Fabric Woven Textile Antenna for Medical Applications

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Abstract. Wearable Technologies are key driving forces in transforming conventional Health care systems to an unprecedented prototype of Connected Health (CH) Care systems. In these Connected Health Care systems, the role of wearable antennas cannot be overlooked. For designing reliable wearable systems, antenna should be of low profile, compact in size, lighter in weight, conformal and flexible to fasten it on Patient’s attire. As a contribute approach, this paper aims at proposal of microstrip patch antenna that resonates at ISM band of 2.4GHz. The proposed antenna is built on Rubber substrate with Polyester (Ground plane) as a conducting fabric driven by a microstrip line feeding structure. Improvement in antenna performance could be achieved by using Defected Ground Structure (DGS) polyester ground. Performance characteristics such as Directivity, Gain, VSWR and Radiation Pattern are measured. Specific Absorption Rate (SAR) value for Human Phantom model was calculated by on Body Simulation. The antennas and the human body tissue effects is observed in CST tool.

1. Introduction

Global Demography has shifted to a great extent on a par with increase in access to health care units during this pandemic outbreak. Countries around the globe are facing challenges due to increase in demand for health care support as well as limitations on movement that disrupt the delivery of health care support. This lead to dramatic increase in mortality rate due to both COVID-19 outbreak as well as negligence of health issues which are treatable. These issues could be resolved by remote health monitoring systems that uses wearable antenna and devices.

Antenna is a radiating device used at both transmitting and receiving end of a communication system. These antennas converts the electrical signals into radio waves at the transmitter side based on Maxwell’s equations whereas receiving antenna accepts the radio waves from the space and converts them into equivalent electrical signals[1]. Textile antennas are specially designed antennas made of textile material to make it flexible and conformal to the human body. These antennas are used in Body Centric Communication [2]. Smart textile systems represent a novel design of garments that offer supplemental features such as sensing, actuating and communication accomplished by integrating wearable devices into the “smart” garment apart from providing shield from external environment. Alongside textile antennas, Body-centric Communication is one of the popular research filed in recent years. Generally, Body Centric Communications combines textile antenna with a wearable transceiver.

Textile or cloth-based antennas has become a requisite part in WLAN, Telemedicine, military and Navigation. The main downside of this antenna in medical applications is its size which makes the whole measuring setup as bulkier and complicated. Solution to this problem could be arrived by using
microstrip patch antenna using rubber substrate and polyester (Ground Plane) as a conducting Fabric excited by Microstrip Line feeding structure. The proposed antenna is simulated using Computer Simulation Technology (CST) tool and parameters like Directivity, Gain, VSWR, Efficiency, Radiation pattern, Surface current flow and Power flow are observed. SAR (Specific Absorption rate) value is also determined by designing flat Human phantom model to study the back radiations from the antenna structure. Furthermore, antenna performance is improved by integrating Defective Ground Structure (DGS) on the ground plane.

2. Related Works
A great transformation in wearable technology during the last decade is evident from plethora of journal articles and patent documentation [3]. Current advancements in field of wearable antennas are innumerable in recent years. Wearable textile antennas, as the name implies, are the antennas made out of textile material that can be used in diversity of applications like disaster recovery services, health monitoring systems and physical training in defence sector [4, 5]. These antennas are built over a nonconductive fabric layer called substrate, which is made out of materials like leather, felt, fleece and a conducting textile as a ground [4, 6]. Felt is a preferred substrate substrate due to its low permittivity that results in efficient radiation performance [4, 7].

The antenna used for medical applications are of two types namely, wearable antenna and implantable antenna. These antennas are studied in various journals and the survey mentioned below is mainly focused on wearable antenna otherwise known as textile antenna. Shenbaga.K, Takshala Devipriya.A (2019) proposed Wearable antenna for biomedical application [8]. The antenna is designed on different conducting material and its characteristics have been studied. Conducting material like Cu sheet, conductive sewing thread, electro textile and silver are used. Circular patch with slots on strips produces better performance compared to other designs. The antenna is designed for medical application. Mica is used as a substrate material. The antenna is designed and simulated using the HFSS software. It resonates at the frequency of 2.8GHz with low return loss of -19.007dB and VSWR value of 1.2525.

Jaspreet Singh, Jyothi (2018) proposed wearable textile antenna and an annular slot antenna for wireless and medical application [9]. The microstrip patch antenna resonates at 5.5GHz and 7.5GHz, with the return loss of -18dB and -24dB. The annular slot antenna resonates at 5.8GHz and 7.6GHz, with the return loss about -46dB and -43dB.

