Dual Band and Dual Mode Microstrip Antenna for Body Centric Wireless Communication

Seiran Khaledian and Zahra Atlasbaf

Department of Computer and Electrical Engineering
Tarbiat Modares University, Tehran, Iran
Seiran.kh@gmail.com, atlasbaf@modares.ac.ir

Abstract **─** A compact dual band and dual mode microstrip patch antenna, suitable for body centric wireless communication (BCWC) network is presented. The BCWC network works in two on-body and off-body modes. The proposed antenna has an outward radiation pattern for the off-body mode, which is suitable to communicate from on-body devices to off-body unite. Moreover, the antenna has an end-fire radiation pattern for the on-body mode, to communicate with other co-located worn devices from which data can be easily gathered. The proposed antenna resonances at 2.44 GHz (IEEE 802.11b/g) with 7.1 dB gain and linear polarization for the off-body mode and also at 5.43 GHz (IEEE 802.11a) with 6.6 dB gain and circular polarization for the on-body mode. Free space and on-body simulated and measured performances of the proposed antenna are shown. Specific absorption rate (SAR) value is also studied. The results show that the maximum averaged 10gr SAR is 0.26W/Kg for on-body mode when the antenna is placed on the chest of the human body model.

Index Terms **─** BCWC network, dual band, dual mode, microstrip patches antenna, miniaturization, on-body/off-body antenna.

I. INTRODUCTION

Advances in wireless technology have led to the development of wireless body area network (WBAN), where a set of communication devices is deployed in close proximity and around the human body. There are two main channels of interest for wireless body area network: off-body and on-body. The off-body channel is concerned for communication between a device on the body and a remote location. Some typical applications include short range communication between two soldiers on a battlefield or transmission of medical data from a wireless sensor body area network to a remote network access point. On-body channel is necessary for communication between devices located on the surface of a user's body; e.g., in telemedicine applications where wireless biosensors are distributed across the body, a controller rode is often located on the body to act as a relay between the biosensors and a non-local station several meters or more away from the user. In such applications, it is clear that both propagation modes (on the body and off-body) are required [1, 2]. Antennas used in this kind of applications require a low profile, tolerable power consumption, low manufacturing cost and must have little effects on the human body. In this regard, microstrip patch antennas are good candidates due to their low cost, physical size (low profile), higher power efficiency and their ability to provide proper radiation parameters. Radiation pattern in off-body link needs to have a good boresight (normal to the body surface) directivity and must propagate through a tangential creeping wave in the on-body link.

The antennas already designed for WLAN applications fall into two main groups: the first group includes antennas which can only run in the on-body or the off-body modes, separately [2-4]. On the contrary, a second group exists where simultaneous on or off-body modes can be expected [5, 9]. In [5], a dual band, dual mode and dual feed compact antenna is discussed where coaxial cables are used. In addition, a dual band and dual pattern antenna with two radiate elements and coaxial cable as the feed is introduced in [6-8]. To properly design, develop and apply these antennas on the human body model, the associated electrical characteristics must be first determined to explore the human body effects on the antenna propagation and vice versa. Antenna performance around the human body has already been carried out by a number of researches, most of whom have used simplified rectangular cube with electrical parameters of human muscle, representing the human body. In this paper, a compact square microstrip antenna with a single microstrip feed line and a single radiating element is proposed for dual band and dual mode WLAN operation. The gain of the antenna is increased compared to [5, 9] at both frequency bands. Moreover the proposed antenna is fed with a single probe at its edge which provides more practical device in order to implant on body surfaces, in comparison with antennas

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which are fed by coax cable or multi probes. The antenna is simulated, fabricated and tested. Moreover, a human body model designed in CST microwave studio is used to investigate radiation characteristics of the antenna and SAR measurement.

