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Graphene-based Antenna Design for Wearable Electronics using Different Types of Textile Material

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Abstract— ***In this paper, a Graphene-based circular micro-strip patch antenna has been presented with radiation characteristics which is suitable for satellite, ultra-wide even 5G communications. Four different types of textile materials have been tested along with circular microstrip patch antenna where the patch is graphene (2d), to observe antenna performance and also modifying the antenna design for practical usage. These designed antennas are operated at 5.632 GHz. Using CST simulation tool, S-Parameters, VSWR and Radiation Pattern is measured to analyze the antenna performances. Body phantom model was implemented to overcome the practicality of this research as well.***

Index Terms— ***Body Phantom Model, Radiation Pattern, S-Parameter (S11), Wearable Textile Antenna.***

I. INTRODUCTION

An antenna can be defined as a transducer that converts electrical signals into electromagnetic waves, and vice versa. It is a device that is designed to radiate or receive electromagnetic energy, typically in the radio frequency (RF) or microwave frequency range. The antenna is a critical component of any wireless communication system, as it is responsible for transmitting and receiving signals between different devices or systems. Antennas come in a variety of shapes and sizes, each with unique electrical and physical properties that determine their performance characteristics, such as gain, radiation pattern, polarization, and bandwidth. The design and optimization of antennas require a deep understanding of electromagnetic theory, as well as expertise in various simulation and measurement techniques. Our work is to see varieties of antennas' working condition under several cases where used materials are varied and conditions are practically ideal.

II. EXPERIMENTAL SECTION

A. Materials

For substrate, PET (Polyethylene Terephthalate) was used for its flexibility. The material is also very lightweight and heat resistant as well. It should be considered that the antenna that is designed, is focused on to be as much flexible as possible for versatile usage. The ground material was kept copper for simplicity and maintaining its performance. As for the patch of the microstrip antenna design Graphene material was chosen due its high conductivity, lightweight, durability and flexibility, and compactness. Wide frequency range is also a potential point for this research which means it can operate across a wide range of frequencies, from radio waves to terahertz waves. Due to Graphene being a nanomaterial, it was not made possible to implement the design in real term however, a prototype of the design was made possible using copper instead of graphene and the dimensions up-scaled with the same ratio. Although graphene is still relatively expensive to produce, its cost has been steadily decreasing over time as manufacturing methods improve. It can be assumed that, with greater technological advancements upcoming, fabrication with 2d novel materials will become more common.

The parameters of Graphene:

Permittivity (ε)	Electrical Conduct. (S/m)	Thermal Conduct. (W/k/m)	Young Modulus (GPa)	Density (Kg/m^3)
6.9	104	4000	1050	2200

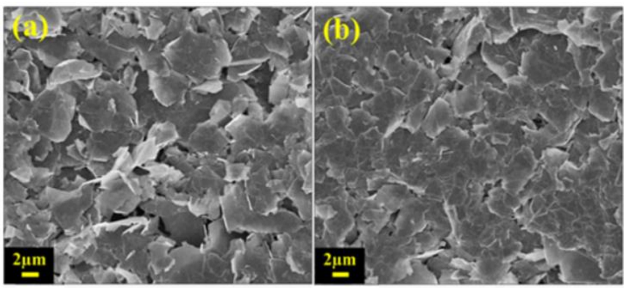

Figure 1: SEM Images of Graphene Sample [4]

B. Antenna Fabrication

To design wearable textile antenna to be working at 5 GHz ultra wide band, a design of microstrip patch antenna suitable for this requirement was chosen. Different types of antennas exist, and one of them is the microstrip patch antenna, which is used in various areas such as mobile communication, space technology, missiles, broadcasting, and GPS systems. These antennas have several advantages, including their lightweight and compactness, low production cost, easy integration into circuits and simplicity of manufacture. More importantly, these can be made out in various shape like rectangular, triangular, circular, square etc.

