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# Design of a Wearable Textile Antennas for Body Centric Wireless Communication and Performance Analysis at Different Textile Materials

Raja Rashidul Hasan, Sayed Muhammad Baker, Abedul Hadi, Sharmin Jahan

**Abstract—** In this paper, we have presented a circular micro-strip patch antenna with radiation characteristics which is suitable for on-body communications. Eight different types of textile materials is tested along with circular micro strip patch antenna to observed antenna performance and also modified the antenna design. These designed antennas are operated at 2.4 GHz ISM band frequency. Using CST simulation tool Return losses, Radiation Patterns, S-Parameters is measured to analyze the antenna performances.

**Keywords**: Wearable Textile Antenna, Body Area Network, Industrial Scientific and Medical (ISM) band, Patch Antenna

## 1. Introduction

TEXTILE antennas are uses of those scenarios where the bearer is moveable and has to keep the antenna with themselves, and attaching the antenna with their clothes, keeping it flexible and low profile alongside efficient for break free communication. These textile antennas can help the bearer to maintain personal communications, computer systems and wireless monitoring of vital functions, like, monitoring patients' health, any wearable gadgets etc. There were several works done on this field, like- on 2012's research on "A Review of Implantable Patch Antennas for Biomedical Telemetry: Challenges and Solutions" Asimina Kiourti and Konstantina S. Nikita tried to show some overview on the challenges and their solutions of designing implantable patch antenna for biomedical uses, as there are so many issues related to the biocompatibility, miniaturization, patient safety, improved quality of communication with exterior monitoring/control equipment, and insensitivity to detuning [1].On 2013's research paper "Wireless Body Area Networks: A Survey", Samaneh Movassaghi and others tried to show different aspects of wearable antenna and their usages and limitations [2]. The main design criteria for textile antenna modules are weight, physical size, flexibility and power efficiency, which all are directly related to antenna performance.

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The objective of this work is to design and simulate microstrip patch antenna with eight different textile materials to observe their performances, which will work at resonant frequency ranging from 2.4 GHz to 2.5 GHz ISM band frequency. The principal requirement for the antenna is to design wearable antennas by using flexible materials and to integrate antennas into clothing. Using a micro-strip feed not only guarantees a flat structure, but also allows the assembly of electronic components directly on the fabric in antenna proximity. We added a ground plane at the bottom in order to minimize the amount of power absorbed by the human body.

## 2. Choosing Antenna Frequency

An antenna is always designed for any specific band of frequency. For wearable antennas choosing any frequency would not be right, as the antenna would be carried or attached to human or animal being, and not all frequencies are suitable for human or animal bodies, besides harmful. Also it should be considered about the antenna size, desirable application, while choosing frequency. A low frequency will give lower attenuation, but will need relatively larger antenna size. Again, a higher frequency antenna will give higher attenuation using a smaller antenna. So at low frequencies the antenna becomes an inefficient radiator, and at high

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frequency relatively efficient radiator but higher frequency radiator also causes higher tissue absorption rate [3]. Considering all these factors, 2.4 GHz ISM band is more often suitable for on body use for wearable antenna.

ISM band is open frequency bands for Industrial, Scientific and Medical purpose use for unlicensed operation, such as Wi-Fi, Bluetooth, ZigBee, Z-Wave, etc. ITU Radio-communication Sector (ITU-R) defined ISM band ranges (center frequencies) from 6.780 MHz to 245.000 GHz in their 5.138, 5.150, and 5.280 of the Radio Regulations [4]. The data transfer rate is higher in 2.4 GHz compared to other ISM bands like 900 MHz and other lower frequencies. Other frequencies, like- latest emerging 5 GHz frequency works on shorter range than 2.4 GHz. 2.4 GHz antenna also allows to use multiple frequencies doing some minor changes in the antenna length. Though 2.4 GHz attenuated much faster for higher frequencies and also do not penetrate for some materials, but these drawbacks can be overcome by doing some attenuation adjustments.

## 3. Antenna Design

To design wearable textile antenna working at 2.4 GHz ISM band, a design of microstrip patch antenna suitable for this requirement was chosen. There are several types of antenna models available. Microstrip patch antennas are used in various fields like space technology, missiles, mobile communication, GPS system, and broadcasting [5]. Microstrip patch antennas are light-weight, smaller is size, with low production cost, simplicity of manufacture and easy integration to circuit [6]. More importantly, these can be made out in various shape like rectangular, triangular, circular, square etc. [7]. The most popular models for analysis of microstrip patch antenna are the transmission line model, cavity model and full wave model. For the design, circular type patch antenna was chosen, and for analysis the transmission line model was chosen. Then for the designing, firstly relative permittivity of several types of textile materials were chosen, which were used as dielectric substrate, and using them and using the resonant frequency, the lengths, widths and radiuses of antennas for those collected types of textile materials were calculated. Then proposed antenna has been designed and simulated by using CST (Computer Simulation Technology) software for Microstrip patch analysis. Transient analysis (Time domain solver) for the simulation was used. As all of all desired textile materials were not available in the software library, some had to be set manually putting relative permittivity values of those materials to design the substrates, and the antennas to simulate.

