Performance Study of a Bluetooth Antenna for Wearable Applications

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Abstract:
The evolution of antenna technology for man-machine interface has taken quantum leaps in utilizing textile materials as antenna substrates. In future this will allow complete freedom to develop body-worn antenna systems embedded in so-called “smart clothes”. Smart clothes will emerge in various sports outfits, emergency workers’ outfits, military, medical, space applications and so on. The ability to establish wireless communication link is an essential requirement for smart clothes. In this paper, a textile microstrip rectangular patch antenna for such wireless data communication via smart clothes has been developed. The wearable antenna meant to meet the Bluetooth specifications has been developed by choosing polyester combined cotton [65:35] fabric as its substrate material and copper for conducting parts. Thus the suitability of fabric substrate materials for the development of microstrip patch antennas is also well demonstrated.

1. Introduction
In recent years the Industrial, Scientific and Medical (ISM) radio bands have been shared with license-free error-tolerant communication applications such as Wireless LANs. These Wireless LAN devices use the following ISM wavebands according to IEEE 802.11 standards:

- Bluetooth - 2.45 GHz band
- Hyper LAN - 5.80 GHz band

The Bluetooth ISM band ranges from 2.4 – 2.485 GHz. Bluetooth is aimed for short range communication between all kinds of wireless devices [1]. These devices can be divided into two main groups: (i) Devices connected to the wired network with fixed power supply (e.g. VCRs) and (ii) Mobile devices with battery power supply (e.g. cell phones). This short range wireless communication plays an important role in mobile wireless systems. These communication systems contain several subsystems and antenna is an essential subsystem of these systems. Therefore wearable antenna plays a paramount role in optimal design of any wearable system. Recently, wearable antennas have been presented at International Conferences [2 – 3]. The aim of this paper is to design and investigate the performance characteristics of a Bluetooth antenna for wearable applications. A rectangular microstrip patch configuration is chosen for this study purpose.

2. Antenna Design Procedure:
The geometry of a Bluetooth antenna developed for wearable applications is shown in figure 1. In order to design this type of antenna, it is necessary to know the exact value of dielectric constant of the substrate material chosen. The accurate value of dielectric constant of polycot fabric material is determined experimentally by employing a novel technique proposed by the authors in [4]. This technique is based on resonance method and focuses on the use of microstrip patch radiator, which contains the fabric material as the substrate. The permittivity of the fabric is easily extracted from the
measured resonant frequency of a patch radiator designed using an assumed approximate value of the substrate dielectric constant. The permittivity of the polycot fabric is determined as 1.48, from the knowledge of shift in measured frequency from design frequency. The design specifications of the wearable antenna are listed hereunder:

![Figure 1: Geometry of a bluetooth antenna for wearable application](image)

### Design Specifications:
- resonant frequency ($f_r$) = 2.45 GHz
- height of the substrate (h) = 3.0 mm.
- relative permittivity ($\varepsilon_r$) = 1.48
- loss tangent (tan $\delta$) = 0.02

The design procedure involves the following steps:
The patch width (W) has a minor effect on the resonant frequency ($f_r$) and it is calculated using the following formula [5].

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

where $c$ is the velocity of electromagnetic wave and $\varepsilon_r$ is the relative permittivity of the polycot fabric. Actually, the microstrip patch lies between air and the dielectric material and thus the electromagnetic wave sees an effective permittivity ($\varepsilon_{reff}$) given by [5],

$$\varepsilon_{reff} = \left[\frac{\varepsilon_r+1}{2}\right] + \left[\frac{\varepsilon_r-1}{2}\right] \times \left[1 + \frac{12h}{W}\right]^{-1/2} \quad (2)$$

where $h$ is the height of the substrate.
The patch length determines the resonant frequency and is a critical parameter in design because of the inherent narrow bandwidth of the patch. The design value for L is given by [5],

$$L = \left[\frac{c}{(2f_r\sqrt{\varepsilon_{reff}})}\right] - 2\triangle L \quad (3)$$