II. ANTENNA DESIGN

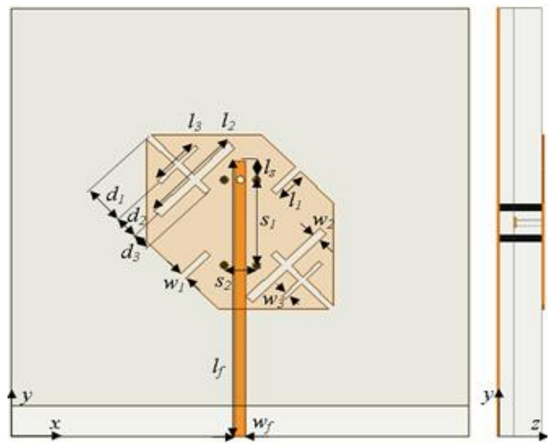
Figure 1 shows the geometry of the proposed antenna. It consist of a square patch of dimensions 28×28 mm^2 etched on a two-layer stratified substrate (70×70 mm^2) of RO4003 with εr=3.55, tanδ=0.0027 and a thickness of 2.43 mm. In order to avoid coaxial feed and thereby making the antenna conformal to the body, a strip feed line is designed. It is etched on a 70×70 mm^2 substrate of RO4003 of thickness 0.813 mm.

The feed line excites the patch using a copper post of radius 0.6 mm that extends from the feed line to the patch. The substrate supporting the patch has a height of 1.623 mm with a dimension of 70×65 mm^2. The upper and lower substrates are different in dimension to implant SMA, feeding the strip line and also to provide a better impedance matching. Table 1 summarizes the dimensions of the antenna components designed.

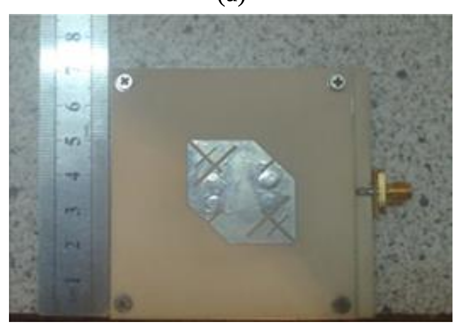
The antenna is about to have a microstrip patch with a single radiating element to operate at two frequency bands of 2.4-2.484 GHz and 5.15-5.815 GHz for IEEE 802.11b/g and IEEE 802.11a, respectively. The antenna is considered to operate as a relay between sensors located on the body and non-local station so it's an advantage for the antenna to be able to have tangential radiation over the body surface in the on-body mode and a boresight pattern in the off-body mode at the frequency bands of 802.11a and 802.11b/g, respectively.

A corner truncated square patch with eight embedded slots in its structure is used to set the resonant frequency for IEEE 802.11 b/g without enlarging the whole patch dimensions. By means of cutting two long slots across the diagonal slots, with a length of l2, the TM10 current path will be prolonged but still not long enough to be fixed at our lower band, consequently by using two other shorter parallel slots (l3), the resonant frequency band is decreased to 2.44 GHz as required. At this frequency band (fundamental mode), the antenna's main beam is at boresight. To generate this monopole-like radiation pattern, various antenna types have been proposed. A compact patch antenna with a vertical ground wall and a shorting wall was proposed in [9]. A planar inverted antenna using a shorting wall on a two-third muscle equivalent arm phantom was published in [10]. Inspired by the design in [9], a higher mode (TM21) microstrip patch antenna (HMMPA) was introduced in [1], [11].

In this paper, in order to have a tangential pattern over the body surface at the upper band, shorting posts are used in the antenna structure. This shorting post acts as short-circuit to the capacitance of the antenna constituted by the upper plane above the ground plane. In a first approximation, we can consider that the inductance due to the shorting post(s) is set in parallel with the antenna capacitance, and so constitutes an anti-resonating circuit which explains the presence of the parallel resonance phenomenon [9]. Two grounding (shorting) posts offset from the fed are used to force nulls in the electric field between the ground plane and the patch element, exciting the higher order resonant mode (TM_{21}), [1].