## 4. Essential Equations for the Design Procedure

Length of the Antenna,

$$L = \frac{c}{2f_r\sqrt{\varepsilon_r}} \quad (1)$$

Width of the Antenna,

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

Radius of the Antenna,

$$r = \frac{2L}{\pi} \text{ or, } r = \frac{W}{2} \quad (3)$$

Here,
L = Length of the Antenna,
W = Width of the Antenna,
r = Radius of the Antenna,
fr= Resonant Frequency,
εr = Relative Permittivity of the Substrate Element

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.

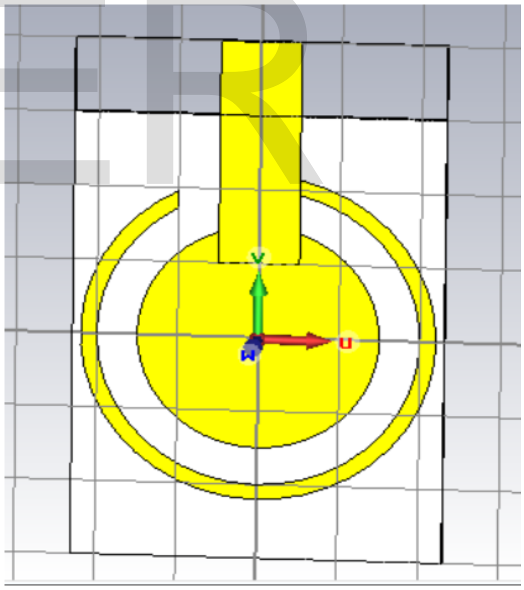

Fig. 1: Designed Antenna by CST

### A. Textile Materials Used in Antenna Design

To design the antenna we used Copper to design the patch of the antenna along with different (eight) types of textile materials to observe the performance of the antenna along with them, so that the suitable antenna can be chosen from the designed antennas for specific purposes. 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 [8]. We have tried to design and simulate antennas for above mentioned materials. For same type of material there are multiple types of permittivity, depending on their fabric (weave), and we also considered those textiles for our designing and simulation.

TABLE 1
TEXTILE MATERIALS USED AS ANTENNA SUBSTRATE, ALONG WITH PERMITTIVITY [9]

| Serial | Material | Weave | Permittivity ( $\varepsilon_r$) |
|---|---|---|---|
| 1 | Cotton | Plain | 2.077 |
| 2 | Wool | Plain | 1.865 |
| 3 | Wool + Polyamide | Twill | 1.529 |
| 4 | Elano-wool | Twill | 2.053 |
| 5 | Elano-wool | Plain | 1.670 |
| 6 | Polyester | Plain | 1.748 |
| 7 | Polyester | Plain | 2.122 |
| 8 | Viscose + Polyethylene | Twill | 1.707 |



### *B.* CALCULATED VALUES FOR ANTENNA DESIGN

The lengths and widths of the antennas is calculated by considering eight different permittivity of eight different textile materials. As it is a circular patch antenna that's why using those widths and lengths the radius (r) of antennas are calculated which is shown in table 1.

TABLE 2:
CALCULATED VALUES FOR ANTENNA DESIGN

| Textile Materials | Substrate Permittivity ($\varepsilon_r$) | Length of the Patch (mm) | Radius of the Patch (mm) |
|---|---|---|---|
| Wool + PA (polyamide) | 1.529 | 100 | 22 |
| Elano-wool (twill) | 1.670 | 100 | 20 |
| Viscose + PE (polyethylene) | 1.707 | 100 | 22 |
| Polyester | 1.748 | 104 | 22 |
| Wool | 1.865 | 100 | 22 |
| Elano-wool (plain) | 2.053 | 100 | 22 |
| Cotton (plain) | 2.077 | 84 | 20 |
| Polyester | 2.122 | 100 | 20 |

