Design of Wearable Textile Antenna for Biomedical WBAN Application using ISM Band

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ABSTRACT

Design of Wearable Textile Antenna for Biomedical WBAN (2.36-2.45GHz) application using ISM band. In this paper, a low-profile Wearable microstrip patch antenna is designed and suggested for constant observation of human vital signs such as blood pressure, pulse rate and body temperature using Wireless Body Area Network (WBAN) technology. In our work, prototype antennas were built using natural rubber, denim and cotton with different carbon filter substances. The developed antenna has been simulated tested and compared for various performance of parameters like Reflection coefficient, Gain, Directivity, VSWR, Efficiency and Bandwidth. The proposed micro-strip patch antenna is designed at 2.45GHz frequency in order to obtain better return loss, VSWR, Grain and low value of Specific Absorption Rate (SAR) as compared to other existing wearable antenna of different substrates. CST Studio suite is used to design and simulate the proposed antenna. This paper discloses the performance analysis of the wearable textile microstrip patch antenna using different substrates in WBAN application by creating an impact on intensifying healthcare provisions.

Keywords: Wearable antenna, WBAN (Wireless Body Area Network), SAR (Specific Absorption Rate), CST, Dielectric substrates.

INTRODUCTION:

Wireless Body Area Networks are being particularly used for the various real-time health monitoring applications. These networks include the use of wearable antennas for transmitting and receiving of the data for healthcare related systems. A wearable antenna can be used in a variety of applications such as GPS navigation, military, monitoring of athlete's fitness, telemedicine, satellite communication, digital watches, and RFID. Advancements in the field of wearable electronics have progressed rapidly in recent times and as a result, intensive research activities are being held over body conformal antennas. These days, some vital signs of the human body such as heart rate, blood glucose, blood pressure, and electrocardiogram (ECG) need to be monitored regularly due to their severe implications on the human health. Therefore, multiple sensors can be placed on the human body to monitor those vital signs of the human body. The body-worn sensors store information regarding various physiological parameters and transmit them to the wearable devices, which further transmit them to the nearest receiving node.

In existing model, the antenna was designed by silk, nylon and leather as the dielectric substrate material.The three types of wearable textile substrate material have own dielectric values for leather ἐr=1.8, silk ἐr=1.2 and nylon ἐr = 3.5 and the conductive parts were made of copper material. The antenna is designed and analysed on nylon, silk and leather with dimensions of 100 x 90 x 0.5 mm. The return loss of the nylon is -16.5 dB, silk is -25db and leather is 34 dB in which the return loss is high, so in order to reduce the return the return loss, now we move on to the proposed model by using the cotton, rubber and denim as the substrates. These fabrics will be simulated and tested for the better return loss. The material which possesses the low return loss will be fabricated on the human phantom model using the WBAN technologies.

Various types of wearable sensors are mounted on or implanted into the human body in order to access human vital signs information such as body temperature, blood pressure, and heartbeat. The medical information is then sent through sensors to the receiver at low frequency. After the reception of medical information, all the data is collected from the sensors mounted on the human body and then, sent to an external device. The doctor in the hospital or any remote location can look after the situation of the patient and suggest medicines immediately to improve the quality of healthcare.

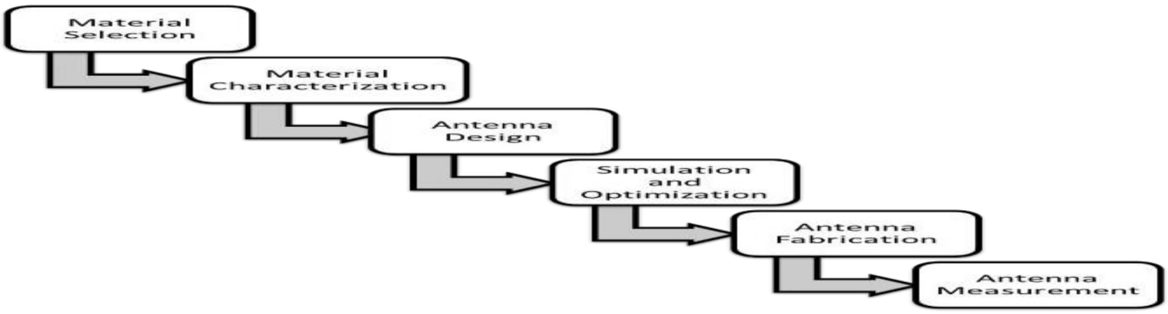
DESIGN METHODOLOGY:

The reason behind using smart cloths is they monitor vital parameters like bio signals of patients and soldiers. In a low cost and easy to combine wearable antenna has been designed on fabrics such as Cotton, denim and rubber. The antenna was fabricated on Wash cotton substrate and the measured result was compared with simulated results.

The proposed antenna used a common denim material which can easily achieve in our daily life. Due to the different textile have different craftsmanship, dielectric constant for each fabric is also different. Therefore, it is necessary to detect dielectric constant of substrate material before design wearable antenna.

Natural rubber is characterized to design flexible wearable antenna for on-body communications. We conclude our study by reporting characterization of actual antenna prototype, including details of fabrication processes, dielectric properties of the substrate and the consequence of filler contents on antenna quality factor (Q).Further to this, different challenging factors for flexible antennas like bending, wrinkling, Wash ability and environmental factors (humidity and thermal effects) that effects on antenna efficiency and gain in addition to the return loss, radiation pattern are also investigated.

However, the major simulation parameter of an antenna is a frequency that can be defined according to the application of the proposed antenna. After the computation of geometrical parameters, the design of the suggested antenna can be modelled in the CST. The general methodology to model a patch antenna in CST is explained in the flow chart given below.

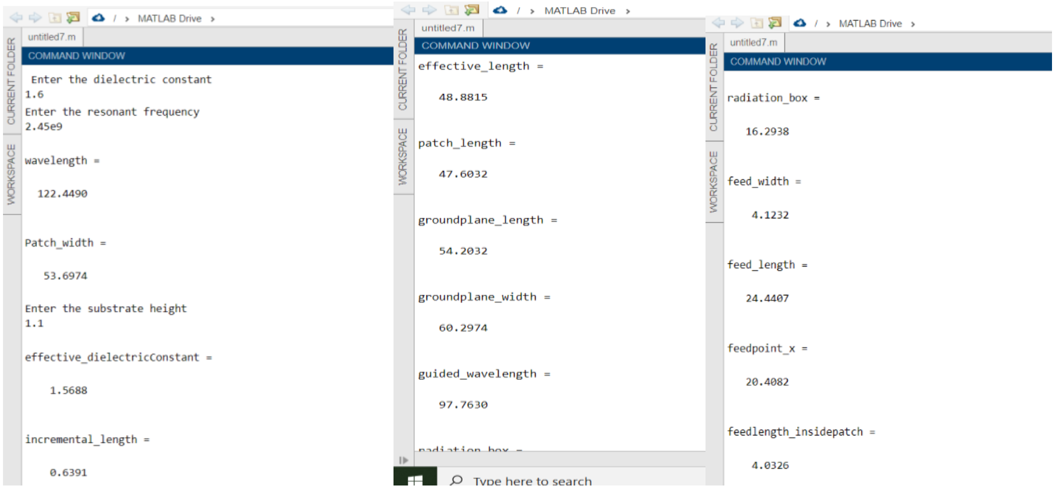


THEORY AND CALCULATION:

Microstrip line inset feeding technique is utilized to design the proposed wearable patch antenna. This antenna is implemented on the polyester substrate material that has a low dielectric constant, which results in a reduction in the surface wave losses. The relative permittivity Î r of substrate material is 1.44, the thickness h is 2.85 mm and the loss tangent tans is 0.01. The substrate dimension is 90* 90 mm. As microstrip inset fed technique is utilized to design the proposed antenna. Antenna geometrical parameters such as patch width W p and patch length L p have been computed using the MATLAB code https://matlab.mathworks.com/

```
clc;
clear;
c = 3*(10^8);
prompt = ' Enter the dielectric constant';
dielectric_constant = input(prompt);
prompt = 'Enter the resonant frequency';
Resonant_frequency= input(prompt);
wavelength = (c/Resonant_frequency)*(10^3);
display(wavelength);
% Antenna Patch Width Calculation
Patch_width = (c/(2*Resonant_frequency))*(sqrt(2/(dielectric_constant+1)))*(10^3);
display(Patch_width);
% Substrate Height Calculation
prompt='Enter the substrate height';
substrate_height = input(prompt);
% DENIM substrate height = 0.5;
% COTTON substrate_height = 1;
% RESIN substrate_height = 1.6;
% Effective Dielectric Constant Calculation
effective_dielectricConstant = ((dielectric_constant+1)/2)+(((dielectric_constant-1)/2)*(1/(sqrt(1+(12*(substrate_height/Patch_width))))));
display(effective_dielectricConstant);
% Incremental Length Calculation
incremental_length = (0.412*substrate_height)*(((effective_dielectricConstant+0.3)*((Patch_width/substrate_height)+0.264))/((effective_dielectricConstant-0.258)*((Patch_width/substrate_height)
display(incremental_length);
% Effective Length Calculation
effective_length = ((c)/(2*Resonant_frequency*sqrt(effective_dielectricConstant)))*(10^3);
display(effective_length);
% Antenna Patch Length Calculation
patch_length = effective_length-(2*incremental_length);
display(patch_length);
```

```
% Antenna Patch Length Calculation
patch_length = effective_length-(2*incremental_length);
display(patch_length);
% Ground Plane Calculation
groundplane_length = (6*substrate_height)+patch_length;
groundplane_width = (6*substrate_height)+Patch_width;
display(groundplane_length);
display(groundplane_width);
% Guided Wavelength Calculation
guided_wavelength = wavelength/(sqrt(effective_dielectricConstant));
display(guided_wavelength);
% Radiation Box Calculation
radiation_box = guided_wavelength/6;
display(radiation_box);
% Feed Width Calculation
B = (60*(pi^2))/(50*sqrt(dielectric_constant));
feed_width = ((2*substrate_height)/(pi))*((B-1-log((2*B)-1))+(((dielectric_constant-1)/(2*dielectric_constant))*(log(B-1)+0.39-(0.61/dielectric_constant))));
display(feed_width);
% Feed Length Calculation
feed_length = guided_wavelength/4;
display(feed_length);
% Feed Point location
patchEdge_resistance = 108;
feedpoint_x = wavelength/6;
display(feedpoint_x);
% The length of the feed inside the patch
feedlength_insidepatch = feed_length - feedpoint_x;
display(feedlength_insidepatch);
```



1. **Wavelength**

$$\lambda = \frac{c}{f}$$

2. **Patch Width**

$$W = \frac{c}{2f}\sqrt{\frac{2}{\varepsilon_r+1}}$$

3. **Effective dielectric constant**

$$h = \frac{0.0606\lambda}{\sqrt{\varepsilon_r}}$$

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

4. **Incremental length**

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

5. **Effective length**

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

6. **Patch length**

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

7. **Ground plane**

$$L_g = 6h + L$$
$$W_g = 6h + W$$

8. **Guided wavelength**

$$\lambda_g = \frac{\lambda}{\sqrt{\varepsilon_{eff}}}$$

9. Radiation box

$$\frac{\lambda_g}{6}$$

10. Feed width

$$B = \frac{60\pi^2}{Z_0\sqrt{\varepsilon_r}}$$

$$W_f = \frac{2h}{\pi}\left[\left[(B-1) - \ln(2B-1)\right] + \left(\frac{\varepsilon_r - 1}{2\varepsilon_r}\right) * \left[\ln(B-1) + 0.39 - \left(\frac{0.61}{\varepsilon_r}\right)\right]\right]$$

11. Feed length

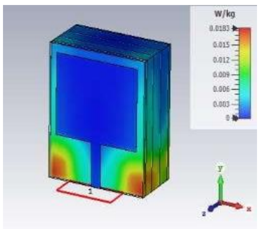
$$L_f = \frac{L_g}{4}$$

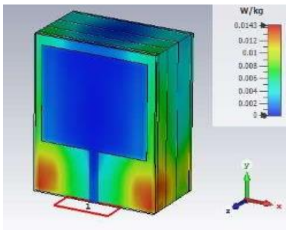
RESULT AND DISCUSSION:

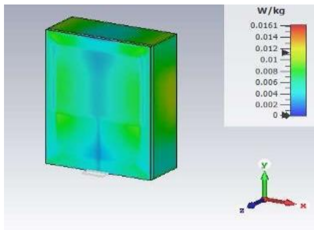
Textile materials: COTTON, RUBBER AND DENIM.

The Reflection Coefficient is obtained at 2.36 GHz in case of Wash cotton Substrate. The Voltage Standing Wave Ratio (VSWR) is obtained at 2.3GHz. To Study the effect of rubber substrate, flexible wearable antenna simulations were conducted by using commercially existing CST studio to disclose several dielectric properties, and further to calculate their impacts on the antenna performance in terms of quality factor (Q). The simulated and measured return loss S11 over a frequency range of 4.5–7.0 GHz, measured resonates at 5.78 GHz and has an excellent matching with the simulated result. It proves that the dielectric constant of denim samples is 1.54.

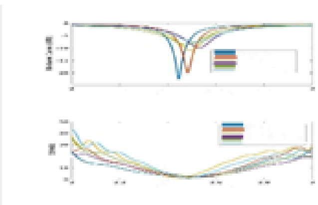
COTTON SAR STRUCTURE **DENIM SAR STRUCTURE** **RUBBER SAR STRUCTURE**

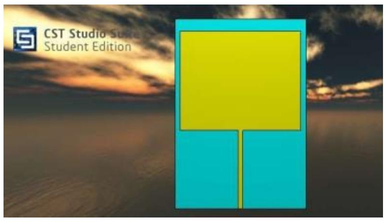




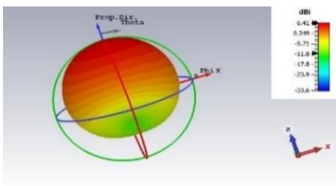


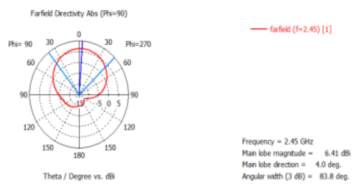
RETURN LOSS AND VSWR OF THE SUBSTRATES **OVERALL STRUCTURE**





RUBBER FABRICS:

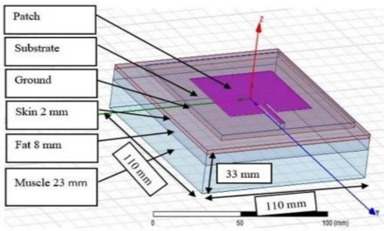


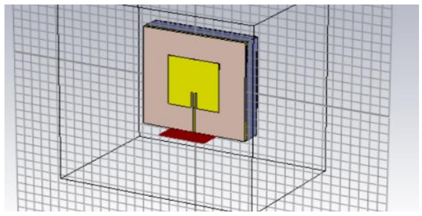


The band-width increases with the addition of carbon contents in the rubber substrate. As the carbon contents increases, Tanδ increases and the rubber substrate gets loss and hence the Q decreases. The return loss degraded with the accumulation in rubber contents. As, the rubber contents increases, the substrate resistivity and permittivity changes, leading to variation in impedance match . The resonant factor is also affected by carbon contents. The shift in frequency is enlightened by the act as the permittivity changes, the wavelength variations as well, giving increase to frequency.

HUMAN PHANTOM MODEL

The proposed wearable patch antenna is simulated in HFSS antenna simulation tool using simulation parameters. The antenna is characterized by 50 Ω input impedance. The scattering parameters return loss of the simulated antenna is illustrated in Fig. 3. The minimum return loss curve value achieved at 2.45 GHz is -10.52 dB i.e., marked by m2 and the achieved value is acceptable. The theta values are taken from 0° to 180°. It can be seen the major lobe of the antenna is radiating a majority of its power in the front direction, which concludes it has the high front to back ratio. In addition, it can be seen that the antenna has minimal minor lobes, which are very good for wearable applications.





SUBSTRATE MATERIAL

The substrate material used to design wearable antenna is polyester. The main advantage of selecting the polyester material as a substrate is its flexibility. Furthermore, it is used in daily life fabric and readily available in the market. The material characteristics listed in TABLE I are as follows:

PARAMETERS	SYMBOL	VALUE
Dielectric constant	εr	1.44mm
Loss tangent	tan σ	0.01mm
Thickness	h	2.85mm

DIMENSIONS OF PATCH ANTENNA

The dimensions of patch antenna play a pivotal role to make an effective antenna design in terms of efficient results. TABLE II illustrates the calculated parameters of the suggested patch antenna model.

PARAMETER	**SYMBOL**	**VALUE**
Operating frequency	f_o	2.45 GHz
Patch dimension along x	W_p	55.43 mm
Patch dimension along y	L_p	47.9 mm
Substrate thickness	h	2.85 mm
Substrate dimension along x	W_s	90 mm
Substrate dimension along y	L_s	90 mm
Insert distance	Y_o	10 mm
Insert gap	G	2 mm
Feed width	W_f	3.3 mm
Feed length	L_f	24 mm
Di- electric constant of substrate	$\in_r$	1.44
Input impedance	Z_o	50 Ω

LAYERS OF HUMAN PHANTOM MODEL:

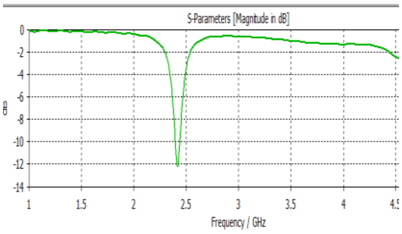
A 3-layer human phantom model is created in HFSS for the calculation of specific absorption rate (SAR). The 3-layer human phantom model consists of 3 layers of human body tissues i.e., muscle, fat, and skin. The width of muscle, fat, and skin are 23 mm, 8 mm and 2 mm, respectively.

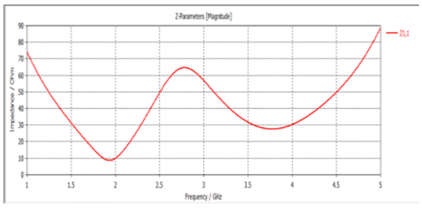
PROPERTIES OF HUMAN BODY TISSUES

Tissue	**Permittivity (εr)**	**Conductivity (S/m)**	**Loss Tangent (tan σ)**	**Density (Kg/m³)**
Skin	31.29	5.0138	0.2835	1100
Fat	5.28	0.1	0.19382	1100
Muscle	52.79	1.705	0.24191	1060