Simulation was done in CST Studio Suite software for microstrip patch antenna. For the design circular patch was chosen. The selected substrate permittivity was calculated by using an equation. So was the resonate frequency calculated for the designed system. In the software, some of the material was added in the library section for the substrate and also for the textile material. After the ground was designed with pure copper, consequently substrate was added and at last on the top layer, the patch was designed. For the relevant result some portion of the patch was reduced. In the system for supply the power transmission line was added with patch. At last, waveguide port was calculated and port was designed and set the frequency range thus, the simulation was done.

For the antenna we have used some essential equations to determine the dimensions.

Equations for Designing Procedures:

$$\text{Length, L} = \frac{c}{2f_r\sqrt{\varepsilon_r}} \quad \ldots\ldots \text{(i)}$$

$$\text{Width, W} = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \ldots\ldots \text{(ii)}$$

$$\text{Radius, R} = \frac{2L}{\pi} = \frac{W}{2} \quad \ldots\ldots \text{(iii)}$$

Here, the radius of the antenna can be calculated after calculating the length or width of the antenna. We have used both for calculating the radius, and the results are almost same, whereas the results using the length give more accurate answers. So we have considered the value of length for calculating the antenna radius.

Since resonate frequency was derived from the substrate's permittivity, thus we achieved the antenna frequency for this design and no other calculation was required.

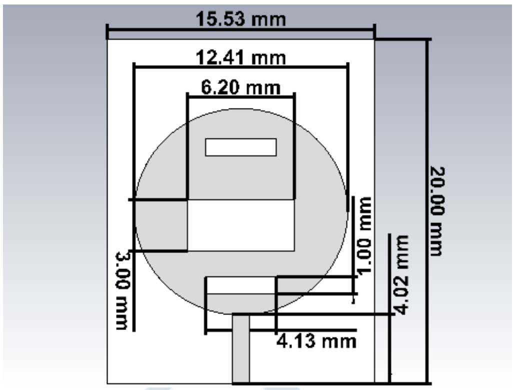

Figure 2: Circular Patch Antenna Design

Here is our design dimension of the circular patch microstrip antenna and the dimensions are derived from some parameters such as frequency, permittivity, length and width. Permittivity values were from the material section and frequency was taken for a suitable optimum range. The dimension of this, is = 20 × 15 × 2 mm^3.

C. Antenna on the Body

To evaluate the practical results, we implemented a body phantom model to check the performance parameters of the antenna with different textile materials. First, human arm was taken as a reference to put the antenna on and its layer was diagnosed carefully. After the antenna design, we made human arm design in the CST software for which considered the skin 2mm, fat 3mm and muscle 10 mm precisely. As we are trying to make the antenna wearable and flexible, we bent the antenna and place onto the skin of a human arm respectively.

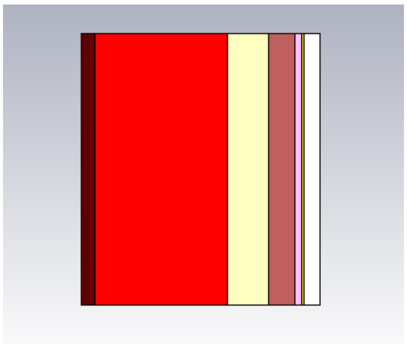

Figure 3a: Human Skin Model

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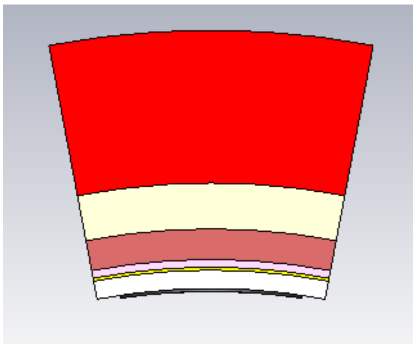