## 5. SIMULATIONS & RESULTS

### *A.* COTTON (PLAIN)

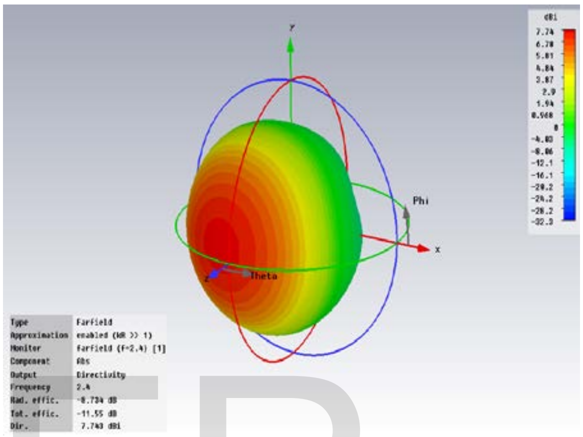


Fig 2: Far-field of Cotton (plain)

Figure 2 shows the far-field of Cotton (plain). From the output it has been observed total radiation efficiency has found to be -8.734 dB and directivity is 7.743 dBi. The blue color shows the reactive near field region; hence, in this region the directivity is too much low. The directivity increased from green to yellow in the radiation near field (Fresnel) region. Top red color indicated the far field region because in this region the directivity is too much high.

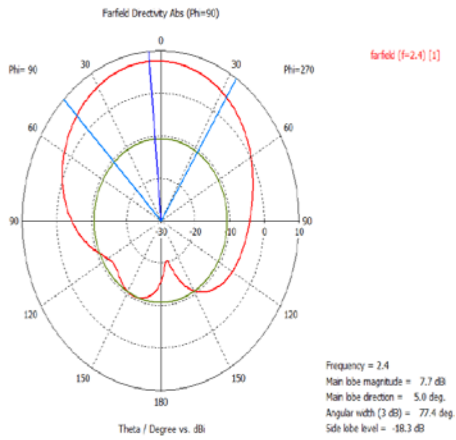


Fig 3: Far-Field (polar view) of Cotton (plain)

Figure 3 shows the far-field (polar view) of the Cotton (plain). From the figure it has been observed the main lobe is centered at five degrees and the main lobe magnitude is 7.7 dBi. The blue lines in figure indicated the half power beam width, is the angular separation in which the magnitude of the radiation pattern decreases by 50% or -3db from peak of the main beam. From the figure it has seen the half power beam width is 77.4 degrees. The side lobes are smaller beams that are away from the main beam. These side lobes has usually radiated in undesired direction, which cannot be eliminated. The side lobe level in this simulated figure is -18.3 dB.

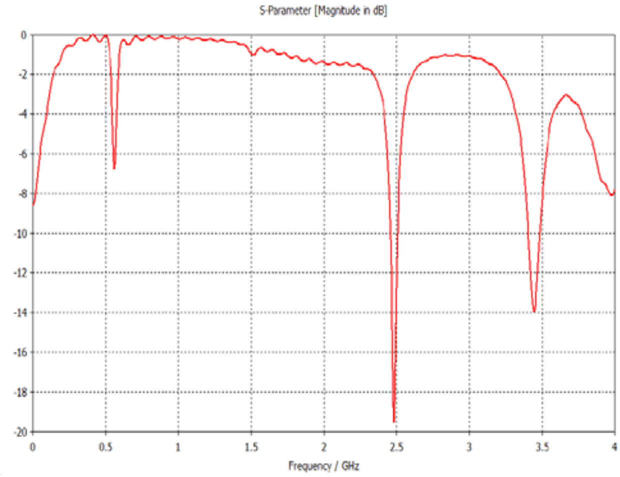


Fig 4: S-Parameter of Cotton (plain)

S-Parameter (S11) represents the return loss (the amount of power reflected from antenna and nothing is radiated), which is better for antenna when it is less. From figure 4 it has been observed the S11 of Cotton (plain) is about -19.5 dB, which is better for antenna performance.

### *B.* Elano-Wool

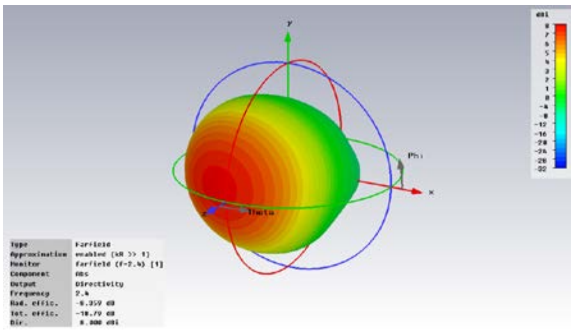

Fig 5: Far-field of Elano Wool

Figure 5 shows the far-field of Elano Wool. From the output it has been observed total radiation efficiency has found to be -8.359 dB and directivity is 8.000 dBi.

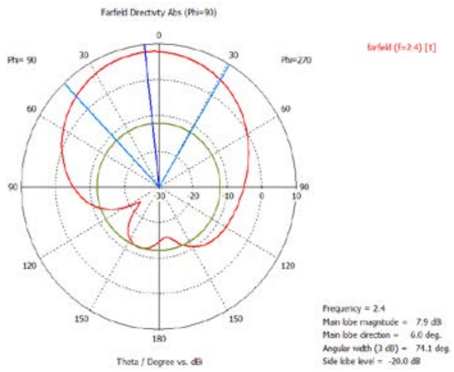


Fig 6: Far-Field (polar view) of Elano Wool

Figure 6 shows the far-field (polar view) of the Elano Wool. From the figure it has been observed that, the main lobe is centered at five degrees and the main lobe magnitude is 7.9 dBi. The half power beam width is 74.1degrees and the side lobe level in this simulated figure is -20.0 dB.

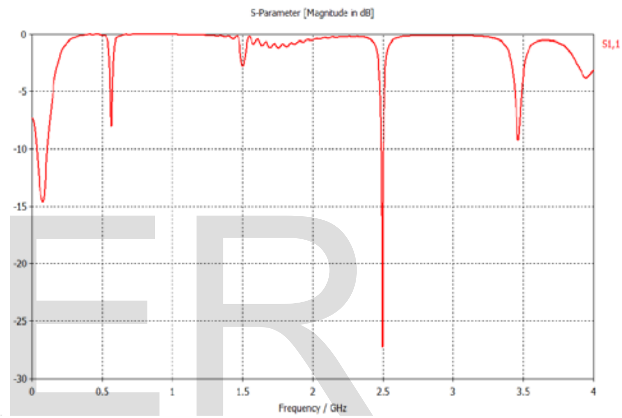


Fig 7: S-Parameter of Elano Wool

From figure 7 it has been observed that the S11 of Elano Wool is about -27 dB, which is better for antenna performance.

### *C.* Elano-Wool (twill)

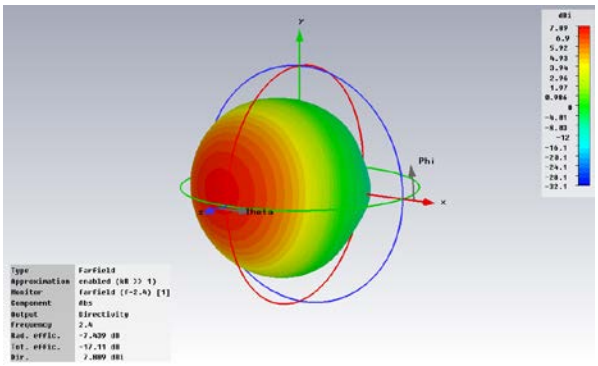

Fig 8: Far-field of Elano Wool (twill)

Figure 8 shows the far-field of Elano Wool (twill). From the output it observed that the total radiation efficiency has found to be -7.439 dB and directivity is 7.889 dBi.

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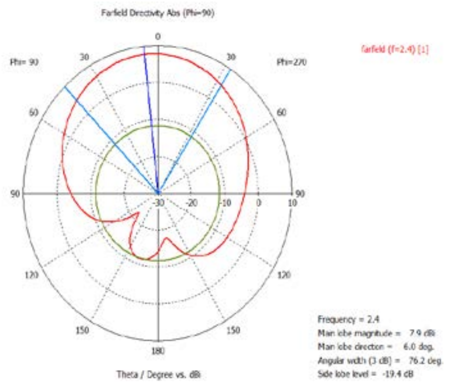


Fig 9: Far-Field (polar view) of Elano Wool (twill)

Figure 9 shows the far-field (polar view) of the Elano Wool (twill). From the figure it has been observed that, the main lobe is centered at five degrees and the main lobe magnitude is 7.9 dBi. The half power beam width is 76.2degrees and the side lobe level in this simulated figure is observed -19.4 dB.

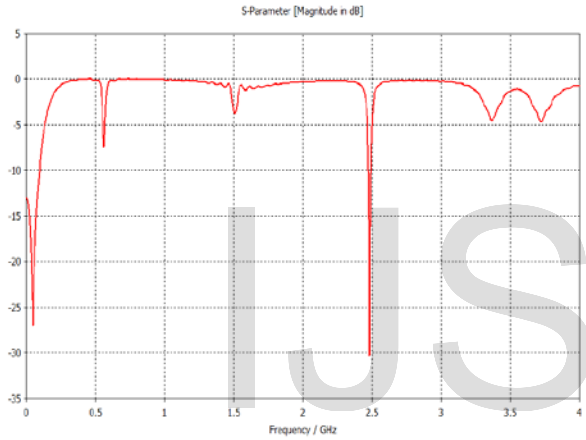


Fig 10: S-Parameter of Elano Wool (twill)

From figure 10 it is observed that, the S11 of Elano Wool (twill) is about -31 dB, which is better for antenna performance.

## *D.* Far-Field of Polyester (1)

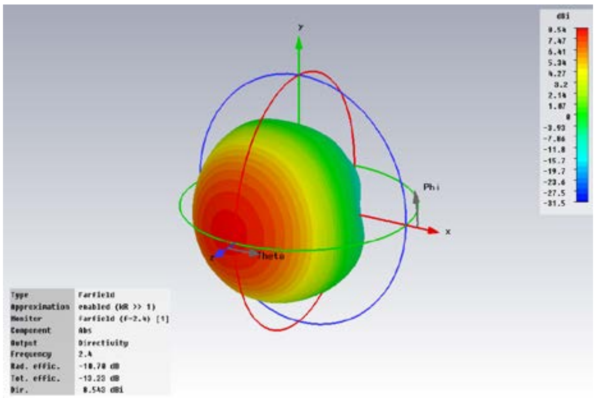

Fig 11: Far-field of Polyester (1)

Figure 11 shows the far-field of Polyester (1). From the output it observed that the total radiation efficiency has found to be -10.70 dB and directivity is 8.543 dBi.

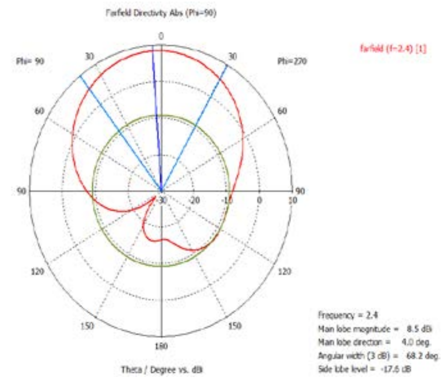


Fig 12: Far-Field (polar view) of Polyester (1)

Figure 12 shows the far-field (polar view) of the Polyester (1). From the figure it observed that, the main lobe is centered at 5 degrees and the main lobe magnitude is 8.5 dBi. The half power beam width is observed 68.2 degrees and the side lobe level in this simulated figure is obtained -17.6 dB.

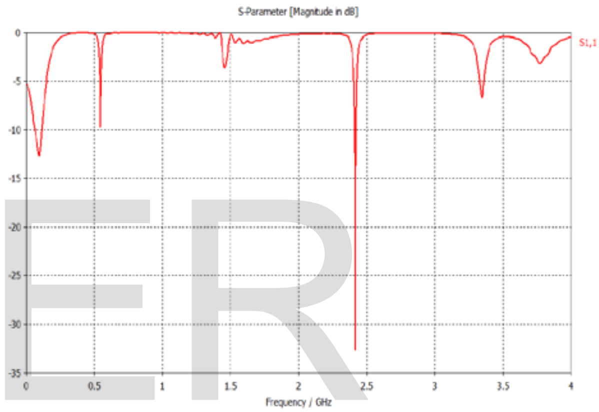


Fig 13: S-Parameter of Polyester (1)

From figure 13 it has been observed that the S11 of Polyester (1) is about -19.5 dB, which is better for antenna performance.

## *E.* Far-Field of Polyester (2)

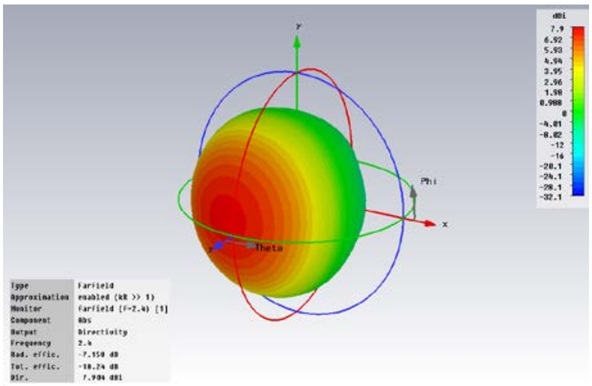

Fig 14: Far-field of Polyester (2)

Figure 14 shows the far-field of Polyester (2). From the output it has seen that the total radiation efficiency has found -7.158 dB and directivity is 7.904 dBi.

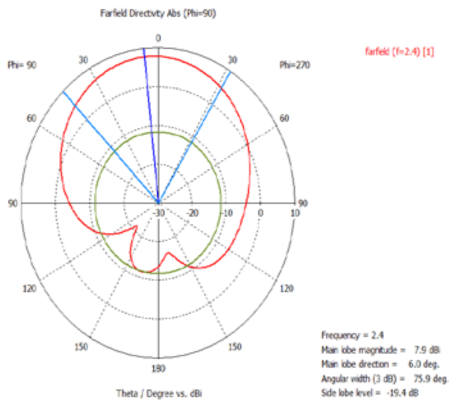


Fig 15: Far-Field (polar view) of Polyester (2)

Figure 15 shows the far-field (polar view) of the Polyester (2). From the figure it is observed that, the main lobe is centered at 5 degrees and the main lobe magnitude is 7.9 dBi. The half power beam width is found 75.9 degrees and the side lobe level is observed -19.4 dB.

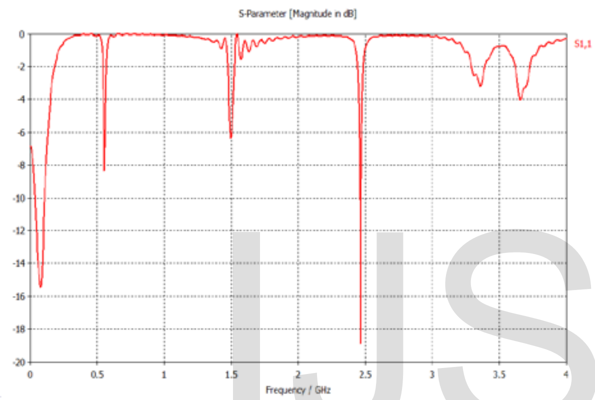


Fig 16: S-Parameter of Polyester (2)

Figure 16 it has been observed that the S11 of Polyester (2) is about -19 dB, which is better for antenna performance.

## *F.* Viscose + PE

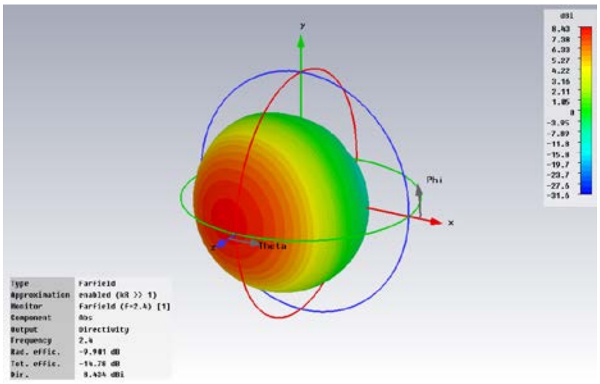

Fig 17: Far-field of Viscose + PE

Figure 17 shows the far-field of Viscose + PE. From the output it observed that the total radiation efficiency has found to be -9.901 dB and directivity is 8.434 dBi.

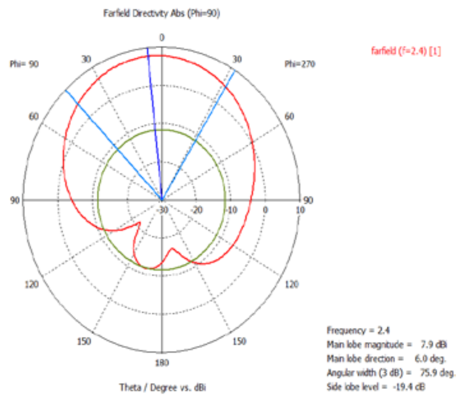


Fig 18: Far-Field (polar view) of Viscose + PE

Figure 18 shows the far-field (polar view) of the Viscose + PE. The main lobe is centered at five degrees and the main lobe magnitude is observed 7.9 dBi. The half power beam width is obtained 75.9 degrees, and the side lobe level in this simulated figure is -19.4 dB.

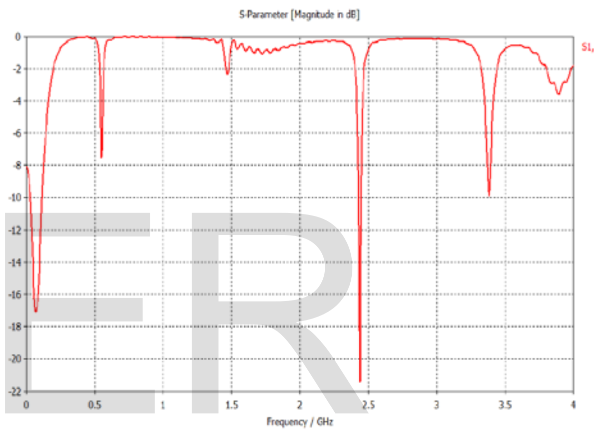


Fig 19: S-Parameter of Viscose + PE

From figure 19 it has been seen that the S11 of Viscose + PE is about -21.5 dB, which is better for antenna performance.

