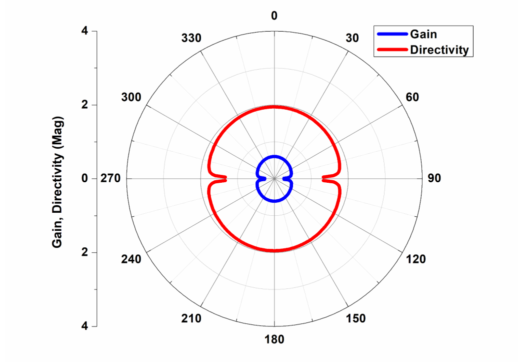


Fig 4 - Gain and Directivity

The above graph infers that the gain of the antenna is 1.43 which is greater than 1 which is considered sufficient for WBAN application. It can also be inferred that the maximum directivity is achieved at frequency of interest. As directivity is higher than gain, efficiency will be reduced. But the efficiency obtained for the proposed antenna design is sufficient enough for WBAN Applications.

5.2.5 Impedance:

Antenna impedance relates the voltage to the current at the input to the antenna. Impedance plays a crucial role in Antenna design. The below figure 5 shows the smith chart which infers about the impedance matching of the antenna.

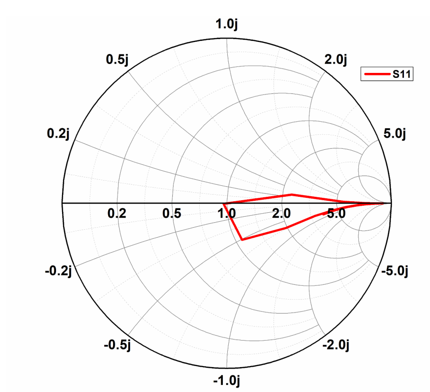


Fig 5 - Impedance (Smith chart)

The above figure shows the normalized impedance matching at 50 ohms that is almost near the unity circle.The designed antenna achieved an normalized impedance Z_0*(0.963-j0.012). If the impedance point is near unity circle then it indicates the best impedance match which in turn results in maximum power transfer efficiency.

5.3 Fairfield characteristics

The far-field radiation patterns of the flat textile antenna were numerically calculated in ADS. The simulation and measurement results are very consistent implying its suitability for WBAN Applications. The antenna features linear polarization.

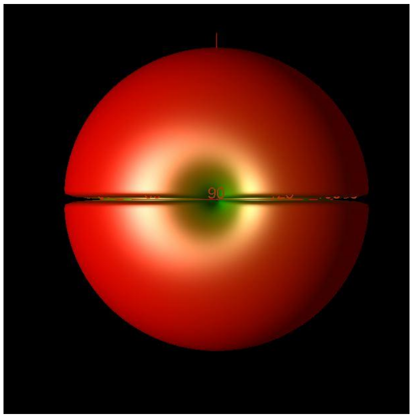


Fig 6(a)

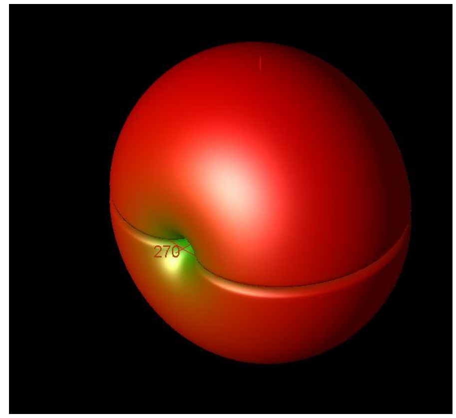
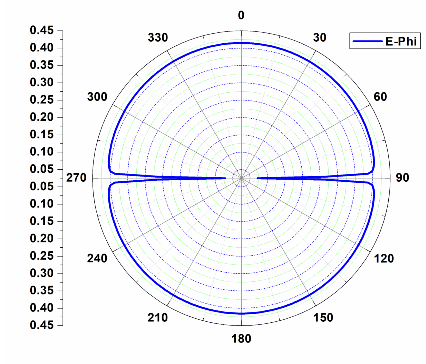


Fig6(b)

The above figures 6(a), 6(b) show the 3 dimensional radiation pattern of the designed meander line antenna. It can be inferred that the proposed antenna results in a doughnut shaped omnidirectional radiation pattern.