(a)



(b)

Fig. 1. (a) Configuration of the proposed antenna, and (b) the fabricated antenna.

Table 1: Design parameters

Component	Unit	Component	Unit
w_f	1.7 mm	l_2	16.8 mm
l_f	45 mm	l_3	5.84 mm
l_s	3 mm	d_1	3.3 mm
w_1	1 mm	d_2	2.54 mm
w_2	1.35 mm	d_3	2.07 mm
w_3	0.75 mm	s_1	14 mm
l_1	5.21 mm	s_2	2.5 mm

The radiation characteristics of the antenna are controlled by the dimension of the feed line, grounding posts' location and number of them, length and location of the slots, and also by the height of the substrate and permittivity.

III. PARAMETER ANALYSIS

With the dimensions given in Table 1, the proposed antenna was simulated and tested in, first free space, then in close proximity of the human body are also investigated. We developed a human body. The human body model was developed in the CST Microwave Studio. It is an adult male of mass 100 kg, height 180 cm and chest circumference of 115 cm, including muscle, skeleton and brain with human tissue. The electrical properties were defined at the frequency band of 2-6 GHz with resolution of 100 MHz, [9]. Figure 2 shows the placement of the antennas on the model. The antenna is placed 0 mm, 2.5 mm and 10 mm apart from the chest of the model. The free space and on body simulated and measured S_{11} of the proposed antenna are illustrated in Fig. 3. In free space simulation, the antenna bandwidth is 28 MHz for the lower band and 116 MHz for the upper band while in measurement 35 MHz and 130 MHz bandwidths are achieved for lower and upper bands, respectively. Nevertheless, bandwidths of 80 MHz and 25 MHz for the upper and lower bands are achieved when the antenna is placed on the human model.

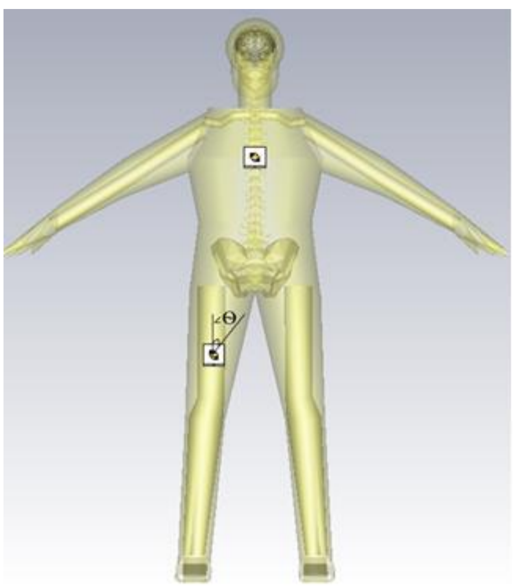


Fig. 2. The proposed antenna placed on the chest and right leg of the human body model.

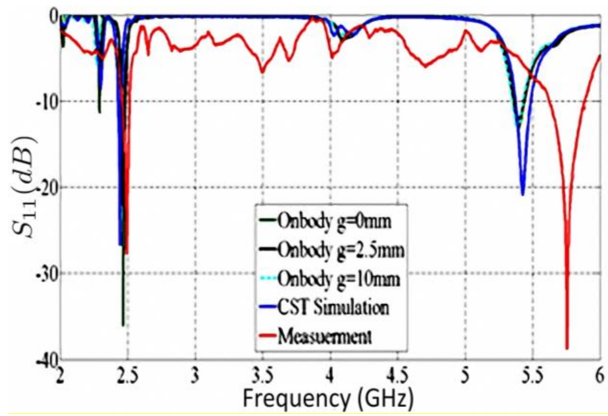
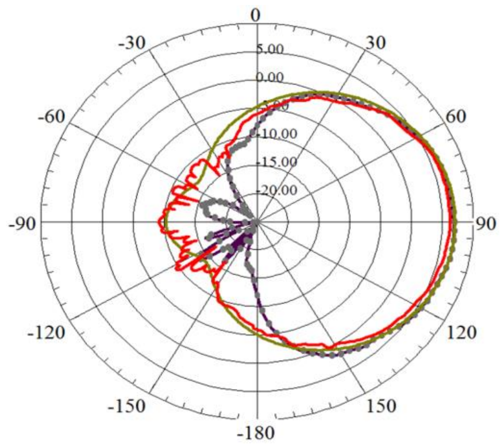