## G. Wool

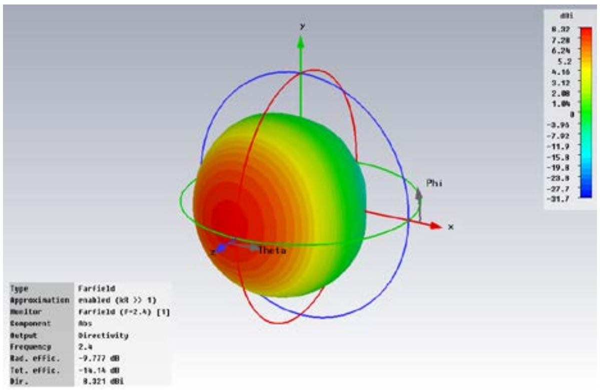

Fig 20: Far-field of Wool

Figure 20 shows the far-field of Wool. From the output it has been observed total radiation efficiency has found to be -9.777 dB and directivity is 8.321 dBi.

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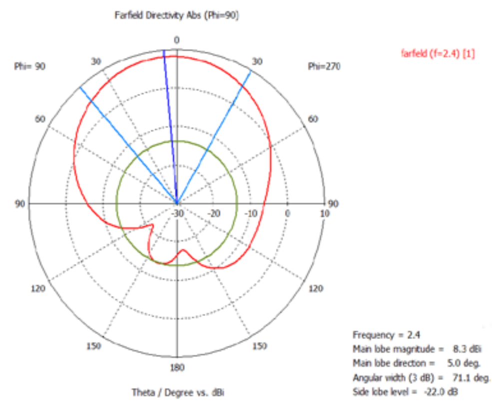

Fig 21: Far-Field (polar view) of Wool

Figure 21 shows the far-field (polar view) of the Wool. From the figure it has been seen that, the main lobe is centered at five degrees and the main lobe magnitude is 8.3 dBi. The half power beam width is observed 71.1degrees. The side lobe level is found -22.0 dB.

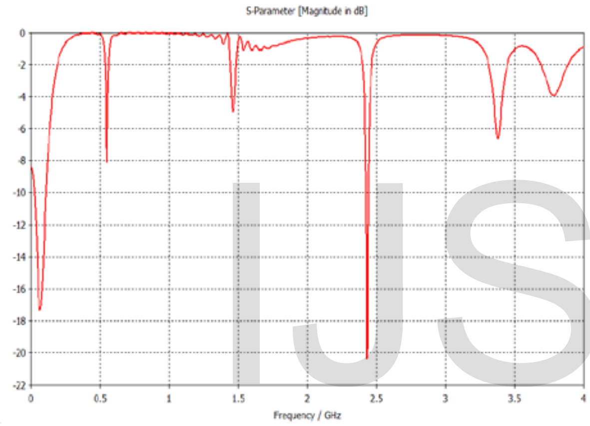

Fig 22: S-Parameter of Wool

From figure 22 it has been seen that the S11 of Wool is about -21 dB, which is better for antenna performance.

## *H.* Wool + PA

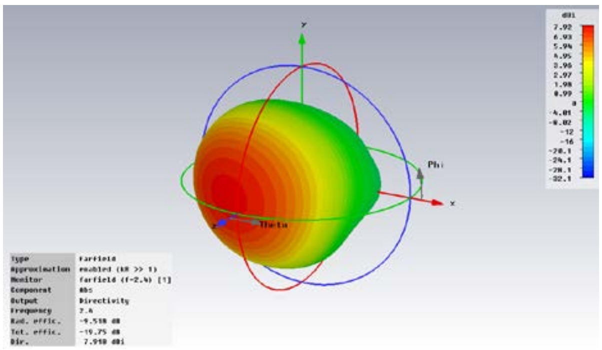
Fig 23: Far-field of Wool + PA

Figure 23 shows the far-field of Wool + PA. From the output it has been seen that the total radiation efficiency has found to be -9.518 dB and directivity is 7.918 dBi.

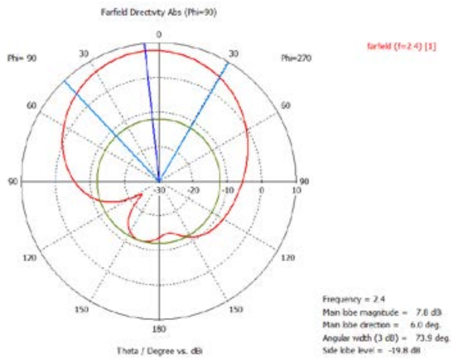

Fig 24: Far-Field (polar view) of Wool + PA

Figure 24 shows the far-field (polar view) of the Wool + PA. From the figure it has been seen that, the main lobe is centered at five degrees and the main lobe magnitude is 7.8 dBi. It is observed that the half power beam width is 73.9 degrees and the side lobe level is -19.8 dB.