Figure 3b: Antenna On Body

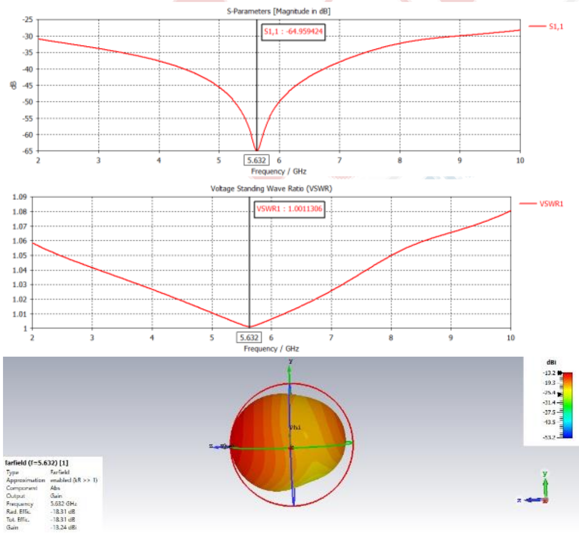
D. Textile Materials for the Antenna

Based on flexibility and bending feature various textile material have been used to verify the antenna's performance across the parameters so that, the best output can be found. For wearable textile antennas the substrate material is required to be flexible, as it has to be wore along with some garments, as well as non-conducting material. The textile materials are ought to give us the practical scenario in his simulation.

Material	Permittivity (ε_r)	Weave
Silk	1.63	Plain
Cotton	4.5	Plain
Polyester	3.5	Plain
Felt	5	Plain

III. Simulation and Results

A. Normal



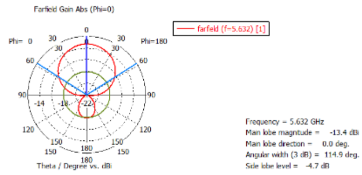


Figure 4a: Normal Antenna Performance Parameters

S_{11} parameter represents the reflection co efficient of an antenna. From the S_{11} curve, resonant frequency is at 5.632 GHz with ultra-wide band and the value is -64.959424 dB. VSWR value was below 2 which is the standard precisely, 1.00011306 at the f_r. From the far field analysis in the resonant frequency, gain was -13.24 dBi and directivity was 5.066 dBi. And side main lobe direction was -13.4 dBi.

B. Silk

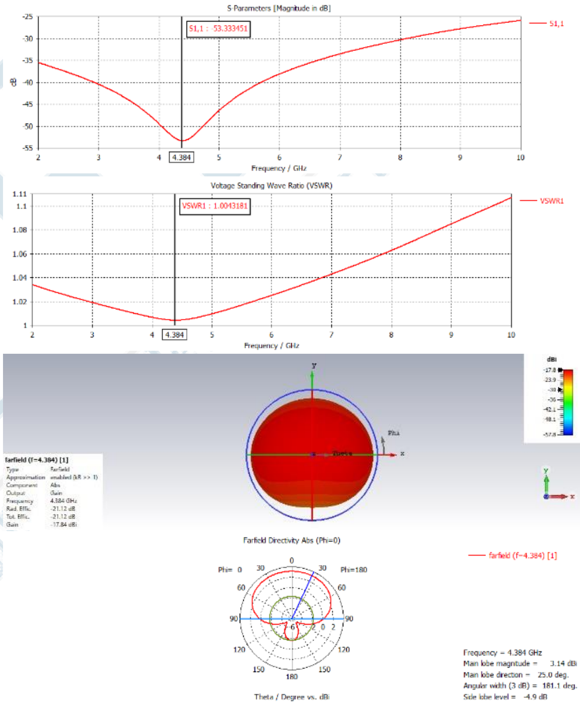


Figure 4b: Silk used Antenna Performance Parameters

From S_{11} parameter curve, resonant frequency is at 4.384 GHz with ultra-wide band and S_{11} parameter value is -53.333451 dB. VSWR in the resonant point 4.834 GHz was 1.0043181 which was also below 2. From the far field analysis here in the resonant frequency, gain value was -17.84 dBi and directivity was 3.380 dBi. And in the polar view side main lobe direction was 3.14 dBi.