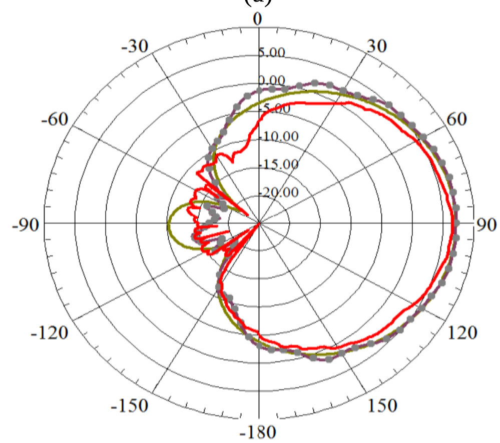
Fig. 3. Simulated, measured and on body S_{11} of the proposed antenna.

Figure 4 depicts the simulated and measured radiation patterns of the proposed antenna. The simulated results show that the maximum gain is about 7.1 dB at 2.44 GHz and 6.6 dB at 5.4 GHz. These are about 6.4 dB and 6.51 dB at 2.49 GHz and 5.56 GHz in measurement, respectively. The simulation shows 75% efficiency at 2.44 GHz and 82% at the upper band (5.4 GHz). It is observed that at the lower frequency band, the radiation pattern is directed towards the body, Figs. 4 (a, b), (it should be mentioned that the mismatch of the back-lob gains is because of measurement tolerance) and at the upper band it is tangential over the body surface, Figs. 4 (c, d). The results also show that when the antenna is placed on the human body model, the maximum gain decreases 0.2 dB at the lower band and increases to 1.35 dB at the upper band compared to the free space simulation. To investigate the antenna performance in the on-body communication mode, two antennas were placed on the chest and left leg of the human body model making an angle of ϴ=0, 15, -30, -40 degrees to each other (Fig. 2). Antenna coupling (|S21| path gain) at the on body frequency (5.4 GHz) is shown in Fig. 5. As it can be noticed from Fig. 5, the best path gain is obtained as -33 dB when the antennas are placed in ϴ=15.

Generally, the simulation results are in good agreement with those of measurement; though a frequency detuning is observed at the upper band. This may be explained by the manufacturing difficulties. The comparison between this work and related works can be found in Table 2.



(a)



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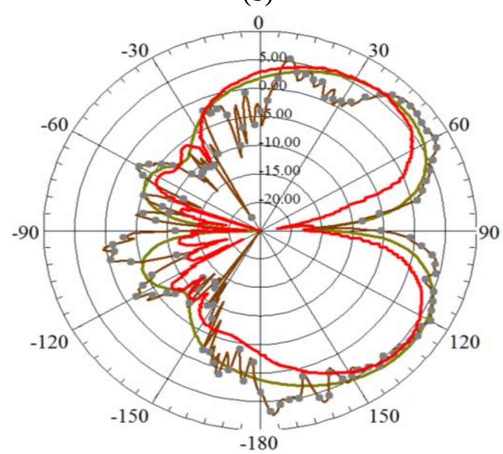