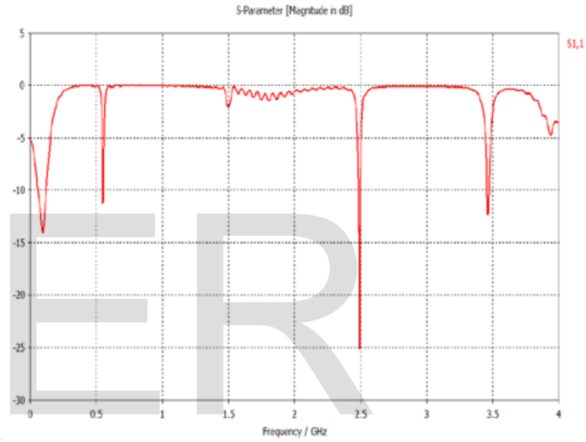

Fig 25: S-Parameter of Wool + PA

S-Parameter (S11) represents the return loss which is better for antenna when it is less. From figure 25 it has been seen that the S11 of Wool + PA is about -25 dB, which is better for antenna performance.

## I. Combined S11 Parameter for Different Materials

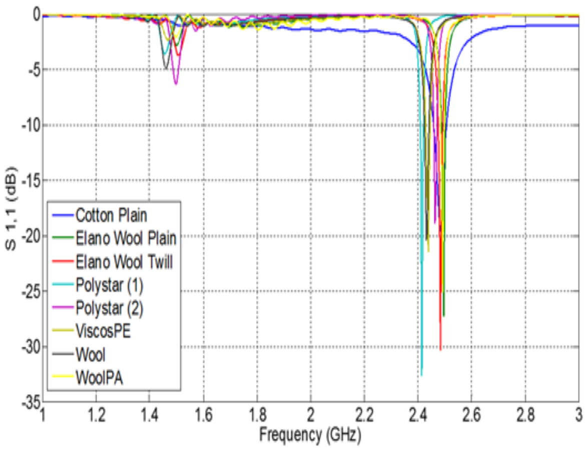

Fig 26: Combined S Parameters of Eight Materials

Figure 26 shows the combined S parameters of Cotton (plain), Elano Wool (plain), Elano Wool (twill), Polyester (two types), Viscos (with polyethylene), Wool (normal and with polyamide). From the figure it is seen that some of the materials are performing best at 2.4 GHz and some are a little bit beyond that, within our desired frequency range of 2.4 GHz to 2.5 GHz. The most commonly quoted parameter in regards to antenna is S11. It represents how much power has reflected from the antenna and hence known as the reflection coefficient or return loss. If S11= 0 dB, it implies that all power is reflected from the antenna and nothing is radiated. For all of our used materials, the return loss were beyond -20 dB, and sometimes -33 dB, which are really good for antenna performance.

TABLE 3: A
NTENNA PERFORMANCE FOR TEXTILE MATERIALS

| Textile Material | Substrate Permittivity ($\varepsilon_r$ ) | Radiation Efficiency (dB) | Retur n Loss (S11) (dB) | Resonant Frequenc y ($f_r$) (GHz) |
|---|---|---|---|---|
| Wool + PA | 1.52 | -9.51 | -25 | 2.4 |
| Ellano wool (twill) | 1.67 | -7.43 | -31 | 2.5 |
| Viscose + PE | 1.70 | -9.90 | -21.5 | 2.4 |
| Polyester (1) | 1.74 | -10.70 | -31.9 | 2.4 |
| Wool | 1.86 | -9.77 | -21 | 2.4 |
| Ellano-wool (plain) | 2.053 | -8.35 | -27 | 2.5 |
| Cotton (plain) | 2.077 | -8.73 | -19.5 | 2.48 |
| Polyester (2) | 2.122 | -7.15 | -19 | 2.45 |

From Table 3, it is seen that, Ellano-wool (twill) has the best efficiency along with least return loss.

## 6. CONCLUSION

A wearable antenna, by definition, meant to be worn by bearer into their clothes or other garments, or within any other utilities that are worn, and can easily assume that it has to be flexible to the bearer to be worn. The use of these antennas are very useful for personal communications, computer systems and wireless monitoring of several aspects, like- patients, babies,, animals, and so on. As the antennas will be used in such devices those will be smaller in size, yet intelligent, the antenna has to be smaller in size, yet powerful and effective being less harmful to the bearer. Many of these wearable antennas are used with various devices, but mostly with garments/textiles. But different types of clothes have different types of permittivity and other effects on antenna's performance. Considering those all effects designing an antenna suitable for using with different textile materials are important. In this thesis, our main focus was to design wearable textile microstrip patch antenna working at 2.4 GHz to 2.5 GHz ISM band. We designed our desired antenna for eight types of textiles. All the designed antennas showed acceptable return losses, along with good gain. All designs were designed using CST Simulation software.

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