Analysis of Different Performance Parameters of Bodywearable Antenna- A Review

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Abstract
Body-worn antenna is ideally used in military, mobile communication and healthcare applications. Planar structure, compactness, flexible construction material, good radiation efficiency and bandwidth are some of the specific requirements for body-worn- antennas. The right choice of antenna design is important to minimize the losses because the body also deteriorates the performance of antenna. The shape of the patch and properties of dielectric substrate like thickness directly effects the performance of simple microstrip patch antenna. Therefore it is important to know how these aspects influence the performance of body-wearable antenna. This paper presents a review of the various dielectric substrate used in wearable antenna design, effect of human body on antenna performance and various shapes and techniques used in literature to minimize unwanted effects. Various dielectric substrates can be used in body-wearable antenna design. Generally, textile materials are used, because they reduce the surface wave losses and enhance the radiation efficiency and bandwidth of antenna. Human body limits the performance of antenna significantly. The human body plays a very significant role in antenna performance. Human body being a lossy medium which reduces the performance of antenna. Various microstrip patch shapes and diversity techniques have been proposed by the researchers to improve the impedance bandwidth and radiation efficiency. The metamaterial technology improves the overall performance of the antenna and reduces the body Specific Absorption Rate (SAR) values. The performance of proposed shapes can also be tested on different textile substrates and metamaterials.

Keywords: Bodywearable Antenna, Textile Substrates, Metamaterial, Return Loss, Impedance Bandwidth.
I. INTRODUCTION

The body centric wireless communication has drawn the attention of researchers in the present era. The body worn antennas are widely used for these type of communications and have received much attention in commercial sports, entertainment and healthcare applications [1]. Body worn antenna may be made from textiles [2-5] or may be worn as a button antenna[6]. The wearable antenna may be operating on single or dual frequencies. For body worn applications the antennas should be of small size, light weight, consumes less power, almost maintenance free, and with no installation cost. The compact size, low cost, easy fabrication makes microstrip patch antenna highly suitable and comfortable on body surface. But the reduction of the size of the antenna leads to reduced performance of the antenna such as poor efficiency, impedance and bandwidth. Hence design of a wearable antenna is quite challenging [7].

Wearable antennas are usually placed in human torso or arm. The human body acts as a lossy medium which degrades the performance of wearable antenna [8]. In order to design a bodywearable antenna the design parameters and different dielectric properties of substrates should be clearly studied. Also the effect of body on antenna parameters needs to be understood. These parameters should be optimized according to body-worn applications. To improve the bodywearable antenna performance, various techniques have been proposed by the researchers like selecting thick and high dielectric substrates materials, various radiating microstrip patch shapes, slotting in patch to improve bandwidth, the array of antennas etc. The wearable antenna may use the combination of these techniques to give favorable performance in the vicinity of the human body. This paper presents a brief review of design parameters of patch antennas, different types of dielectric substrate materials and patch shapes along with their performance analysis.

The remaining paper is organized as, section II presents the analysis of various dielectric substrates for bodywearable antennas, effect of body on antenna performance are discussed in section III, Section IV outlines the different shapes of microstrip patch used in literature for body worn applications and finally we conclude in section V.

II. ANALYSIS OF VARIOUS DIELECTRIC SUBSTRATES FOR BODYWEARABLE ANTENNAS

The microstrip patch antenna consists of a radiating patch etched on a dielectric substrate and a ground plane as shown in figure 1<insert figure 1 here>. The radiating patch is made of gold or copper and can be of any possible shape. The dielectric substrate is a main component of patch antenna. Before selecting the dielectric substrate different design criteria’s like permittivity, loss tangent, thickness of dielectric, electrical surface resistivity of conductive dielectric fabric, the moisture content of fabric should be considered. Generally the dielectric properties rely upon
temperature, frequency, surface roughness, moisture content, purity and homogeneity [9].

The dielectric constant value for the fabrication of patch antenna should be in between $2.2 \leq \varepsilon_r \leq 12$ [10]. For textile materials like flectron, zelt, shieldit etc. dielectric constant should be less than 2 because lower $\varepsilon_r$ decreases losses occurred by surface waves and improves impedance bandwidth of an antenna. The amount of power converted into heat in the material is called loss tangent or dissipation factor denoted by tanδ. If loss tangent value is high losses will be high and radiation efficiency will decrease [10].