where $\varepsilon_{reff}$ is the effective permittivity of the polycot fabric. The additional line length $\triangle L$ on either ends of the patch length, due to the effect of fringing fields, is given by [5],

$$\frac{\triangle L}{h} = 0.412\times \left[\frac{(\varepsilon_{reff}+0.3)}{(\varepsilon_{reff}-0.258)}\right] \times \left[\frac{(W+h+0.264)}{(W+h+0.8)}\right] \quad (4)$$
The effective patch length $L_e$ is written as

$$L_e = L + 2 \Delta L$$

Therefore,

$$L_e = \frac{c}{2f_r\sqrt{\varepsilon_{reff}}}$$  \hspace{1cm} (5)

The width and length of the patch are computed to be 55.2043 mm and 47.3 mm respectively. This Bluetooth antenna modeling is performed using the Method of Moments (MoM) utilized within IE3D simulator [6] from Zeland Software Inc., USA. An infinite ground plane is assumed so as to (i) avoid back lobes in the radiation pattern of the antenna (ii) reduce the diffraction and scattering effects at the edges of the ground plane and to (iii) minimize the undesirable effects of surface waves. The conductive parts of the antenna are made up of copper whereas the substrate material is polycot. While modeling the coaxial probe feed to patch, the inner and outer diameters of the probe are taken as 1.3 mm and 4.1 mm respectively. The feed position is optimized to get good matching characteristics (50 ohm impedance) at the centre frequency. It is located at a distance of 10.4 mm from the centre of patch along the direction of length towards the edge.

3. Simulation Results:

3.1 Return loss characteristics:

Simulations are carried out for the frequency range from 2.0 GHz to 3.0 GHz with a frequency step size of 20 MHz. As depicted in figure 2, the Bluetooth antenna resonates at a frequency of 2.449 GHz and provides an impedance bandwidth of 99 MHz (4%) covering the entire ISM band. The resulted impedance bandwidth is good enough for Bluetooth applications.

![Figure 2: Return loss characteristics of the antenna](image1)

![Figure 3: Total radiation patterns](image2)

3.2 Far-field radiation pattern characteristics:

First the simulations are carried out at a single frequency of 2.449 GHz (resonant frequency) to get the total far-field radiation patterns for both planes of $\phi = 0^\circ$ and $\phi = 90^\circ$. Figure 3 shows the far-field radiation pattern plots. In the $\phi = 0^\circ$ plane, the developed wearable antenna provides a gain of 6.99015 dB and a 3 dB beam width of 74.0679°. The gain and beam width obtained in the $\phi = 90^\circ$ plane are 6.99015 dB and 72.5554° respectively.

3.3 Gain and Efficiency:

The simulations are done for a range of frequencies from (2 – 3) GHz. The variations of gain and directivity as a function of frequency, as obtained from these simulations, are shown in figures 4 and 5 respectively. At the centre frequency of 2.45 GHz, the antenna’s directive gain and power gain are 8.71626 dBi and 6.98306 dBi respectively. Therefore the efficiency of the antenna works out 80.1%, which is adequate enough for practical considerations.
4. Conclusions:

The microstrip antenna is a suitable candidate for wearable applications, as it can be built using fabric substrate materials. In this paper a Bluetooth antenna for wearable applications has been designed and its performance characteristics studied. The antenna presented is very versatile and it is easy to make it to operate at various frequency bands. In addition, the well known techniques [7] of improving bandwidth and obtaining different polarizations, adopted for microstrip patch antennas are readily suitable for wearable antennas too. It may be concluded that textile microstrip patch antennas are very good alternatives to the conventional PCB patch antennas. The textile antennas must be drapable as the fabrics can take diverse shapes. It is under consideration to study these bending effects on the performance characteristics of wearable antennas. It is also planned to use electro-textiles instead of copper conductive parts in order to facilitate antenna’s integration into clothing.

References: