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ENHANCED ULTRAWIDEBAND (UWB) MICRO-STRIP ON-BODY WEARABLE ANTENNA

Ajmal Hussain Shah[1, 2], Suriyya Begum[1], Veeraiyah Thangasamy[1] and Noor Ain Kamsani[3]
[1]School of Engineering, Asia Pacific University of Technology and Innovation, Technology Park Malaysia,
Bukit Jalil, Kuala Lumpur, Malaysia
[2]Faculty of Information and Communication Technology (KICT), International Islamic University Malaysia (IIUM), Malaysia
[3]Department of Electrical and Electronics Engineering, Universiti Putra Malaysia, UPM Serdang, Malaysia
E-Mail: ajmal@apu.edu.my

ABSTRACT

This paper presents an ultra-wideband micro-strip patch On-Body wearable antenna for medical applications using WiMAX. The antenna uses thick indigo blue jeans as substrate. The antenna is designed at the resonant frequency of 3.5 GHz. The dimensions of the antenna and the slit have been modified to achieve wide bandwidth. By doing so, not only the bandwidth of 15 GHz has been achieved but the antenna size is reduced by 13.4% as well. The proposed antenna simulation results including gain, directivity and radiation pattern are reported. The results show that the antenna not only provides satisfactory results for the WiMAX applications but also provides extremely good results including the VSWR of 1.12, the gain of 5.8 dB and the directivity of 6.8 dB at 20 GHz. The proposed antenna achieves a remarkable bandwidth improvement as well as a significant reduction in antenna size. Hence, the proposed antenna can be used for medical applications using WiMAX as well as the applications operating up to at 20 GHz.

Keywords: micro-strip patch on-body wearable antenna, ultra-wideband, bandwidth enhancement, gain, radiation pattern, return loss, directivity, WiMAX.

1. INTRODUCTION

The antenna plays an important role in electronic communications. Extensive and remarkable growth in wireless communications industry has compelled RF design engineers and researchers to design low profile antennas with low cost, small size and wide bandwidth. Wireless communication systems with ON-Body wearable antennas, so called Wireless Body Area Network (WBAN), with the use of miniaturized sensors are suitable for medical applications. Such systems are of great interest for various applications including sport, multimedia, health care, and military applications as well [1]. High data rates can easily be achieved by WBAN devices with low power management. The trend of designing a low cost and low-profile antenna is growing due to the increasing demand of high speed data services through smart phones.

Ultra-wideband (UWB) antennas have been identified as a highly promising solution for WBAN. One of the major advantages of the UWB systems at 3.1 GHz - 10.6 GHz is their high data-rate-transmission capabilities (typically 100 Mbps) with low power spectral densities (41.3 dBm/MHz) [2], ensuring thereby low interference with other narrow-band wireless devices. A UWB antenna for the body-centric communications is a challenge, as the antenna is not only carefully optimized in frequency-and time-domains but also is small in size and possesses low profile with good On-Body propagation. Certainly, such antennas should be considered and characterized in both the domains [3-6], and the interaction with the human body [7]. Besides, the miniaturization of UWB antennas is particularly important for wearable applications. Significant research efforts have been undertaken to reduce the size of radiating structures, and some interesting miniaturization techniques have been proposed in [8-10]. In [11], a body centric antenna with reduced dimensions is proposed. The antenna was tested at 5.2 GHz resonant frequency for WiMAX and WLAN applications with an achievable bandwidth of 210 MHz. We have presented earlier an enhanced On-Body worn wideband antenna in [12] for the similar applications. The antenna has a bandwidth of 4.3 GHz and is not only sustainable in different human postures but easy to fabricate as well.

In this paper, a further enhanced wearable ultra-wideband antenna using WiMAX for medical applications is proposed. The antenna size is relatively small and easy to place on a jacket or an equally recommended (dress) for medically ill patients under critical observations. The antenna is simulated and evaluated at 3.5 GHz and the results of return loss, radiation pattern, gain, VSWR, and directivity between 5 GHz and 20 GHz are presented here. The proposed antenna is suitable for the intended applications including WiMAX and 20 GHz band. Moreover, the gain achieved for the entire band is more than 3 dB. The proposed antenna design geometry and simulation results are presented in section 2 and section 3 respectively.