The thickness of dielectric substrate should be in between $0.003\lambda < h < 0.005\lambda$ [10] where $\lambda$ is operating wavelength of an antenna. The selection of thickness of substrate is a trade off between bandwidth and efficiency [11]. A thick substrate with low value of relative permittivity results in larger patch size and if same relative permittivity is chosen with same thin substrate the patch size decreases [12].

In literature, ample of work has been done on different substrates. Various dielectric substrates have been proposed by the researchers. Air with least dielectric constant of 1 gives the return loss of -22.644 and benzocyclobutane which has dielectric constant of 2.6 shows return loss of -18.1248 [13]. The Duroid 6010 with dielectric constant of 10.7 is used in phased array configuration of 1*4 at 1.35 GHz and it shows optimized results [14]. FR4 epoxy is widely used substrate in microstrip patch antenna design. P. Kumar et al. used rectangular patch antenna with FR4 epoxy resin at 2.45 GHz [16]. The calculated gain of patch antenna is 3.954 dB and the author concluded that it is well suited for body centric communication.

Fractal shape microstrip patch antenna is implemented using foam substrate. Using foam substrate the size of the antenna reduces to 84%. B.T.P. Madhav et al. [14] demonstrated that RT-Duroid gives better performance in terms of gain, directivity than LCP substrate but it is costlier than LCP.

Nowadays the microstrip patch antennas are fabricated on textile substrates. For textile antenna design, the conductive fabric should have low and stable electrical surface resistance. Also, It should be flexible and homogenous over entire area. The moisture content of the fabric should also be considered. The author in [15] described that zelt which is high quality nylon based substrate is highly suitable for body wearable applications due to its durability. The author compared the performance of proposed zelt antenna with conventional FR4 antenna. The gain of zelt antenna was 0.5dB higher than FR4 antenna. The proposed antenna was found suitable to be mounted on human body. It shows better return loss and radiation pattern performance. Nylon has a medium dielectric constant of 3.6. The work demonstrates that the antenna fabricated using nylon as a substrate resonates at 989MHz with return loss of -35.42 dB and a gain of 6.1 dB. S. Sankaralingam et al. compared the performance characteristics of wearable circular zelt, flectron and shieldit patch antenna on polyester substrate in both free space environment and human body vicinity [9].

The table 1 shows the performance characteristics of these proposed antennas. It is clear from the table that zelt antenna gives best performance.
Table 1: Performance characteristics of zelt, flectron and shielded antennas.[8]

<table>
<thead>
<tr>
<th>Performance Characteristics</th>
<th>Electron antenna (#1)</th>
<th>Zelt antenna (#2)</th>
<th>Shielded antenna (#3)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Free Space</td>
<td>Lossy Medium</td>
<td>Free Space</td>
</tr>
<tr>
<td>Resonant Frequency (GHz)</td>
<td>2.452</td>
<td>2.457</td>
<td>2.455</td>
</tr>
<tr>
<td>Impedance Bandwidth (MHz)</td>
<td>109</td>
<td>144</td>
<td>80</td>
</tr>
<tr>
<td>Gain (dB)</td>
<td>6.1</td>
<td>4.7</td>
<td>7.67</td>
</tr>
<tr>
<td>Directivity (dBi)</td>
<td>9.4</td>
<td>9.0</td>
<td>9.4</td>
</tr>
<tr>
<td>3 dB Beamwidth in azimuth (deg)</td>
<td>60.1</td>
<td>70.8</td>
<td>60.3</td>
</tr>
<tr>
<td>3 dB Beamwidth in elevation (deg)</td>
<td>69.9</td>
<td>72.9</td>
<td>69.9</td>
</tr>
<tr>
<td>Radiation efficiency (%)</td>
<td>69</td>
<td>61</td>
<td>82.3</td>
</tr>
</tbody>
</table>

The author in [17] proposed a 3D foldable antenna using flexible Kapton substrate. The results show the excellent performance of up to 75% radiation efficiency with -8dB return loss. Hence, the antenna is highly suitable for body worn wireless devices.

The author in [18] gives a complete survey of textile materials in wearable antenna designs. The various textile materials and their electrical properties viz. moisture content, assemblage on human body and their selection criteria are studied. The textile materials used for wearable antenna design are also discussed.

Table 2 shows the comparison of the textile materials. From the Table it is clear that for Bluetooth applications, polyamide spacer fabrics, woollen felt and PDMS performs better.

### III. EFFECT OF HUMAN BODY ON ANTENNA PERFORMANCE

The human body acts as an irregular shaped medium. The body has a frequency dependent conductivity and permittivity. Due to high permittivity of body tissues resonant frequency of an antenna changes. It acts as a lossy medium and it reduces the gain of the body worn antenna at lower operating frequencies. Hence for body worn devices the electrical properties of body tissues and their interactions with the antenna should be studied before designing the wearable antenna. In literature various simplified body models like homogenous model, 3 layer model and complex 3D body models are discussed [19]. The layer model of human tissue is shown in figure 2. In this model the effect of outermost body tissue is also acknowledged. This model has three layers: skin, fat and muscle and the antenna is to be placed on top layer.
Skin and muscles have high water content that adversely affects the operating wavelength of the antenna [20]. Skin has homogeneous design. It has inhomogeneous dielectric properties. Muscles have average dielectric properties and fat has poor dielectric properties. Table 3 shows the electrical properties of various tissues at 6.5GHz and 8GHz provided by National Research Council [21].

The placement of antenna on human body has a crucial effect on performance. When antenna is placed on triceps and thighs that have average skin and fat thickness it performs better. When it is placed on site with less thickness like forehead and wrist, its performance deteriorates [22]. As operating frequency increases, permittivity decreases which leads to better reflection away from the body and hence antenna performance boosts. Table 4 shows the performance of antenna at various sites at 4.6 GHz and 8 GHz.

### Table 2. Comparison of various dielectric materials [18]

<table>
<thead>
<tr>
<th>Application</th>
<th>Dielectric material</th>
<th>Material</th>
<th>$h$(mm)</th>
<th>$\varepsilon_r$</th>
<th>$\tan\delta$</th>
<th>Conductive materials</th>
<th>Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>GSM (900MHz) and Bluetooth (2.4GHz)</td>
<td>Unspecified material</td>
<td>0.236</td>
<td>3.29</td>
<td>0.0004</td>
<td>-</td>
<td>-</td>
<td>Acceptable</td>
</tr>
<tr>
<td>WLAN (2.4GHz)</td>
<td>Fleece fabric</td>
<td>3</td>
<td>1.04</td>
<td>-</td>
<td>Knitted copper fabric</td>
<td>Acceptable</td>
<td></td>
</tr>
<tr>
<td>GPS (1.5GHz)</td>
<td>Cordura</td>
<td>0.5</td>
<td>Between 1.1 and 1.7</td>
<td>Copper tape</td>
<td>Good</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ISM (2.4GHz) and GPS (1.5GHz)</td>
<td>Fleece fabric</td>
<td>2.56</td>
<td>1.25</td>
<td>-</td>
<td>Electron</td>
<td>Acceptable to Good</td>
<td></td>
</tr>
<tr>
<td>ISM (900MHz)</td>
<td>Polyurethane protective Foam</td>
<td>11</td>
<td>1.16</td>
<td>0.01</td>
<td>Electron</td>
<td>Acceptable</td>
<td></td>
</tr>
</tbody>
</table>
Table 3. Dielectric properties of skin, fat and muscles [22]

<table>
<thead>
<tr>
<th>Tissue Layer</th>
<th>εᵣ</th>
<th>σ(S/m)</th>
<th>Tanθ (Loss Tangent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skin</td>
<td>34.5</td>
<td>4.3</td>
<td>0.347</td>
</tr>
<tr>
<td>Fat</td>
<td>4.8</td>
<td>0.33</td>
<td>0.191</td>
</tr>
<tr>
<td>Muscle</td>
<td>47.5</td>
<td>5.8</td>
<td>0.338</td>
</tr>
</tbody>
</table>

Table 4. The performance of antenna at various body sites at 4.6 Ghz and 8 Ghz [22]

<table>
<thead>
<tr>
<th>Anatomical Site</th>
<th>Total (dB)</th>
<th>Gain Radiation Efficiency (%)</th>
<th>SAR e-3 (W/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forehead</td>
<td>2.0/6.3</td>
<td>26.5/47.7</td>
<td>2.7/4.1</td>
</tr>
<tr>
<td>Neck</td>
<td>1.6/6.0</td>
<td>22.8/47.1</td>
<td>2.3/4.1</td>
</tr>
<tr>
<td>Biceps</td>
<td>4.5/7.3</td>
<td>41.2/58.5</td>
<td>2.8/4.5</td>
</tr>
<tr>
<td>Triceps</td>
<td>4.8/7.3</td>
<td>41.4/56.8</td>
<td>2.9/4.6</td>
</tr>
<tr>
<td>Chest</td>
<td>4.4/6.5</td>
<td>39.7/53.3</td>
<td>2.9/4.3</td>
</tr>
<tr>
<td>Wrist</td>
<td>4.0/3.9</td>
<td>40.9/38.2</td>
<td>2.5/4.3</td>
</tr>
<tr>
<td>Abdomen</td>
<td>4.6/5.0</td>
<td>44.1/45.8</td>
<td>2.7/4.4</td>
</tr>
<tr>
<td>Anterior Thigh</td>
<td>4.8/6.7</td>
<td>41.7/55</td>
<td>3.0/4.4</td>
</tr>
<tr>
<td>Posterior Thigh</td>
<td>5.2/6.3</td>
<td>44.7/52.4</td>
<td>3.0/5.2</td>
</tr>
<tr>
<td>Calf</td>
<td>4.7/7.0</td>
<td>41.8/56.3</td>
<td>2.9/4.5</td>
</tr>
</tbody>
</table>
IV. WEARABLE ANTENNA DESIGNS

The body worn antenna design must have few requisites like invisible on the body, omni-directional radiation pattern, tuning adjustment to compensate for body effect, high gain etc. To meet above requirements some recently proposed wearable antenna design are discussed in this section.

1. Rectangular Patch antenna
The author M. Wozniak et al. designed a rectangular patch antenna and tested the designed antenna in the vicinity of human body and it is simulated using CST software. The performance analysis revealed that the $S_{11}$ parameter was -33dB and the proposed antenna can be used for GSM 1800 applications. Various disadvantages of this design are stiffness, narrow bandwidth (2%), high fabrication cost [23].

2. 3D Folded Slot antenna
T. Thai et al. proposed a 3D folded slot antenna at 2.4 GHz for body worn applications. The designed antenna showed an excellent performance of 75% radiation efficiency with -8 db return loss. The proposed antenna has high bandwidth and data rate and it is well suited for wearable applications [17].

3. Dual Band Coplanar Antenna on EBG substrate
S. Jhu et al. described the dual band coplanar patch antenna integrated with electromagnetic band gap substrate. The antenna operates at the 2.5 GHz and 5 GHz bands. Due to high impedance surface provided by EBG (Electromagnetic Band Gap), back radiation reduces. The author also studied the electromagnetic properties of different textiles and discussed the textile material suitable for body wearable design. The author compared the proposed antenna with rectangular patch antenna and results showed that the proposed antenna has an operating bandwidth of 4% at 2.4 GHz and 10% at 5.5 GHz. Rectangular patch antenna has bandwidth of 2.5% at 2.45 GHz and 4.6% at 5.5GHz, hence proposed antenna performs better. The proposed antenna reduces back radiation and SAR by a factor of 20. The author also analyzed the bending performance of antenna and measurements revealed that antenna is tolerant to bending in either E-plane or H-plane but only when worn around arms and legs [15].

4. Circular Patch Antennas:
The circular patch antenna using three textile materials namely Flectron, Zelt and Shieldit are presented by S. Sannkaralingam et al. These antennas are mounted on the vicinity of the human body, their impedance and radiation characteristics at 2.4Ghz are analysed. The author concluded that Zelt antenna has highest radiation efficiency of 79.1% as compared to Flectron (61%) and Shieldit antennas (57%). Gain of Zelt antenna can have maximum value of 6.92 db. The simulations showed that proposed wearable antennas have required characteristics and impedance and it is highly suitable for bluetooth applications [8].
5. Omnidirectional Vest Mounted Bodywearable Antenna:
The author presented an omnidirectional bodywearable vest mounted antenna for UHF operations. The proposed design has a compact diversity module with a size of 79*41*28 mm and four antennas for omnidirectional radiation pattern. The performance of the designed antenna is evaluated under an indoor environment and with several human activities. The gain of 21 db was achieved in a multipath indoor environment. The proposed antenna with diversity performed better than a single whip monopole antenna [24].

6. Circular Patch Low Profile Antenna:
T. Bjornien et al. designed a circular patch head worn antenna with a thickness of 7 mm in the 5.8 GHz ISM band. The author outlined the ellipsoid head model so that the antenna is efficiently optimized. It is concluded that the antenna has a zero dbi gain and radiation efficiency of 76% and SAR is below the International Commission on Non-Ionizing Radiation Protection (ICNIRP) and Federal Communications Commission (FCC) limits [25].

7. Swastika Slot UWB Patch Antenna:
V. Kumar et al. investigated the performance of Swastika slot patch antenna for UWB applications at 3.1 and 10.6 GHz. The dimensions of the antenna were 27*27*1.6 mm. The antenna has a gain of 6.43 db at 11 GHz and 1.77/5.6 db at UWB. Antenna radiation efficiency is varied from 81.3% to 90.67% also slotting and notching in the radiating patch improves the impedance bandwidth and radiation pattern of antenna [7].

8. Fractal body worn metamaterial antenna:
Metamaterial technology reduces the size of the antenna by using DGS. The gain, return loss, bandwidth improves by using metamaterial technology in antenna design. Especially for the significant reduction of SAR values metamaterial can be used. The author concluded that antenna with low SAR can be designed by fractal model with metamaterial used as a ground plane or substrate [26].

9. Latex based AMC backed endfire antenna:
The author K. Aggarwal et al. proposed a first latex based end-fire antenna at 2.45 GHz with AMC backed metamaterial surface. The author designed a yagi-uda antenna. The proposed antenna gives significant performance with a gain of 0.12 dBi and has improved on body radiation efficiency of 78.97 [27].

10. Planer Inverted “F” antenna (PIFA):
Nowadays, planer inverted “F” shape antenna is gaining popularity for body wearable applications due to their significant reduction in body SAR values. The author presented a PIFA with metamaterial surface for body SAR reduction. The proposed design consists of AMC structure that acts as a PMC and it controls the radiation
pattern of the antenna and hence designed antenna is capable of preventing hazardous EM radiation from human body [28].

V. CONCLUSION

From this paper, we conclude that bodyworn antennas are useful for many applications like military, medical and sports. The main challenges in bodywearable antenna design include compactness, flexibility, durability, high gain and bandwidth, good radiation efficiency and low body SAR are the main challenges in the bodywearable antenna design. The main performance characteristics of these antennas are mainly the choice of substrate, its thickness, geometry of the patch. It is reviewed that substrates with lower value of permittivity increases the resonance frequency of antenna and improves gains and efficiency. The substrate thickness should be chosen such that the geometry of antenna remains compact and efficiency of antenna improves. The conductive textile materials electromagnetic properties, their placement on human bodies, bending performance, moisture content should also be studied in order to minimize the losses. Slotting and notching in radiating patch improves the bandwidth and radiation efficiency. Therefore various shapes of patch with slots and notches can be designed with these key techniques. The performance of proposed shapes can also be tested on different textile substrates. Metamaterials significantly reduces the body SAR and improves the performance of antenna in terms of gain, return loss, bandwidth and efficiency. The wearable antenna design may also consist of combination of mentioned techniques. The right technique should be chosen such that the antenna gives the optimum performance for bodywearable applications. Also, most of the work has been done on ISM band so, we can also test the performance of body worn antenna on UWB frequencies. The wearable antennas has many challenges in their design but no matter how, they still have a bright future specifically for medical and healthcare applications.

REFERENCES


