Specific Absorption Rate Analysis of Aperture Coupled Antenna for Wireless Body Area Network Applications

G. Santhosh Kumar*, S. Bashyam and B. Ramachandran

Department of Electronics and Communication Engineering, SRM University, Kattankulathur - 603203, Tamil Nadu, India; sandreal03@gmail.com, bashyam.s@ktr.srmuniv.ac.in, ramachandran.b@ktr.srmuniv.ac.in

Abstract

Objective: This work presents the design and analysis of miniaturized aperture coupled antenna. The proposed antenna is designed to operate at 2.45GHz of Industrial Scientific Medical (ISM) band and intended to use for Wireless Body Area Network Applications (WBAN). Methods/Statistical analysis: The H shaped patch with aperture coupled feeding is incorporated to get symmetrical radiation pattern. By adjusting the dimensions of ground plane notch and feed line the miniaturization and desired operating frequency is achieved. The antenna's performance is simulated at the vicinity of human arm biological tissue model to measure Specific Absorption Rate (SAR). Findings: The proposed antenna has compact form factor of 0.32λ₀ x 0.3λ₀ x 0.021λ₀. The electromagnetic numerical simulation software shows the SAR of 2.71 W/Kg. The antenna’s performance in terms of bandwidth, gain, radiation pattern is found invariable in presence of human arm tissue model. Application/Improvements: The result shows the proposed antenna possesses low SAR and small compact form factor which can be applicable for WBAN applications.

Keywords: Aperture Coupled Antenna, Human Arm Model, Industrial Scientific Medical Band, Specific Absorption Rate, Wireless Body Area Network

1. Introduction

Wireless Body Area Network (WBAN) is an essential standard optimized for low power devices and operation on, in or around the human body to serve diversity applications including patient health monitoring, wearable computing and consumer electronics. At the same time, miniaturization allows for increased mobility and accessibility. The development of antenna for WBAN has several challenges. The presence of human body in close vicinity to the antenna affects the antenna performance characteristics such as resonant frequency, radiation pattern, gain, Specific Absorption Rate (SAR) etc. In WBAN, antenna can be placed anywhere in the human body but human arm is more suitable and the performance of antenna need to be studied.

Miniaturization techniques offer several advantages including ease of design and fabrication, low profile and planar structure and easy integration. Dielectric loading is the simplest way to decrease the size of the antenna. The increase in iteration of dielectric resonator loaded fractal antenna reduces resonant frequency by increasing the current path. The form factor is high (0.8λ₀ x 0.8λ₀ x 0.012λ₀). The lens loaded cavity backed transmit sinuous antenna is proposed for low power transceiving applications which is having complex feeding network. Another dielectric loaded antenna with antipodal linearly tapered slot gives high gain at the cost of narrow beam width. Dielectric loaded with shorted loop and monopole elements achieves low gain with coupling effects. Size reduction is achieved by means of dielectric resonator and dielectric loadings but its Omni-directional radiation pattern is not suitable for WBAN applications. Partially dielectric loaded ridged horn antenna comes with broader size and it is difficult to fabricate. The waveguide slot array antenna with dielectric lenses is designed
Specific Absorption Rate Analysis of Aperture Coupled Antenna for Wireless Body Area Network Applications

to optimize the aperture distribution and side lobe level. The dielectric loaded monopole antenna\(^2\) achieves dual polarization at the cost of high cross polarization. Meta surface enabled antenna\(^3\) aims for reduction in SAR and it has form factor of \(0.5\lambda_o \times 0.3\lambda_o \times 0.025\lambda_o\). The SAR value obtained for monopole patch antenna\(^4\) at 2.45 GHz is 3.99 W/Kg. The gain of Slot coupled patch antenna and probe patch antenna proposed by\(^5\) is reduces to very low when it exposes to human head model.

