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An ISM/UWB antenna with offset feeding and slotted ground plane for body-centric communications

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Abstract: An offset-fed ISM/Ultra-wideband (UWB) antenna with a slotted ground plane designed for on-body communications is presented in this paper. The antenna consists of a radiator very close to a square shape, a feed line slightly offset from the middle along the radiator side and three rectangular slots at the top edge of the ground plane. The offset feed line is used to improve the radiation pattern for on-body communications and the slots on the ground plane are used to improve impedance matching of the antenna. The antenna is studied using computer simulation. For verification of simulation results, the antenna is fabricated and measured. Simulated and measured results show good agreements in terms of reflection coefficient, gain, efficiency and radiation pattern. Measured results show that the antenna can achieve a wide bandwidth from 2.38 to 14.5 GHz with more omnidirectional radiation patterns in the E-plane than conventional monopole, making it a potential candidate for on-body communications using UWB.

Keywords: ISM/UWB Antenna; Offset Feed, Body-Centric Communications

1. Introduction

Since the Federal Communications Commission (FCC) allocated 7.5 GHz spectrum from 3.1 to 10.6 GHz for radio applications with low power emission in 2002 [1], Ultra-wideband (UWB) systems have received much attention. However, it needs to be reminded that lots of fundamental works had been done in the last century [2-5]. The design of efficient and compact size antennas for wideband applications is still a major challenge nowadays. Many micro-strip-fed and coplanar waveguide-fed antennas have been reported for UWB applications [6-12] and the UWB propagation channel has also been studied [13]. These antennas employed either the monopole configuration with different shapes (circular ring, ellipse, annular ring, triangle, pentagon or hexagon) [10, 11] or the dipole configuration (e.g. bow-tie antennas) [9]. Since the Industrial, Scientific and Medical (ISM) band from 2.4-2.484 GHz covers the IEEE 802.11b/g standards which are very popular in many countries for accessing the internet, it is useful to have a single antenna to support both the UWB and ISM band.

Different techniques can be used to increase the impedance bandwidths of planar monopole antennas, e.g. using slots on the ground plane [11] and slot antenna geometry [12, 14], increasing the elliptical ratio of ellipse-shaped

monopole [15], adding stairs to the lower edge of the radiator [16], adding a bent stub to one side of the radiating element and stepping the ground plane [17]. Many antennas for ISM and UWB applications have also been proposed. In [18], an L-shaped strip was added to one side of a semi-bevelled-rectangle patch radiator to cover both the ISM and UWB bands. In [19, 20], stub or a folded strip were added to the centre of the radiators to achieve the bandwidth requirement. Different specific applications have also been reported such as for wireless universal serial bus (WUSB) dongle applications in [21] or laptop applications in [22]. For body-centric wireless communications systems, with the existence of human body, several fundamental requirements, such as wide impedance bandwidth, low profile, high front-to-back ratio and good radiation characteristics in the proximity of the body, are needed to be fulfilled in the design of the antennas [23-27]. Depending on the channel used for propagation of the signals, body-centric wireless communication systems can be divided into in-body, on-body and off-body communications [23]. In-body communication refers to communication between two or more devices through the human body, which is from inside of the body to the outside of the body. For off-body communication, it is communication between devices on body with other devices away from the body. An

antenna for off-body communication should have radiation patterns directed away from the body. For on-body communications, it refers to communication between two or more devices which are mounted on the same human body. Thus it is desirable for the antenna to have an omnidirectional radiation pattern on the body surface to achieve good on-body propagation. Most UWB antennas proposed for on-body communications have made different kinds of compromise. In [24], a UWB monopole antenna was installed perpendicularly to the body surface in order to have an omnidirectional radiation pattern in the E-plane on the body surface. However, the design had high profile. Some other designs of UWB monopole antennas were proposed to put in parallel with the body surface to achieve low profile [25-27]. However, the radiation pattern in the E-plane on the body surface then was not omnidirectional.

In this paper, an ISM/UWB monopole antenna employing a radiator very close to a square shape, a feed line slightly offset from the middle along the side of the radiator and a ground plane with three rectangular slots is proposed for on-body communications. To the best of our knowledge, this is the first ISM/UWB antenna designed for body-centric communications. The antenna is studied, designed and fabricated on a Rogers substrate. Results show that the antenna has a wide impedance bandwidth from 2.38 to 14.5 GHz and a radiation pattern more omnidirectional in the E-plane than those of other monopole antennas, which makes it suitable for on-body communications.

The proposed antenna is a further study and an improvement of our previous design in [10]. In the previous design, the antenna on a FR4 substrate with a very small ground plane and could not cover the whole bandwidth of 3.1-10.6 GHz allocated by the US-FCC. Since FR4 substrate does not have constant electrical characteristics particularly at high frequencies, there were large discrepancies between the measured and simulated results in [10]. Moreover, the antenna employed six ground slots on the ground plane. Further studies on the operation of the antenna have shown that three slots are enough if placed in the correct positions. Thus in the present design, the antenna has only three slots on the ground plane and is designed on a Rogers RO4350 substrate.

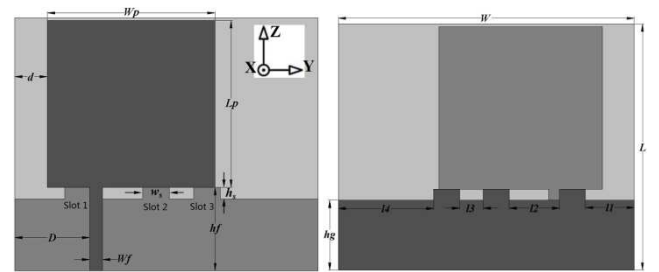
2. Antenna Design

The geometry of the proposed ISM/UWB monopole antenna with microstrip-fed is shown in Fig. 1. The antenna has a radiator very close to a square shape with an area of $W_p \times L_p$. The microstrip-feed line has a width of w_f to achieve 50- Ω characteristics impedance and is placed slightly offset from the middle of the radiator edge. The radiator and feed line are printed on one side of the substrate, and the ground plane with a height of h_g is printed on the other side. Three rectangular slots, slots 1, 2 and 3 as shown in Fig. 1(a), each with a dimension of $w_s \times h_s$ are added to the top edge of the ground plane. The positions of these slots on the ground plane are quite critical on achieving a good matching per-

formance. The antenna is studied, designed and optimized using the EM simulation tool, CST, on a substrate, Rogers RO4350, with a thickness of 0.8 mm, a relative permittivity of 3.5 and a total area of $W \times L$. The optimized parameters are listed in Table 1 which is used to fabricate the antenna as shown in Fig. 1(c) for measurement using the antenna measurement equipment, Satimo Starlab.

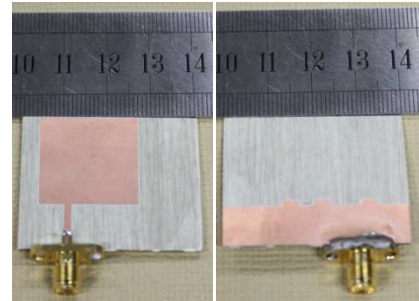
Table 1. Optimized parameters of proposed antenna

Parameter	Value	Parameter	Value
W	40	h_g	9.375
L	33	l_1	6.6
W_p	22	l_2	6.8
L_p	21.75	l_3	3.2
D	10	l_4	12.9
d	4.3	w_s	1.5
w_f	1.7	h_s	3.5
h_f	10.875		



(a) Top view

(b) Bottom view



(c) Photos of the antenna

Figure 1. Geometry of proposed antenna

3. Parameter Study

3.1. Simulated S_{11}

Results of computer simulation have shown that the number of slots used on the ground plane, the height of the slots h_s and the positions of the slots all play important roles in impedance matching. With the optimum slot size of $w_s \times h_s = 1.5 \times 3.5 \text{ mm}^2$, the simulated S_{11} using only one slot and two slots with different positions are shown in Fig. 2. Note that the positions of slots 1, 2 and 3 are determined by parameters l_1 , l_2 and l_3 . It can be seen in Fig. 2(a) that when only one slot is used, the bandwidth cannot cover the whole UWB. As l_1 increases from 6 to 21 mm, i.e. slot 1 moves from left side of the ground plane under the radiator

to right side, the impedance bandwidth of the antenna decreases. With $l_1 = 6$, the bandwidth is from 2.2 to 9.7 GHz, and with $l_1 = 21$, the bandwidth is only from 2.3 to 7.5 GHz. With the use of two slots on the ground plane, the simulated S_{11} with l_1 is fixed at 6 mm is shown in Fig. 2(b). It can be seen that, with $l_2 = 12$, the antenna has wider bandwidths and achieve an impedance bandwidth from 2.2 to 11.8 GHz, covering both ISM and UWB band. In our design, a third slot is added to further broaden the bandwidth.

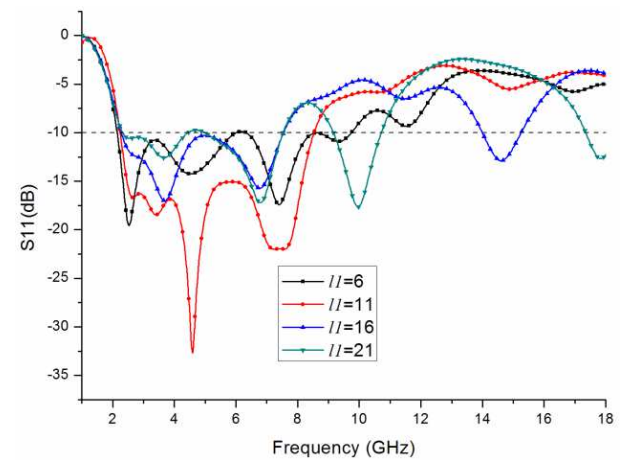
The simulated S_{11} of antenna with three slots is shown in Fig. 3. With slot height of $h_s = 1.1, 1.3, 1.5$ and 1.7 , the simulated S_{11} is shown in Fig. 3(a). As h_s increases, the lower resonant frequency at around 3 GHz shifts down a little bit, but with the lower cutoff frequency ($S_{11} = -10$ dB) remaining unchanged. However, the higher frequency resonance at around 15 GHz moves down significantly with stronger magnitude, reducing S_{11} at higher frequencies and hence increasing the impedance bandwidth toward the high frequency. The resonance at around 8 GHz is weaker with increased h_s , which increases S_{11} at round 5.5 GHz. Thus a compromise must be made to obtain a good performance of S_{11} for the whole frequency band. In our design, the optimum h_s is equal to the gap between the radiator and the ground plane, which is 1.5 mm.

The results of parametric study on l_4 and l_3 , which determine the positions of slots 3 & 2 on the ground plane, are shown in Figs. 3(b) and 3(c), respectively. Fig. 3(b) shows that when l_4 decreases from 13.3 to 12.1 mm, the middle resonant frequency shifts very slightly from 8 to 7.7 GHz, while the higher resonant frequency also shifts down slightly from 16 to 15.7 GHz. When l_4 set at a fixed value of 12.9 mm, l_3 determines the position of slot 2. Fig. 3(c) shows that when l_3 increases from 2.8 to 3.4 mm, the middle resonant frequency shifts down slightly from 8 to 7.6 GHz, while the higher resonant frequency shifts up significantly from 15.9 to 16.8 GHz. It can be seen that l_4 and l_3 affect the middle resonant frequency at around 8 GHz and higher resonant frequency at 16 GHz. However, they do not affect the lower resonant frequency at about 3.5 GHz. The position of slot 1 is determined by l_1 . The simulation S_{11} with different values of l_1 is shown in Fig. 3(d). As l_1 decreases from 6.8 to 6.5 mm, the different resonant frequencies do not shift much. However, the resonances below 8 GHz are only slightly affected but the resonances above 8 GHz, i.e. at around 11 and 14 GHz, are significantly weaker which reduces S_{11} . Since if l_3 and l_4 are fixed, the value of l_2 will change with l_1 which also determines the position of slot 1, thus the parametric study on l_2 is not necessary.

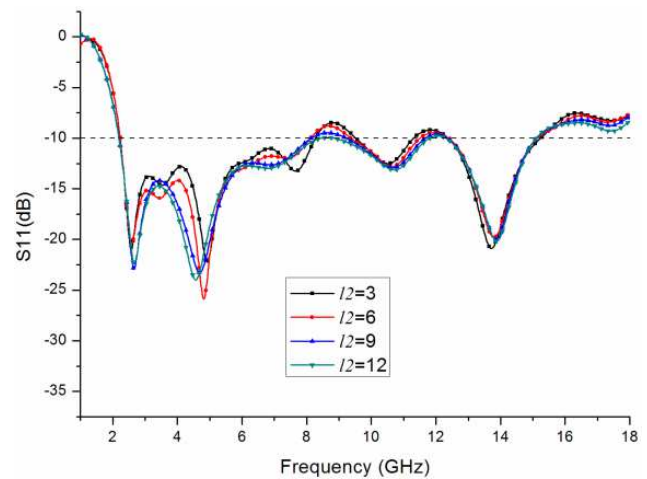
2.2. Simulated current distribution

The operation of the proposed antenna is further studied using current distributions at different resonant frequencies. At 3 GHz, the simulated results in Fig 4(a) shows that the current is mainly on the bottom edge of the radiator close to slots 2 and 3 which contributes to the resonance. At 8 GHz, Fig. 4(b) shows that the current is mainly at the left edge of

the radiator and on slot 1. While at 14 GHz, Fig 4(c) shows that the current is mainly on slots 1 and 2. Higher mode operation can also be seen at the left edge of the radiator. Very little current is on slot 3.

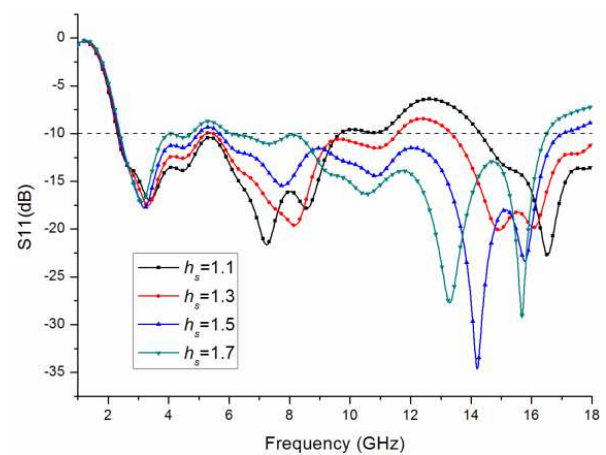


(a)



(b)

Figure 2. Simulated S_{11} with (a) one slot, and (b) two slots with $l_1 = 6$ mm



(a)

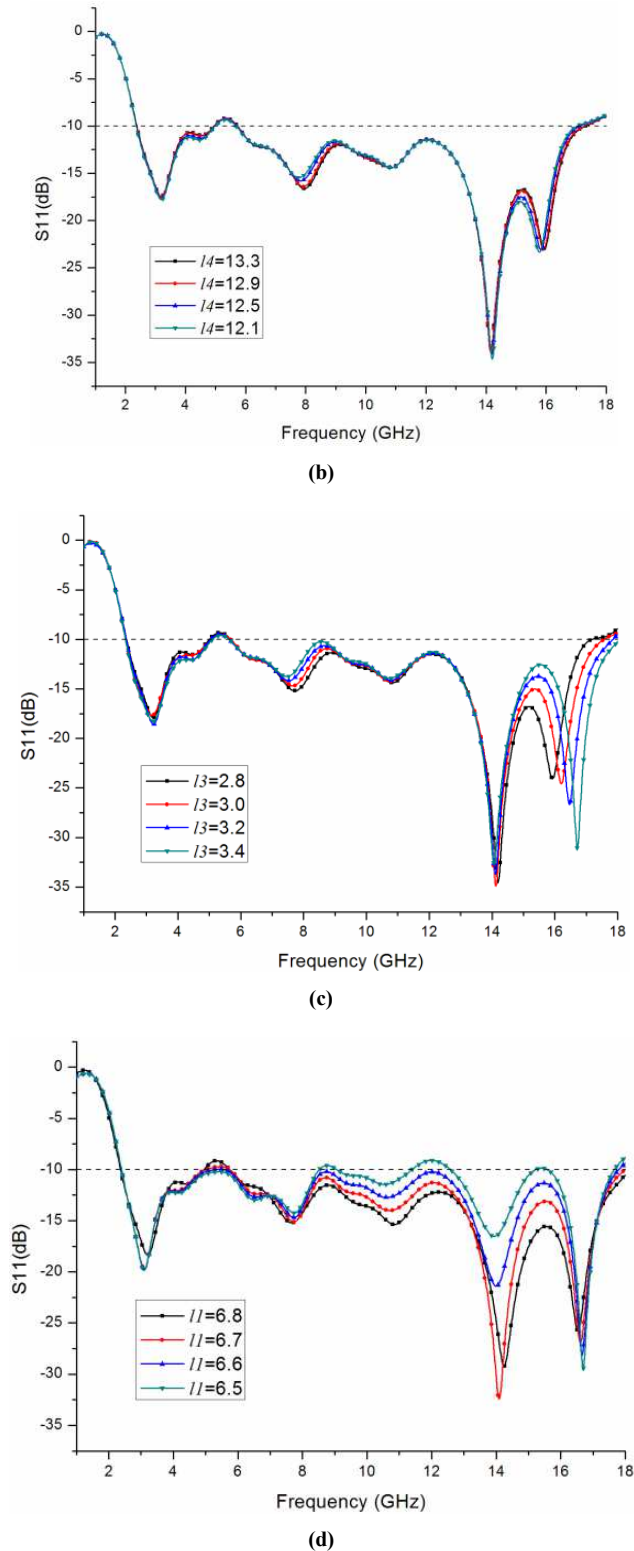


Figure 3. Simulated S11 with (a) one slot, and (b) two slots with $l_1 = 6$ mm

4. Results and Discussions

The proposed antenna shown in Fig. 1(a) has been studied and designed using computer simulation. For verification of simulation results, the antenna has also been fabricated as

shown in Fig. 1(c) and measured using the Satimo Starlab System.

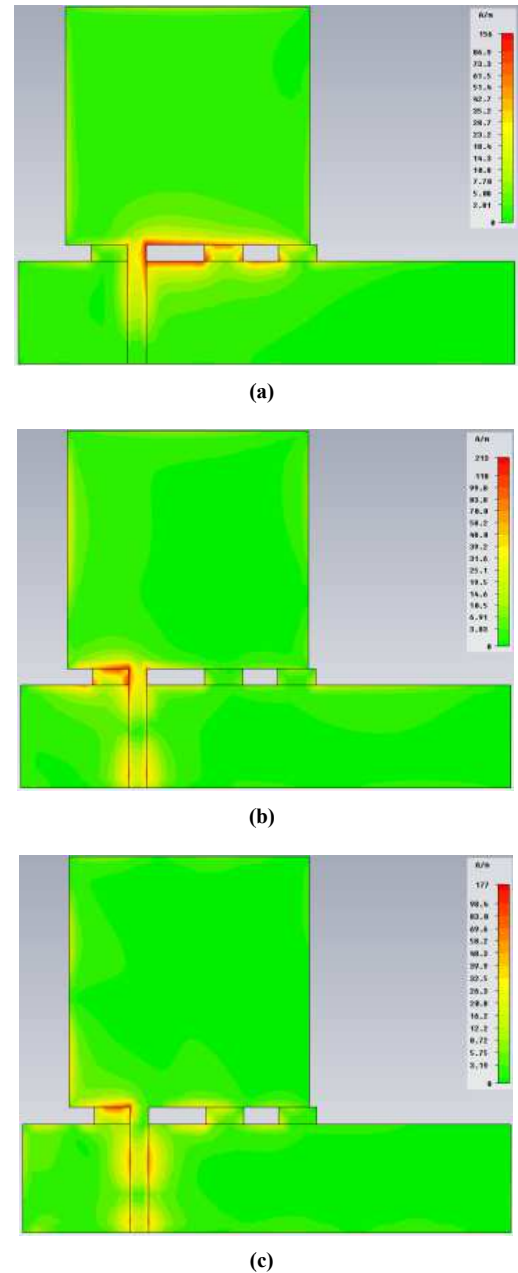


Figure 4. Simulated current distribution at (a) 3 GHz, (b) 8 GHz and (c) 14 GHz

The simulated and measured S11 of the antenna are shown in Fig. 5. The antenna has a measured impedance bandwidth from 2.38 to 14.5 GHz. Results of more studies have showed that the small discrepancy between the simulated and measured results below about 14 GHz is mainly due to the soldering, fabrication tolerance, measurement tolerance and SMA connector, while the large discrepancy above about 14 GHz is mainly due to the SMA connector and measurement tolerance. The peak gain and efficiency of the antenna are shown in Fig. 6. Simulated and measured results showed good agreements. The antenna has a maximum measured gain of 5.9 dBi at 12.7 GHz with an average

gain of 4.42 dBi from 2.38 to 14.5 GHz. It has a maximum measured efficiency of 95.3% at 3 GHz with an average of 86.6% through the whole bandwidth from 2.38 to 14.5 GHz. The efficiencies in simulation and measurement do not agree well at high frequencies from about 15 to 16 GHz, which is mainly due to the SMA connector and measurement tolerance. The radiation patterns of the antenna at 2.45, 10 and 14 GHz are shown in Fig. 7. It can be seen that the antenna does not have dumb-bell shaped radiation patterns in the yz-plane (the E-plane) like a normal monopole should have. At all these three frequencies, the radiation patterns in the yz-plane do not have obvious nulls on top and bottom of the antenna. More simulated results have showed that, without the slots on the ground plane and/or without offset-fed, the antenna behaves like a normal monopole, having dumb-bell shaped radiation patterns in the yz-plane. This indicates that it is the offset feed line and slots on the ground plane which cause the radiation pattern in the yz-plane to be more omnidirectional, making the antenna more suitable for on-body communications. Since the antenna can be put in parallel with the body surface, it has low profile.

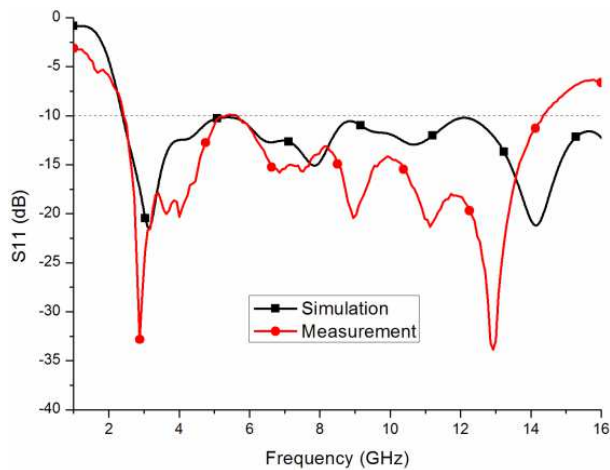


Figure 5. Simulated and measured S11 of the antenna

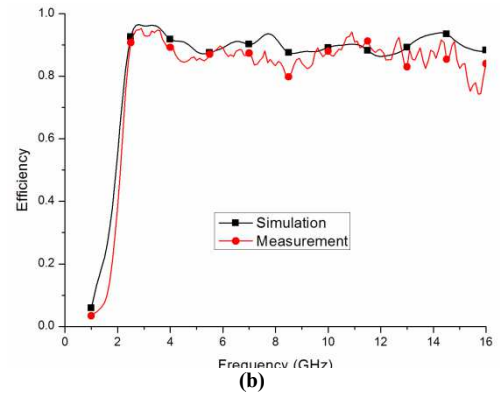
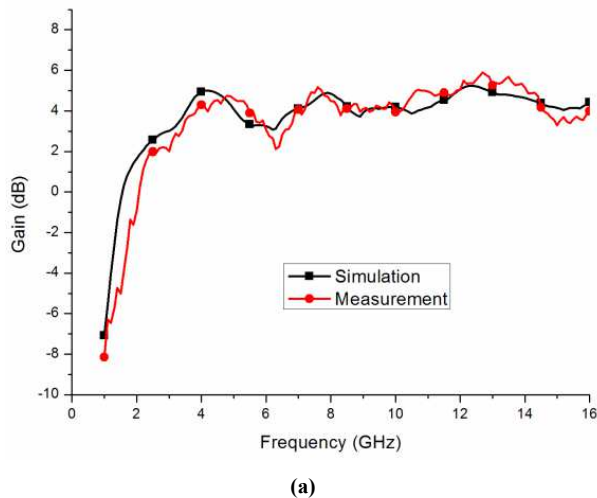


Figure 6. Simulated and measured (a) peak gains and (b) efficiencies

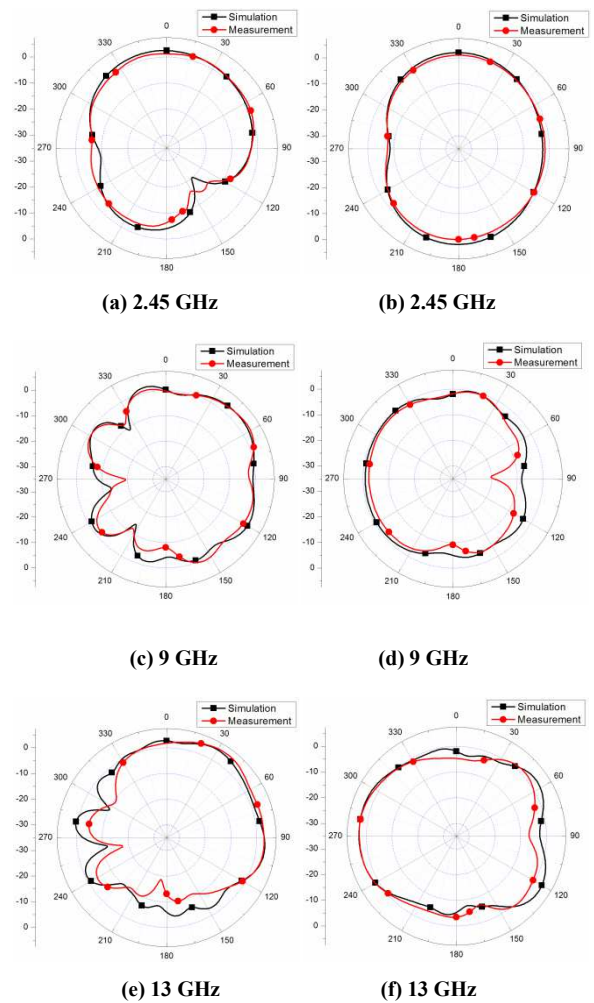


Figure 7. Simulated and measured radiation patterns at (a) 2.45 GHz, (c) 10 GHz & (e) 14 GHz in y-z plane and (b) 2.45 GHz, (d) 10 GHz & (f) 14 GHz in x-y plane

5. Conclusions

An ISM/UWB monopole antenna with offset-fed and a slotted ground plane has been designed and proposed for on-body communications. The antenna has a size of 40×33 mm². An offset feed line and three rectangular slots used at the top edge of the ground plane are used to improve im-

pedance matching, creating a wide bandwidth from 2.38 to 14.5 GHz for the antenna. More importantly, they are also used to improve the radiation characteristic in the E-plane for on-body communications, making the antenna suitable for body-centric communications.

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