S- PARAMETER

Z- PARAMETER

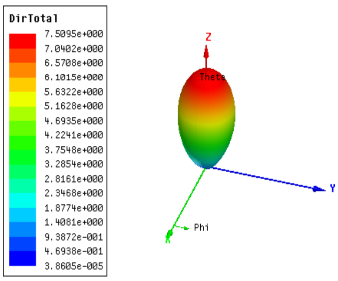


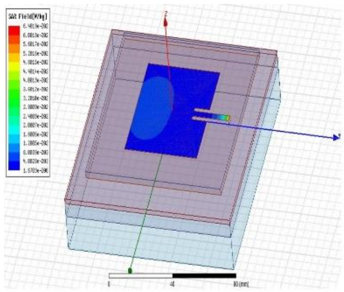


The minimum return loss curve value achieved at 2.45 GHz is -10.52 dB. At 2.45 GHz the peak gain of 7.81 dB has been obtained in the z-axis i.e. perpendicular to the antenna. In the proposed antenna, the VSWR value achieved at 2.45 GHz is 1.84.

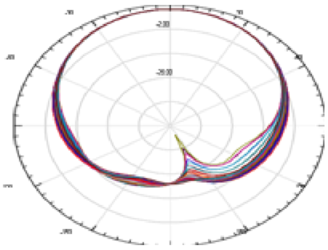
DIRECTIVITY OF THE PROPOSED ANTENNA ANTENNA AT 2.45GHz

SAR VALUE OF THE SIMULATED

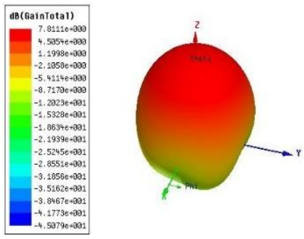




The 2- Dimensional gain of the antenna observed at 2.45 GHz. It can be seen that a peak gain of 7.81 dB i.e., marked by m_1 is achieved at 0°.°. This radiated power is analyzed in the far-field region of the antenna. SAR is a very important parameter for wearable applications also SAR limit should have met the current standard set by IEEE which is 1.6 W/Kg averaged over 1 gm of tissue. The measured SAR value on the 3-layer human phantom model at 2.45 GHz is 0.0640 W/Kg averaged over 1 gm. of tissue. The relative permittivity and loss tangent values are 1.44 and 0.01 respectively. The Inset fed technique is used because it provides planar structure and can be easily fed by 50Ω impedance. The overall antenna dimensions are 90×90 mm^2.



RADIATION PATTERN OF THE SIMULATED ANTENNA



SIMULATED 3D GAIN AT 2.45 Ghz

The achieved SAR value at 2.45 GHz is 0.0640 W/Kg averaged over 1 gm of tissue, which is under the limit of 1.6 W/Kg averaged over 1 gm of tissue. The radiation pattern of the antenna. The theta values are taken from 0° to 180°. It can be seen the major lobe of the antenna is radiating a majority of its power in the front direction, which concludes it has the high front to back ratio. In addition, it can be seen that the antenna has minimal minor lobes, which are very good for wearable applications.

CONCLUSION:

The rubber substrate is considered to be the best material with low return loss compared to the other textile materials. The rectangular patch antenna based on the inset fed patch technique has been designed on the textile material known as polyester. The substrate thickness is taken as 2.85 mm. The relative permittivity and loss tangent values are 1.44 and 0.01 respectively. The Inset fed technique is used because it provides planar structure and can be easily fed by 50Ω impedance. The overall antenna dimensions are 90×90 mm2. The measured return loss achieved at 2.45 GHz is -10.52 dB and a gain of 7.81 dB is obtained to ensure the efficient health monitoring. SAR is a very important parameter for wearable applications also SAR limit should have met the current standard set by IEEE which is 1.6 W/Kg averaged over 1 gm of tissue. The measured SAR value on the 3-layer human phantom model at 2.45 GHz is 0.0640 W/Kg averaged over 1 gm. of tissue. The radiation pattern of the simulated antenna was perpendicular to the axis of the wearer, which means that this antenna is feasible for wearable applications and cannot harm the human body tissues due to its high front to back ratio. Also, the wearable antenna is the best way to be applied for wireless body area network communication and it has vast applications to provide real-time health monitoring.

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