To overcome the above mentioned problems a simple aperture coupled antenna is proposed. It exhibits small form factor \((0.32\lambda_o \times 0.3\lambda_o \times 0.21\lambda_o)\), moderate gain and low cross polarization. The SAR analysis is evaluated on human arm model. The result shows that it is more suitable for low power short range WBAN applications. Section 2 details the design process of aperture coupled antenna. Section 3 provides the return loss and far field characterizations and section 4 deals with SAR performance analysis on human arm model. The results are discussed in section 5 and paper is concluded with section 8.

2. Design of Aperture Coupled Antenna

A new structure of aperture coupled antenna operating in the ISM band 2.45GHz is presented and it is shown in Figure 1. The proposed antenna geometry has an overall dimension of \(39.1\, \text{mm} \times 36.46\, \text{mm} \times 2.6\, \text{mm}\). The antenna consists of two substrates with different dielectric constants namely low dielectric constant (FR4 Substrate) and high dielectric constant (Rogers Substrate). The microstrip patch is placed on top of the FR4 substrate with the thickness of 1.6mm and with a dielectric constant \(\varepsilon_R = 4.4\). The ground plane consists of a notch which is present in between the FR4 substrate and Rogers substrate. The Notch is used to couple the energy from the feed. The Length and Width of the notch present in the ground plane are 2.64mm and 13.28mm. The length and width of the micro strip patch are 26.86mm and 29.5mm. The microstrip patch has two notches on either side with equal length and width of 8.37mm and 6.1mm. The feed line length and width are 31mm and 2mm. The feed line is placed in the bottom of the Rogers substrate with the thickness of 1mm and with a dielectric constant \(\varepsilon_R = 9.8\). Compared to conventional feeding methods, aperture coupled antenna has more freedom to optimize the antenna performance by adjusting dimensions of feed line and notch of ground plane which results in reduction in size and polarization purity. The parametric study has been made and details are shown in Table 1. The ground plane notch and feed line dimensions are optimized to get required resonant frequency and bandwidth.

Table 1. Parametric study

<table>
<thead>
<tr>
<th>F.L(mm)</th>
<th>G.N (mm)</th>
<th>B.W (MHz)</th>
<th>R.F (GHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>W</td>
<td>L</td>
<td>W</td>
</tr>
<tr>
<td>29</td>
<td>1</td>
<td>5</td>
<td>12</td>
</tr>
<tr>
<td>30</td>
<td>1.5</td>
<td>5.5</td>
<td>13</td>
</tr>
<tr>
<td>31</td>
<td>2</td>
<td>6</td>
<td>14</td>
</tr>
<tr>
<td>32</td>
<td>2.5</td>
<td>6.5</td>
<td>15</td>
</tr>
<tr>
<td>33</td>
<td>3</td>
<td>7</td>
<td>16</td>
</tr>
</tbody>
</table>

where, F.L is the Feed line, B.W is the bandwidth, R.F is the resonant frequency, G.N is ground plane notch, L is the length of the feed line and W is the width of the feed line.

3. Simulation Results

3.1 Return Loss Bandwidth (RLBW)

The proposed antenna is modelled using Ansoft HFSS Software. The antenna is designed to operate at 2.45GHz. The return loss bandwidth can be determined from the Figure 2. The -10 dB return loss bandwidth is from
2.4140GHz to 2.4778GHz. The resonant frequency is 2.45GHz. The bandwidth of the proposed antenna is 63.8MHz. The antenna is featured to employ in health monitoring biomedical applications. Though the bandwidth is less, a low power short range communication device like Bluetooth can able to utilize 63 channels with each channel provided 1 MHz spacing since it is using frequency hopping spread spectrum.

Figure 2. Return Loss BandWidth (RLBW).

### 3.2 Radiation Pattern and Gain

The Radiation Pattern of the aperture coupled antenna operated at 2.45GHz is shown in Figures 3 and 4. From the results it is observed that the antenna has unidirectional radiation pattern which is essential for WBAN applications. The gain is observed to be 2.44dB as shown in Figure 5. The gain level is further increased by replacing FR4 substrate with low loss and low dielectric constant substrate at the cost of reduction in bandwidth. Because of this trade-off between quality factor and bandwidth, the obtained gain is considered efficient for low power short range communication.