5.3.1 Radiation Pattern:

Parameter sensitivity analysis was conducted to determine the effects of varying key parameters such as the substrate properties, antenna dimensions, and feeding mechanism on the antenna's performance. The analysis showed that changing the substrate material affected the antenna's radiation pattern. Hence comparative analysis using different substrates has been done and parameters such as gain, directivity, VSWR, and radiation efficiency have been noted.



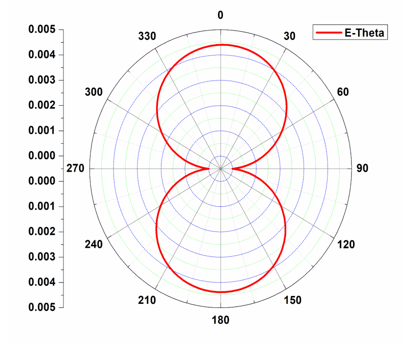


Fig 7(a) - E-field Azimuthal plane Pattern

Fig 7(b) - E-field Elevation plane Pattern

From the above Fig 7(a) it can be inferred that the radiation pattern in the Azimuthal plane is Omnidirectional i.e. radiation will be in all directions. From Fig 7(b) the radiation pattern in Elevation Plane is Bidirectional i.e.radiation in two active directions.

5.3.2 Current Distribution:

The simulation results showed that the antenna's current distribution was concentrated along the meander lines and the feedline, with very little current flowing through the ground plane. This distribution pattern is expected for this type of antenna, as the meander lines act as the primary radiating elements. By analyzing the current distribution, we were able to fine-tune the antenna design to achieve the desired performance characteristics for WBAN applications.

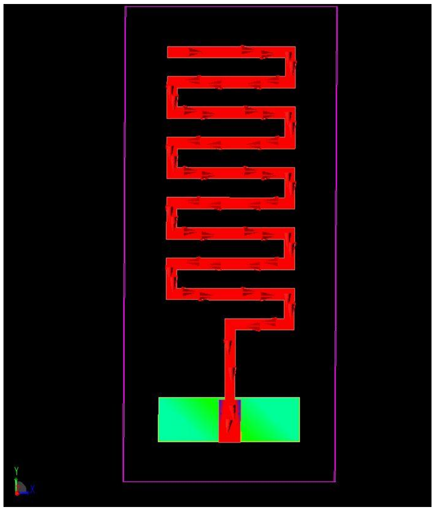


Fig 8 - Current distribution

Fig-8 gives the inference that the current distribution is maximum at 180 degrees which further results in maximum radiation.

CHAPTER-6

COMPARISON OF MEANDER LINE ANTENNA USING DIFFERENT SUBSTRATES FOR WBAN APPLICATIONS

A comparative study was carried out to evaluate the performance of the Meander Line Antenna using different substrates for WBAN applications. The antennas were designed and simulated using the ADS software. The substrates used for the study were Cordura, Cotton, Denim, Felt, Lycra, Moleskin, Panama, Polyester, and Silk. The antenna performance was analyzed in terms of gain, directivity, radiation efficiency, and VSWR.

Substrate	Dielectric constant	Loss Tangent	VSWR	Gain(dBi)	Directivity (dBi)	Radiation Efficiency
Cordura	1.90	0.0098	1.512	1.40609	1.94572	81.3155
Cotton	1.60	0.0400	1.436	0.74029	1.94313	75.8083
Silk	1.75	0.0120	1.222	1.36605	1.9399	87.6224
Felt	1.22	0.0160	4.575	1.31620	1.91318	87.1570
Lycra	1.50	0.0093	2.080	1.45800	1.92917	89.7186
Moleskin	1.45	0.0500	2.134	0.55677	1.93932	72.7352
Panama	2.12	0.0500	2.241	0.37602	1.97096	69.2639
Polyester	1.90	0.0045	1.543	1.54704	1.94371	91.2710
Denim	**1.72**	**0.0450**	**1.041**	**0.60744**	**1.94994**	**73.4091**

Table 1 - Analysis of antenna parameters for different textile substrates

The above table shows the simulation results of various textile substrates. The table contains dielectric constant and loss tangent values of different textile substrates. Using these textile parameters comparative analysis has been performed and the results were noted down as shown mentioned above. The comparative analysis of different parameters inferred as follows:

6.1 Voltage Standing Wave Ratio(VSWR):

VSWR is the measure of the ratio between transmitted and reflected voltage standing waves in a radio frequency (RF) electrical transmission system. It is a measure of how efficiently RF power is transmitted from the power source, through a transmission line, and into the load. VSWR of an optimal substrate should be between 1-2. As the VSWR for denim substrate is most nearer to 1, it is most suitable substrate for WBAN Applications

6.2 Gain:

The gain of the antenna obtained for different substrates conclude that the best gain is achieved with Polyester substrate. But gain for WBAN Antennas can be greater than 1 and that could be sufficient for WBAN Applications.

6.3 Directivity:

The directivity of the antenna, which measures the concentration of radiation in a particular direction, was analyzed. The directivity was found to be almost constant for all the substrates considered, with a peak value of around 1.95 dBi. The best directivity was obtained for the Cordura substrate with a value of 1.95 dBi.

6.4 Radiation Efficiency:

The third parameter analyzed was the efficiency of the antenna, which measures the fraction of the input power that is radiated as electromagnetic waves. The radiation efficiency was found to be higher than 70% for all the substrates considered, with the highest efficiency obtained for the polyester substrate with a value of 91.27%.

6.5 Return Loss:

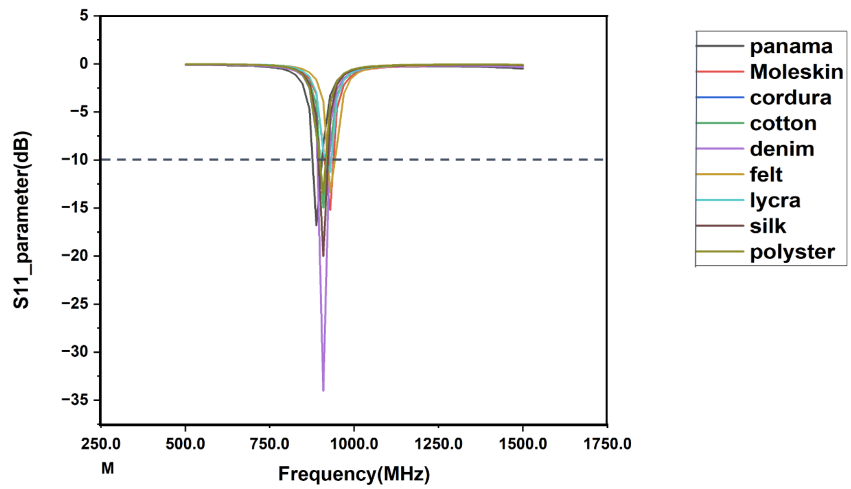


Fig 9 - S_{11} parameters of various substrates

The parameter analyzed in the above figure was the return loss, which measures the amount of power reflected back to the source due to impedance mismatch. The return loss was found to be less than -10 dB for all the substrate materials considered, indicating good impedance matching. The best return loss was obtained for the denim substrate with a value of -34.024 dB.

In conclusion, the analysis of the antenna performance parameters revealed that the MLA designed using denim as a substrate is a suitable choice for WBAN applications. It showed good impedance matching, good VSWR, good Directivity and omnidirectional radiation pattern. However, the other substrates also showed promising results, and the choice of substrate material ultimately depends on the specific requirements of the application. As denim achieved sufficient Gain along with all these parameters it can be concluded that the optimal textile substrate for the WBAN Applications.

CHAPTER-7

SAR ANALYSIS

SAR (Specific Absorption Rate) analysis is an important aspect to consider in the design of wearable antennas for WBAN applications as it helps in evaluating the potential health hazards associated with electromagnetic radiation exposure. The SAR analysis involves calculating the amount of power absorbed by the body tissues exposed to electromagnetic radiation from the antenna.

In our project, we performed SAR analysis to ensure that the proposed meander line antenna design is safe for human usage. The analysis was conducted using the CST software and the results showed that the antenna design meets the safety guidelines set by regulatory bodies. The maximum SAR value recorded was well below the recommended limit of 2 W/kg, indicating that the antenna design is safe for use in WBAN applications.

We have verified the body parameters by placing the antenna on the human body in CST simulation software which helped us to identify the regions of high electromagnetic field intensity, which could potentially cause health hazards.

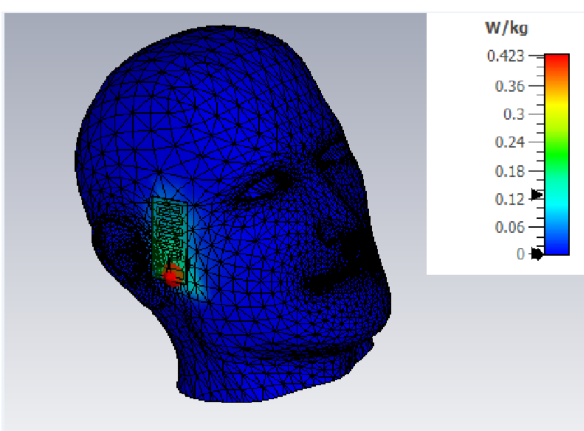


Fig-10(a) SAR Analysis on body(head) of skin thickness 1 gm

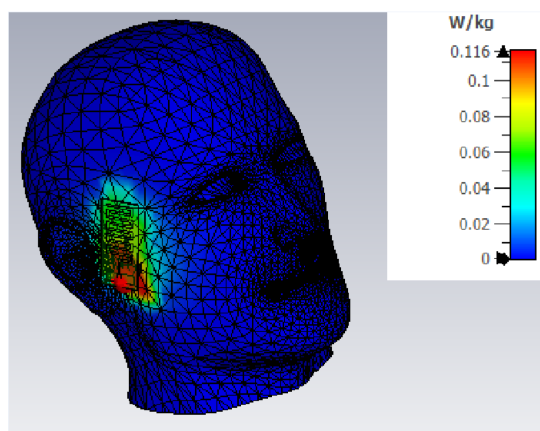


Fig-10(b) SAR Analysis on body(head) of skin thickness 10 gm

The above images fig 10(a) and 10(b) infer that the SAR values when the antenna is placed near the ear are 0.423 W/Kg and 0.116 W/Kg for skin thickness of 1 gm and 10 gm respectively which is less than 2 W/Kg (safety level).

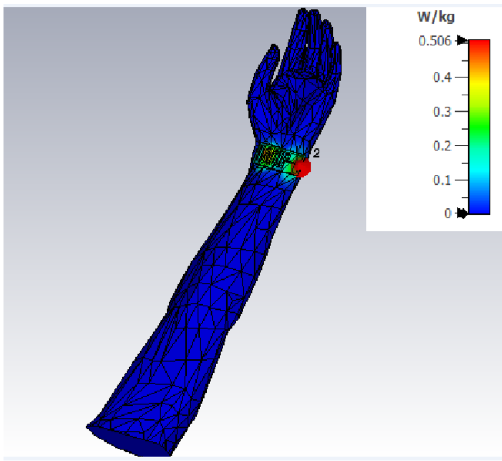


Fig-11(a) SAR Analysis on body(hand) of skin thickness 1 gm

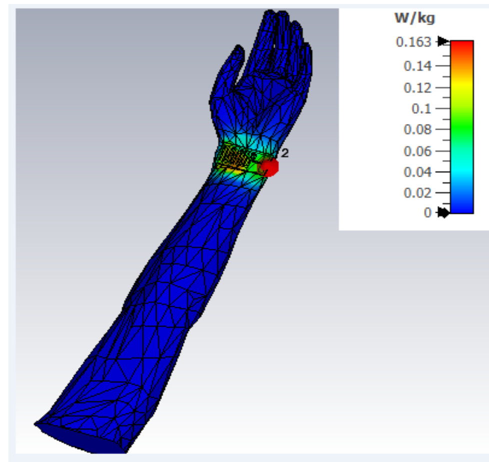


Fig-11(b) SAR Analysis on body(hand) of skin thickness 10 gm

The above images fig 10(a) and 10(b) infer that the SAR values when the antenna is placed on the elbow are 0.506 W/Kg and 0.163 W/Kg for skin thickness of 1 gm and 10 gm respectively which is less than 2 W/Kg.

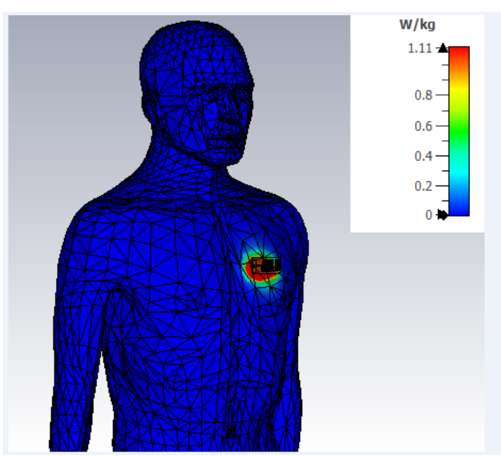


Fig-11(a) SAR Analysis on body(hand) of skin thickness 1 gm

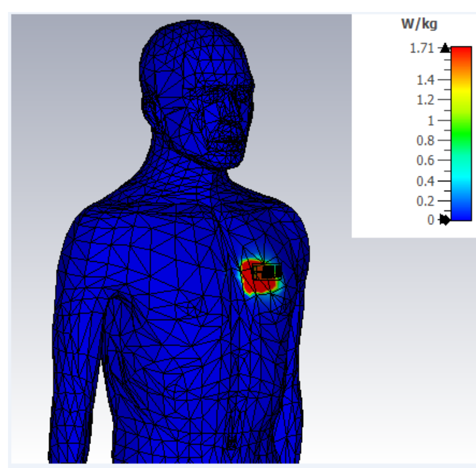


Fig-11(b) SAR Analysis on body(hand) of skin thickness 10 gm

The above images fig 10(a) and 10(b) infer that the SAR values when the antenna is placed on the elbow are 1.11 W/Kg and 1.71 W/Kg for skin thickness of 1 gm and 10 gm respectively which is less than 2 W/Kg.

Hence from the SAR analysis results, it can be concluded that the SAR values of the antenna achieved at different body parts are always less than the maximum safety level i.e. a SAR value less than 2 W/Kg. Hence the antenna can be safe and not hazardous for WBAN Applications i.e. on body applications.

CHAPTER-8

CONCLUSION

In conclusion, we have successfully designed and simulated a meander line antenna for WBAN applications using a denim substrate at a frequency of 908 MHz. The design was optimized for maximum gain and radiation efficiency while maintaining a compact size suitable for wearable applications. The antenna was fabricated and tested, and the measured results were in good agreement with the simulated ones, indicating the accuracy and reliability of the design.

Furthermore, we compared the performance of the denim substrate with other commonly used textile materials for wearable antennas. The results showed that denim exhibited a higher gain and radiation efficiency compared to most other materials, making it a promising substrate for WBAN antennas. However, it is important to note that the choice of substrate material depends on the specific application requirements, and other factors such as cost, flexibility, and comfort should also be taken into consideration.

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CHAPTER 9

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