Though the above mentioned antennas have satisfactory results, these antennas have the downside of design complexity. This paper aims at design of microstrip fabric woven patch antenna with defected ground structure to reduce the structural complexity while achieving the required radiation characteristics.

3. Textile Patch antenna Design
The vital parameters involved in design of any textile patch antennas are frequency of operation, substrate dielectric constant and dimensions of the dielectric substrate. The proposed antenna resonates at ISM band of 2.4GHz. The ability of the textile transmission line is determined by the vital parameter called dielectric constant. Low dielectric constant of textile material is due to the porosity of the material that makes the relative constant value to be unity. Table 3.1 represents the dielectric properties of commonly used textile materials. Dielectric materials with low dielectric constant reduce surface wave losses.
Table 3.1. Dielectric Constant of Fabric Materials

| Distance (m) | Velocity (m/s) |
|-------------|----------------|
| Felt fabric | 1.220          |
| Cordura fabric | 1.900        |
| Cotton fabric | 1.600         |
| Polyester fabric | 1.900      |
| Quartzel Fabric | 1.950      |
| Rubber fabric | 3.00          |
| Silk fabric | 1.750          |
| Jeans fabric | 1.700         |

The dielectric material used in proposed design is Rubber fabric having dielectric constant value of 3.00. Generally, when a substrate with high dielectric constant value is used, the antenna size reduces. While designing, high importance has to be given for antenna profile, so that the structure of antenna is not too bulky. This is the reason for selecting the dielectric substrate height as low as 0.8mm. Figure 1(a) and 1 (b) depicts the outlook of proposed textile Antenna and polyester fabric ground plane respectively.

**Figure 1(a).** Outlook of proposed Textile Antenna. This design has a Rubber substrate at the top with polyester ground plane at the bottom. The resonant length of the patch is 17.2mm.

**Figure 1(b)** Polyester Fabric Ground plane of designed antenna. The Polyester fabric has the thermal conductivity of about 0.003 W/m-K using PEC as the material type.
The dielectric and thermal properties of rubber substrate are given in Table 3.2. Figure 1(c) and 1(d) represents the rubber substrate of designed textile antenna and defected ground structure of the designed textile antenna. Defected Ground structures are used to improve the performance of the microstrip patch antennas.

**Table 3.2 Thermal and Electrical Properties of Rubber Substrate**

| Property                        | Value                                      |
|---------------------------------|--------------------------------------------|
| Epsilon(ε)                      | 3                                          |
| Mu(μ)                           | 1                                          |
| rho(ρ)                          | 930[kg/m$^3$]                             |
| Thermal Conductivity(K)         | 0.16[W/m-K]                               |
| Heat Capacity(Q)                | 2[kJ/K/kg]                                |
| Diffusivity(D)                  | 8.60215e-8[m$^2$/s]                       |
| Young’s Modulus(Y)              | 0.05[kN/mm$^2$]                           |
| Poisson’s Ratio(v)              | 0.49                                      |
| Thermal expansion (α$L$)        | 77[1e-6/K]                                |

The geometric dimension of designed antenna represented in terms of parameters like length, width and height are given in Table 3.3

**Table 3.3 Proposed Antenna Dimension**

| Parameter         | Dimension in mm |
|-------------------|-----------------|
| Ground Length ($L_g$) | 20              |
| Ground Width ($W_g$)  | 20              |
| Patch Length ($L_p$)   | 17.2            |
| Patch Width ($W_p$)    | 17              |
| Feed Width           | 1.69            |
| Dielectric Constant($\varepsilon_r$) | 3              |
| Height of Substrate  | 0.8             |
4. Annular slot antenna design

Annular slot textile antenna is also designed for obtaining performance improvement. The annular slot antenna has many circular slots in the form of rings on the polyester ground structure. Feed is given to the antenna structure through a microstrip line structure built on the bottom of the rubber substrate. Annular slot is the radiating element as the current is available around the periphery of the slot. Feed line length is of 1.69mm for achieving impedance matching. Dimension of slotted ring antenna has been optimized to make the antenna resonate at desired frequency band.

![Figure 2. Designed Annular Slot Antenna](image)

5. Measured Results with Comparison

The simulated S11 parameters of textile antenna and annular slot antenna are given in Figure 3(a) and 3(b). Though it is observable that the microstrip patch antenna and annular slot antenna are resonates at the same frequency of 2.4GHz, the return loss of microstrip patch antenna and the annular slot antenna is observed as -35dB and -49dB.