2. ANTENNA DESIGN GEOMETRY

In this section, the design steps including design equations are presented. The parameters of the proposed antenna are calculated at 3.5 GHz. Since the Dielectric substrate has significant impact on both the radiation pattern and the impedance of a micro-strip antenna. It is then essential to choose right substrate material for an antenna. Beside other electrical properties, dielectric constant and loss tangent are the most critical features when selecting a substrate. The size of an antenna is inversely proportional to the value of dielectric constant of a substrate. A blue indigo jean has been used due to light in weight. The proposed antenna dimensions are 30 x 25 mm^2. The thickness of the substrate material is 0.8 mm with a tangent factor of 0.03 while having a dielectric constant of 1.67.

A patch is a conducting plane with any shape and the most commonly used patches are square, rectangular and triangular. However, the proposed antenna is designed with a circular patch, since it acquires less space compared to other patches. The patch radius of the proposed antenna is determined by equation (1).

$$fr = \frac{(1.8412)c}{2\pi a\sqrt{\varepsilon_r}} \tag{1}$$

a = Radius of the circular patch
ε_r = Dielectric constant of the substrate
c = Speed of light

There are many configurations that can be used to feed a Micro-strip antenna. Conducting and non-conducting are the two antenna feeding techniques. In the conducting technique, the power is directly fed to the radiating patch while in the non-conducting technique, the coupling between the patch and the line is required. The Micro-strip line feed technique, due to its distinct features, has been used in the proposed antenna. The length and the width of line feed are 14.7 mm and 2.59 mm, respectively. Copper is used for the makeup of transmission line and the patch to provide a perfect matching with a 50 Ω load. The transmission line impedance is then computed by equation (2).

$$Z_o = \frac{120\pi}{\sqrt{\varepsilon_{eff}}\left[\frac{W}{H} + 1.393 + \frac{2}{3}\ln\left(\frac{H}{W} + 1.444\right)\right]} \tag{2}$$

ε_{eff} = Effective permittivity
H= Height of substrate
Z_o= Impedance of the transmission line
W= Width of Micro-strip line

The proposed antenna geometry is shown in Figure-1. In the geometry, L_{feed} is the length of the transmission line. L_{sub} and W_{sub} are the length and the width of the substrate respectively. The partial ground technique is used which helps to increase the bandwidth of an antenna. Moreover, the area of the square slot at the middle of the patch has been decreased which in turn increased the gain. (T-slot with three slits, one is shown above while the other two are shown below the patch for enhancing the bandwidth). The dimensions of slit above the patch has been increased and optimized in a way to achieve wide bandwidth. The length and width of the slit are 1.6 mm and 1 mm, respectively.

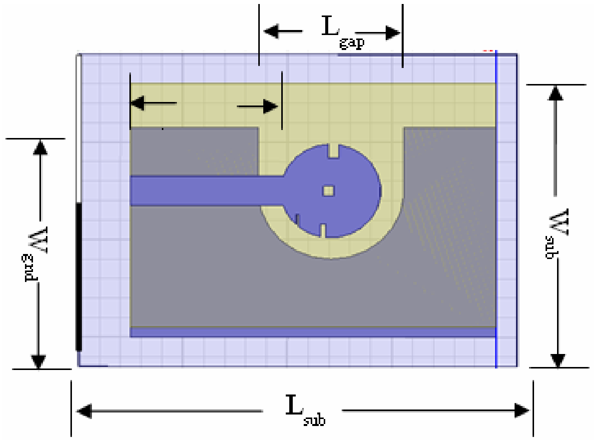

Figure-1. Geometry of the proposed antenna.

Complete specifications of the proposed design are given in Table-1.

Table-1. Specifications of the proposed antenna.

Length of the substrate	35 mm
Width of the substrate	25 mm
Radius of the patch	4.8 mm
Height of the patch	0.1 mm
Width of the transmission line	2.59 mm
Resonant frequency	3.5 GHz
Dielectric constant	1.67
Bandwidth	15 GHz

3. SIMULATION RESULTS

The antenna is simulated and the following parameters were captured and analyzed. While analyzing the antenna, various frequency bands are identified which cover WiMAX applications.

a) Return loss (S_{11})
b) Bandwidth (BW)
c) Radiation pattern
d) Gain (S_{21})
e) Directivity

The proposed antenna has been simulated at various bands between 5 GHz and 20 GHz range including WiMAX bands. Figure-2 shows the return loss for the mentioned frequency range. It can be noticed that there is a remarkable bandwidth improvement of 15 GHz compared to the existing design [12].

The results of return loss at various frequency bands between 5 GHz and 20 GHz are listed in Table-2. At 5.2 GHz, a threshold value of the return loss is achieved, where a return loss of -24.31 dB is obtained at 20 GHz. However, the return loss is obtained between -10 dB and -24.31 dB. This shows that the proposed antenna is suitable for the applications running over the entire bandwidth.

Figure-3 to Figure-7 show the 3D radiation patterns at 5.2 GHz, 5.8 GHz, 7.2 GHz, 10 GHz and 20 GHz respectively. At 5.2 GHz, a maximum radiated field of 10.986 dB, at 5.8 GHz, a maximum radiated field of 12.155 dB, at 7.2 GHz and at 10 GHz, a maximum radiated field of 11.906 dB and at 20 GHz, a maximum radiated field of 13.693 dB is evident. Though the return loss results for the entire bandwidth are insignificantly higher than the existing antenna design, but the results fulfill the requirement of the intended application standards.

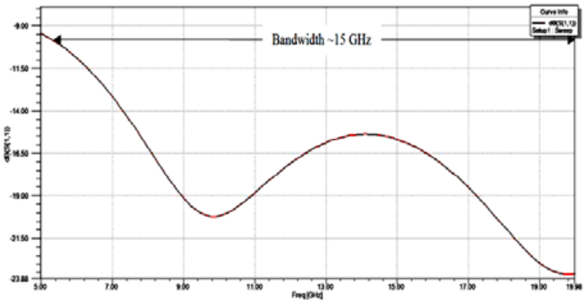

Figure-2. Return loss (S_{11}).

Table-2. Return loss at various frequency bands.

Frequency bands (GHz)	**Return loss** (dB)
5.2 (WIMAX)	-10.00
5.8 (WiMAX)	-10.46
6.2	-11.11
6.8	-12.11
7.2	-14.08
10	-20.33
12.5	-17.02
15	-15.55
17.5	-18.44
20	-24.31

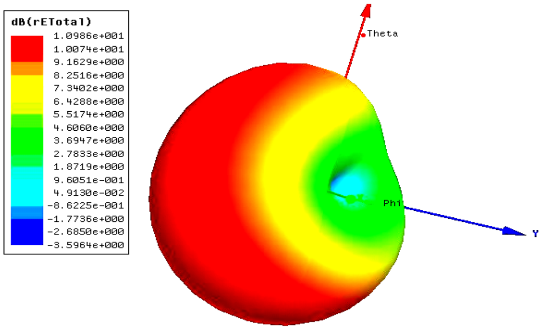

Figure-3. 3D Radiation pattern at 5.2 GHz.

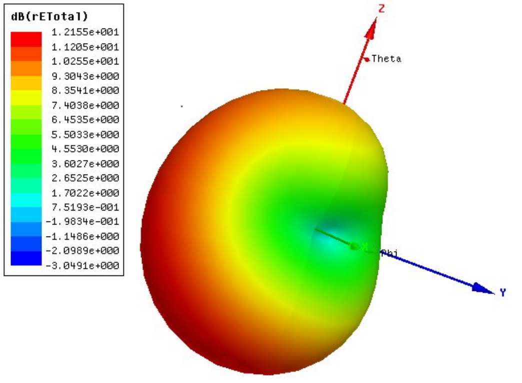

Figure-4. 3D Radiation pattern at 5.8 GHz.

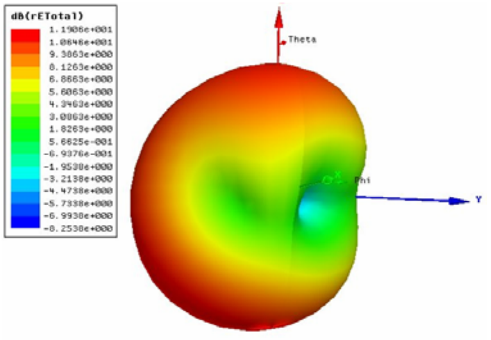

Figure-5. 3D Radiation pattern at 7.2 GHz.

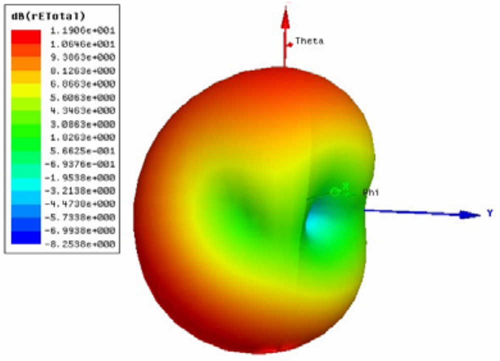

Figure-6. 3D Radiation pattern at 10 GHz.

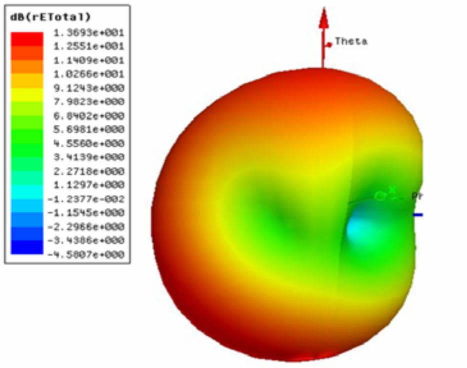

Figure-7. 3D Radiation pattern at 20 GHz.

Table-3 shows the values of gain and directivity of the proposed antenna achieved at various WIMAX and LTE frequency bands.

Table-3. Gain and directivity at various frequency bands.

Frequency bands (GHz)	**Gain** (dB)	**Directivity** (dB)
5.2 (WIMAX)	4.48	4.8
10	4.19	4.8
20	5.8	6.8

Figure-8 shows the Voltage Standing Wave Ratio (VSWR) at 5.2 GHz, 5.8 GHz, 6.2 GHz, 6.8 GHz, 7.5 GHz, 10.2 GHz, 12.5 GHz, 15 GHz, 17.5 GHz and 20 GHz, respectively. At 5.2 GHz, a maximum VSWR of 1.97 dB, and at 20 GHz, a minimum VSWR of 1.12 is evident. Table-4 shows the values of VSWR of the proposed antenna achieved at various frequency bands including WIMAX and LTE frequency bands.

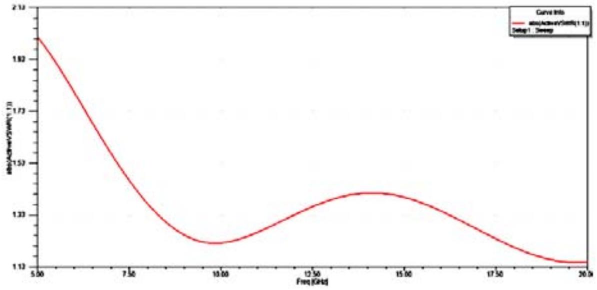

Figure-8. Voltage standing wave rations (VSWR).

Table-4. VSWR at various frequency bands.

Frequency bands (GHz)	**VSWR**
5.2 (WIMAX)	1.97
5.8 (WiMAX)	1.85
6.2	1.77
6.8	1.63
7.5	1.49
10.2	1.21
12.5	1.32
15	1.40
17.5	1.27
20	1.12

Table-5 presents the performance comparison of the proposed and the existing antenna designs. The table shows that there is a noteworthy improvement in the operating bandwidth with the small reduction in the antenna dimensions. The proposed design provides an ultra-wide bandwidth. The bandwidth is improved by 384.83% with 15 GHz compared to 4.3 GHz in the existing design published in the literature [12]. This enhanced bandwidth covers WiMAX band and other applications between 5 GHz and 20 GHz. Besides this, the antenna size is significantly reduced by 13.4% as well.

Table-5. Performance evaluation of the proposed design

PARAMETER	Existing Design [12]	Proposed Design
Length	35mm	35 mm
Width	30mm	25 mm
Thickness	0.8mm	0.8mm
Operating frequencies	3.5 GHz	3.5 GHz
Bandwidth	4.3GHz	15 GHz
Gain	3 dB	4.4 dB

The results clearly indicate that the proposed design not only enhances the bandwidth but also reduces the antenna size. The proposed design satisfies the standards of the WiMAX frequency bands at 5.2 GHz, 5.5 GHz and 5.8 GHz as well as other standards of the ISM band. Moreover, the gain and the radiation pattern results also satisfy these standards.

This bandwidth enhancement over the WiMAX frequency bands is due to the appropriate selection of the dielectric substrate, change in the slit dimension and the optimum antenna design geometry.

4. CONCLUSIONS

Due to simple design geometry and adaptability, the Micro-strip patch antennas play important role in many wireless communication systems and applications. In this paper an On-Body wearable micro-strip antenna for not only the WiMAX frequency band but also for the other wireless communication standards is proposed. It is concluded that there is an incredible bandwidth improvement of 384.3% which is 15 GHz and reduction in antenna size by 14.3 %. The proposed antenna achieves an ultra–wideband with considerable size reduction. Hence, the proposed antenna can be used for WiMAX applications as well as for the applications operate up to 20 GHz.

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