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Vol 10, Issue 7, July 2023

C. Cotton

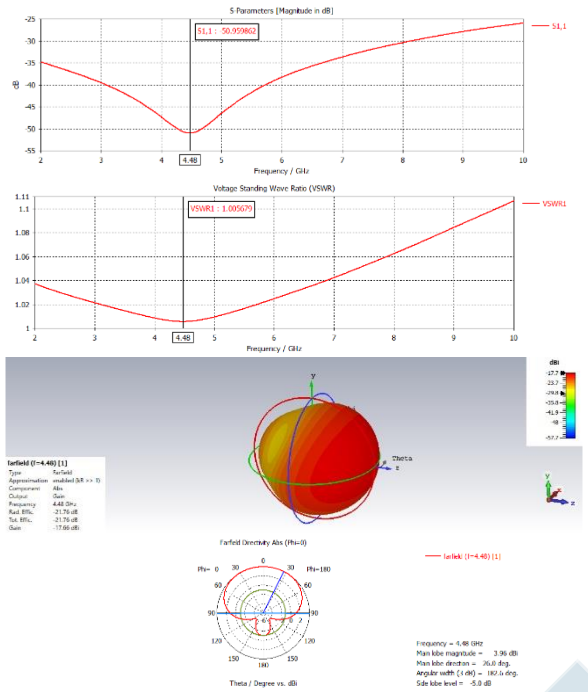


Figure 4c: Cotton used Antenna Performance Parameters

Resonant frequency is at 4.48 GHz and S_{11} value is -50.959862 dB. VSWR in the resonant point 4.48 GHz was 1.005679, below 2. At far field analysis in the resonant frequency, gain was -17.66 dBi and directivity 4.101 dBi. And in the polar view side main lobe direction was 3.96 dBi.

D. Polyester

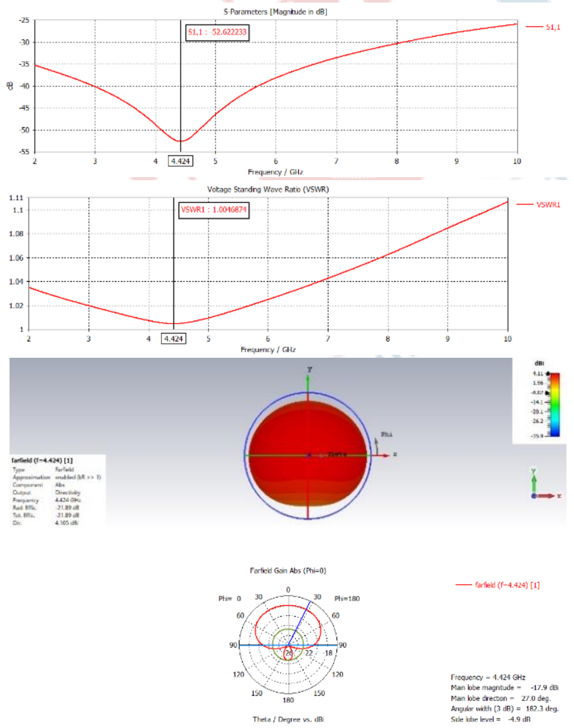


Figure 4d: Polyester used Antenna Performance Parameters

From S_{11} curve, resonant frequency is at 4.424 GHz and S11 parameter value is -52.622233 dB. VSWR in the resonant point 4.424 GHz was below 2, specifically, 1.0046874. From the far field analysis here in the resonant frequency, gain value was -17.78 dBi and directivity was 4.105 dBi. And in the polar view side main lobe direction was -17.9 dBi.