The energy coupled from ground plane notch to the patch is symmetrical which results in symmetrical radiation pattern.

### 4. SAR Analysis on Human Arm

#### 4.1 Modelling of Human Arm

In this section, aperture coupled antenna behaviour near the human body is studied. Here, a model of human arm,

Figure 3. Two dimensional radiation pattern at $\phi = 0$ degree.

Figure 4. Two dimensional radiation pattern at $\phi = 90$ degree.

Figure 5. Three dimensional radiation pattern.
Specific Absorption Rate Analysis of Aperture Coupled Antenna for Wireless Body Area Network Applications

as shown in Figure 6. This model is more similar to a real arm which consists of six layers with elliptical shape. The model presents Thickness of 1.5mm skin layer, 1.5mm fat layer, 15mm muscle layer, 1mm nerve layer, 4mm blood layer and 17mm bone layer.

Figure 6. Layout of human arm.

Since the human body is a complex biological structure having various tissues with particular dielectric properties, it is important to characterize the tissue that constitutes a model. The human arm layer consists of 6 layers with different dielectric properties, Since the SAR value is averaged over 10 gram of tissue the the mass density and the thickness value is important and it is given in 13 which is shown in Table 2.

Table 2. Arm tissues mass density and thickness

<table>
<thead>
<tr>
<th>Tissue</th>
<th>Mass Density(Kg/m³)</th>
<th>Thickness(mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bone</td>
<td>1908</td>
<td>17</td>
</tr>
<tr>
<td>Blood</td>
<td>1050</td>
<td>4</td>
</tr>
<tr>
<td>Nerve</td>
<td>1075</td>
<td>1</td>
</tr>
<tr>
<td>Muscle</td>
<td>1090</td>
<td>15</td>
</tr>
<tr>
<td>Fat</td>
<td>911</td>
<td>1.5</td>
</tr>
<tr>
<td>Skin</td>
<td>1109</td>
<td>1.5</td>
</tr>
</tbody>
</table>

5. SAR Analysis

SAR is a measure of the rate at which energy is immersed by the human body when exposed to a Radio Frequency (RF) electromagnetic field. The conductivity, mass density is fed into the HFSS human arm model. From the electric field distribution average SAR value is calculated with help of HFSS simulation.

The antenna is placed in proximity of the model to perform the simulation on the human body in HFSS. The dielectric properties of the tissue model have greater impact on efficiency performance and it is calculated as below.

The loss tangent is calculated for various tissue layers using the formula,

\[
\tan \delta = \frac{\varepsilon''}{\varepsilon'}
\]

where, \(\varepsilon''\) is the dielectric damping loss and \(\varepsilon'\) is the complex permittivity. The dielectric damping loss can be calculated by using the following equation:

\[
\varepsilon'' = \omega \varepsilon_0 \sigma
\]

where, \(\omega = 2\pi f\), \(\sigma\) is the conductivity of the tissue, \(\varepsilon_0\) is the dielectric permittivity of a vacuum(8.854x10⁻¹² F/m) and \(f\) is the resonant frequency.

The dielectric properties of various layer in human arm at 2.45 GHz has been obtained using the on-line website 14 which calculates tissues characteristics as given in Table 3.

Table 3. Arm tissues parameters at ISM band frequency (2.45GHz)

<table>
<thead>
<tr>
<th>Tissue</th>
<th>Conductivity (s/m)</th>
<th>Relative Permittivity</th>
<th>Loss Tangent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bone</td>
<td>0.095037</td>
<td>5.2969</td>
<td>0.1316</td>
</tr>
<tr>
<td>Blood</td>
<td>2.5448</td>
<td>58.264</td>
<td>0.3204</td>
</tr>
<tr>
<td>Nerve</td>
<td>1.0886</td>
<td>30.145</td>
<td>0.2649</td>
</tr>
<tr>
<td>Muscle</td>
<td>1.7388</td>
<td>52.729</td>
<td>0.2419</td>
</tr>
<tr>
<td>Fat</td>
<td>0.10452</td>
<td>5.2801</td>
<td>0.1452</td>
</tr>
<tr>
<td>Skin</td>
<td>1.464</td>
<td>38.007</td>
<td>0.2826</td>
</tr>
</tbody>
</table>

6. Simulated Results

The designed antenna is placed on the human arm shown in Figure 7 and the performance is simulated. The reflection coefficient, radiation pattern and gain are obtained as shown in Figures 8, 9, 10 and 12. The return loss bandwidth is obtained for the frequency range from 2.3863GHz to 2.4781GHz.

The resonant frequency is 2.43GHz and the bandwidth is 91.8MHz. From the obtained results, it is shown that the bandwidth is comparatively more than that of the antenna in free space, but the resonant frequency is shifted to 2.43GHz.

The radiation pattern of the antenna when placed on the human arm is unidirectional radiation pattern and it
is not much deviated from previous radiation pattern as shown in Figures 9 and 10. The gain obtained is 2.29 dB as shown in Figure 11 which is 0.15 dB less than antenna in free space condition.

The SAR is obtained for the antenna operating at 2.45 GHz is 2.71 W/Kg as shown in Figure 12.

Though the SAR value is little bit high compared to European standard, the proposed antenna gives optimized performance at low profile and less complexity with ease of fabrication

Further the SAR value of designed antenna can be reduced by using low lossy and bio compatibility material substrates. The gain can be increased by designing aperture coupled array antenna at the cost of reduction in beam width.

Figure 7. Layout of human arm with aperture coupled antenna.

Figure 8. Return Loss BandWidth (RLBW).

Figure 9. Two dimensional radiation pattern at $\phi = 0$ degree.

Figure 10. Two dimensional radiation pattern at $\phi = 90$ degree.

Figure 11. Three dimensional radiation pattern.
Specific Absorption Rate Analysis of Aperture Coupled Antenna for Wireless Body Area Network Applications

7. Discussion

The proposed aperture coupled antenna performance is compared with some of the existing antenna design which is shown in Table 4. It shows the proposed antenna exhibits compact Form factor and moderate SAR.

Table 4. Performance comparison

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>F.F</td>
<td>0.8λ₀ x 0.5λ₀</td>
<td>0.5λ₀ x 0.3λ₀</td>
<td>0.45λ₀ x 0.57λ₀ x 0.013λ₀</td>
<td>0.32λ₀ x 0.3λ₀ x 0.021λ₀</td>
</tr>
<tr>
<td>R.F (GHz)</td>
<td>2.4</td>
<td>2.38</td>
<td>2.45 / 5.2 / 5.75</td>
<td>2.43</td>
</tr>
<tr>
<td>B.W (MHz)</td>
<td>700</td>
<td>130</td>
<td>0.69 and 4.23</td>
<td>91.8</td>
</tr>
<tr>
<td>G(dB)</td>
<td>3.1</td>
<td>5.9</td>
<td>Not Specified</td>
<td>2.29</td>
</tr>
<tr>
<td>SAR (W/Kg)</td>
<td>-</td>
<td>16.8</td>
<td>3.99 (ISM) 2.20 (HYPERLAN) 1.91 (WLAN)</td>
<td>2.71</td>
</tr>
</tbody>
</table>

where, F.F is the Form factor, B.W is the Bandwidth, G is the Gain and SAR is the Specific Absorption Rate.

8. Conclusion

The aperture coupled antenna is designed and simulated for WBAN applications with SAR analysis. The antenna operated at 2.45GHz has improved bandwidth, symmetric radiation pattern and miniaturized size at the cost of reduction in gain. This work can be further extended to design a flexible antenna to achieve better gain and SAR.

9. Acknowledgement

The authors would like to thank SRM UNIVERSITY, Kattankulathur, Tamilnadu for providing access to Ansoft HFSS tool.

10. References