![Figure 3 (a). S parameter of designed microstrip fabric antenna](image)

![Figure 3 (b). S parameter of designed annular Slot fabric antenna](image)

Figure 3(c) and 3(d) represents the Surface current flow of the fabric woven textile antenna and the annular slot fabric antenna. The surface current flow of the fabric antenna and the annular slot fabric
antenna is 96.5671 A/m and 111.608 A/m. This shows that annular slot fabric antenna outperforms normal textile antenna.

**Figure 3 (c)** Maximum current Flow in designed microstrip textile antenna. Maximum current flow in this antenna records 96.5671 A/m

**Figure 3 (d)** Maximum current Flow in designed Annular Slot Antenna. Maximum current flow in this antenna records 112 A/m

The power flow ing through the designed fabric antenna and annular slot fabric antenna are provided in Figure 4 (a) and 4 (b) respectively. The power flow value is maximum in designed annular slot antenna compared to former textile antenna.

**Figure 4 (a)** Power Flow of proposed Textile antenna. The power value of designed textile antenna is 27452.5 V.A/m².
Gain of an antenna is defined as the ability of an antenna to radiate equally in all directions. Gain of fabric antenna and annular slotted fabric antenna are shown in figure 5 (a) and 5 (b).
Directivity is ability of an antenna to radiate in particular direction averaged over all directions. From Figures 6(a) and 6(b), it is evident that annular slot antenna has angular width of 100.2 degrees compared to textile antenna with angular width of 92.7 degrees.

**Figure 6 (a) Farfield directivity of textile antenna**

**Figure 6 (b) Farfield directivity of annular slot ring antenna**

VSWR is the measure of amount of mismatch between the antenna and the feedline. VSWR value for an ideal antenna with null reflection is Unity. Figure 7 (a) and 7 (b) shows the VSWR of both the antennas. VSWR value of both the antennas are closer to unity which indicates that ideally no power is reflected back to source.
The radiation pattern of designed antenna reveals that the strongest energy is radiated outward, perpendicular to the antenna in \( x-z \) plane. The energy radiated by designed textile antenna and Annular slot antenna in three dimensional pattern are represented in Figure 8(a) and 8(b).

6. SAR Calculation
SAR (Specific Absorption Rate) defines the rate of absorption of electromagnetic radiation when human body is exposed to it. This includes all forms of radiation including ultrasound. It is the power absorbed per unit mass of human tissue and it is measured in Watts per Kilogram (W/Kg). Phantom is a human body model deployed in measurements. It is usually composed of skin, muscle and fat layers. Measurement of SAR and EM fields in the human body is practically impossible; consequently, the phantom have been designed to model the human body at normal temperature. These models have many shapes such as spherical, rectangle, square, and human like bodies. The layer of phantom model varies with respect to applications and designers.
In this paper, a three layer flat phantom model in CST tool is designed for a male and the designed patch antenna is placed over it with minimal gap of 2mm shown in Figure 9(a) and 9(b). The skin, fat and muscle is placed at the minimal gap of 2mm, 10mm and 30mm, so that the designed antenna is suitable for placing it over the left arm or thigh of human body. The three layer phantom model is designed using CST studio suite. The properties of skin, fat and muscles are tabulated below in the Table 3.4.

**Table 3.4 Properties of Phantom Model**

| Tissue | Thickness (mm) | Permittivity | Conductivity (mm) | Density (Kg/m$^3$) | Metabolic rate(W/m$^3$) |
|--------|----------------|--------------|-------------------|--------------------|------------------------|
| Skin   | 2              | 69.45        | 0.507             | 1100               | 2000                   |
| Fat    | 10             | 6.07         | 0.036             | 900                | 300                    |
| Muscle | 30             | 65.97        | 0.708             | 1080               | 500                    |

The SAR value for the textile and annular slot antenna for 10g tissue is observed as 5.99W/Kg and 2.35W/Kg. The SAR value of the textile and annular slotted antenna of 20g of tissue is observed as 1.14W/Kg and 1.34W/Kg. Hence the SAR values conform to the European standards.
7. Conclusion
This projected work depicts design of fabric woven antenna and annular slotted antenna. Initially, Microstrip patch antenna with textile material which resonates at 2.4GHz frequency with a return loss of -35dB has been designed. Gain and Directivity of the designed textile antenna is about 3.68dBi. Successively, an annular slot antenna that resonates at 2.4GHz frequency having return loss of -49dB is designed. Gain of the annular slotted antenna is 6.08dBi. Then, the comparison between the fabric antenna and the annular slotted antenna is done and it is found that the annular slotted antenna provides better performance over the textile made microstrip patch antenna. These antennas are made up of polyester fabric and rubber fabric materials; therefore, they can be easily attached to human attire. As these antennas resonate at the ISM band of 2.4GHz and SAR value as per European standards, they can be used in medical applications.

8. References
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