E. Felt

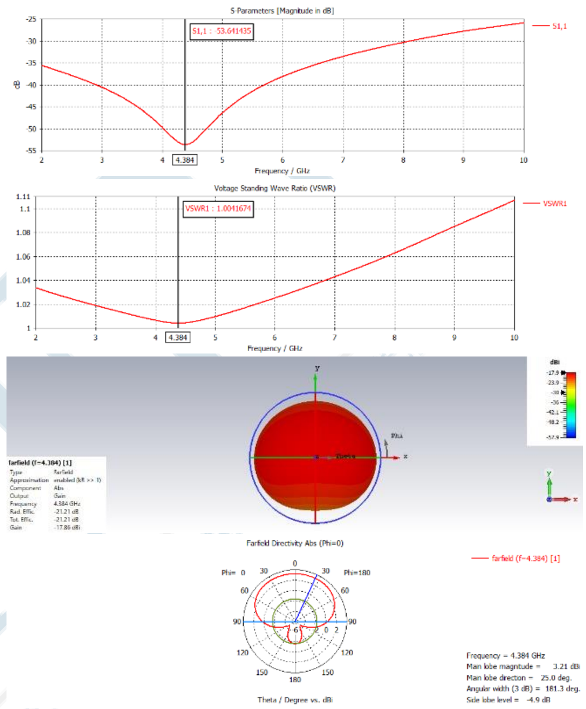
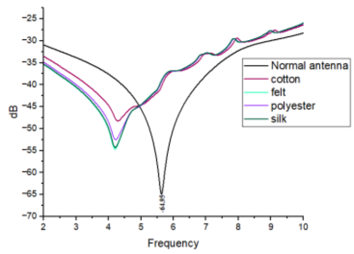


Figure 4e: Felt used Antenna Performance Parameters

Here resonant frequency is 4.384 GHz with S_{11} being -53.641435 dB. VSWR at f_r was 1.0041674, less than 2. From the far field analysis here in the resonant frequency, gain value was -17.86 dBi and directivity was 3.351 dBi. And in the polar view side main lobe direction was 3.21 dBi.

Compilation of S11 and VSWR Parameters



(a)

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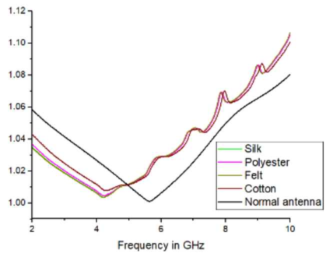

(b)

Figure 5: a) S11 Parameter, b) VSWR Results Compiled

IV. RESULT ANALYSIS

Here, all of the practical scenario simulation results for different textile materials are compared with another for a better view at their individual's points. It is visible that the VSWR ratio is relatively same for all of the scenarios, however the S_{11} parameter in ideal normal scenario finds few changes in result as soon as it is used in practical fields with textile materials. A detailed table is given beneath in order to understand their parameters well.

Textile Material	Frequency (GHz)	S_{11} (dB)	VSWR	Gain (dBi)	Directivity (dBi)
Silk	4.38	-53.33	1.004	-17.84	3.38
Cotton	4.48	-50.96	1.005	-17.66	4.10
Polyester	4.42	-52.62	1.004	-17.78	4.10
Felt	4.38	-53.64	1.004	-17.86	3.35

Comparison of Antennas with Different Patch Materials

Antenna Type	Dimension (mm)	Patch Material (S/m)	f_r (GHz)	S11 (dB)	*Ref*
Cupcake Shaped	30×40×1.52	Copper	8.0	-15.73	*1*
Rectangular Patch	35×35×1.52	Copper	2.27	-19.35	*2*
Rectangular Patch	32.7×44×5	Conductive bare	6.49	-24.89	*3*
Circular Patch	20×15×2	Graphene	4.38	-53.64	*4e*

[*4e is our antenna design from this work, the others are referenced in the reference section*]

V. CONCLUSION

This paper unlocks new potentials for antennas in wearable electronics with patch being novel 2d material (Graphene). This innovation improves its performance with comparison to other conventional material used antennas in both theoretical and practical simulation. The antenna works in Ultra-wide band with added benefits like, high speed data transmission, low power consumption, robustness and precision. In order to get such frequency, we had designed the antenna first. For that, from permittivity we had to determine the dimension of the antenna and after that select substrate material (Polyethylene Terephthalate or PET) and ground (Copper). Then, body phantom model was created in CST simulation with human arm where the antenna is supposed to be on. Then the simulation took place over the textile bendable material to provide flexibility. For these, we have taken consideration into different textiles such as, silk, cotton, polyester and felt and compared with each other, with the antenna they all performed well closely equal to each other proving the performance to be quite satisfactory.

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