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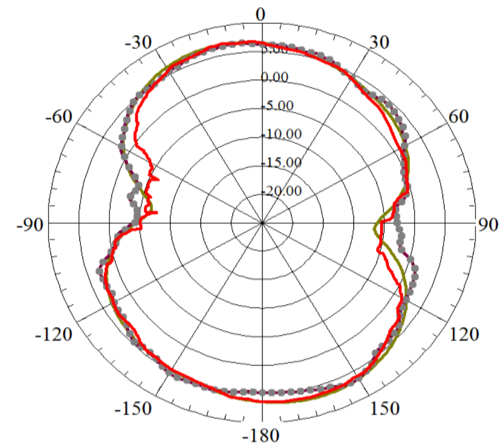

(d)

Fig. 4. Simulated and measured radiation pattern of the proposed antenna: (a) the radiation pattern in the *yz* plane, f_0=2.44 GHz; (b) the radiation pattern in the *xz* plane, f_0=2.44 GHz; (c) the radiation pattern in the *xz* plane, f_0=5.43 GHz; (d) the radiation pattern in the *xy* plane (θ=45̊), f_0=5.43 GHz.

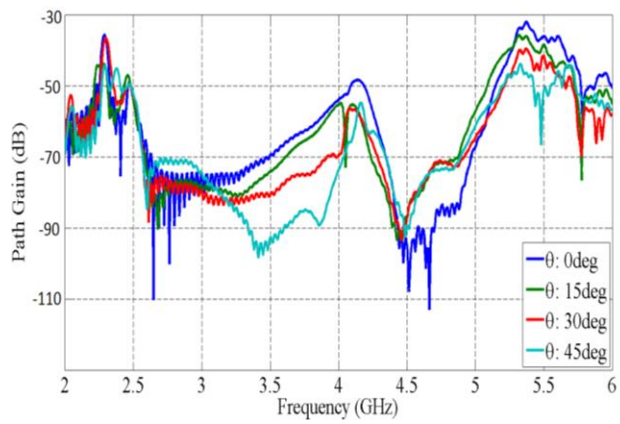

Fig. 5. S21 path gain of proposed antenna placed on the human body model for Θ=0, 15, 30, 45 degree.

Table 2: Comparison of this work with similar works

Parameter	Size LWh (mm)	Matching BW %	Gain (dBi)
Hertlee et al. [4]	50*46*3.94	3.4% @ 2.45 GHz	6.9
Tak et al. [11]	15.5*28*10.5	4.5% @ 2.45 GHz 7.2% @ 5.8 GHz	1.5 @ 2.45 GHz 1.27 @ 5.8 GHz
Conway et al. [1]	18*18*9.5 HMMPa 10 22*22*4.75 HMMPA5	6.7% HMMPA5 8.6% HMMPA10	1.2 HMMPA5 1.5 HMMPA10
Our work	28*28*2.439	3.4% @ 2.45 GHz 12% @ 5.43 GHz	7.1 @ 2.45 GHz 6.6 @ 5.43 GHz

IV. SAR MODELLING

Having investigated the electromagnetic characteristics of the proposed antenna and the effects of the human body, we now turn our focus on the rate of energy absorption as defined by the specific absorption rate (SAR). Table 3 summarizes the absorbed power, maximum SAR point and 1 gr and 10 gr averaged SAR for the proposed antenna. As it is shown in Table 3, maximum 1 gr SAR of the proposed antenna is 1.2 W/Kg which is 0.4 W/Kg less than the restriction of the USA [13].

Table 3: SAR simulation results SAR simulation results

Antenna Mode (f_0)	Off-Body (2.468 GHz)	On-Body (5.4 GHz)
Accepted power [W] (rms)	0.496953W	0.469259W
Absorbed power (tissue power absorbed)	0.0747296W (0.033708W)	0.112307W (0.0718987)
Total SAR (rms) [W/kg]	0.000226889 W/Kg	0.000483952 W/Kg
Max. point SAR (rms) [W/kg]	9.20803 W/Kg	20.5825 W/Kg
Max. SAR (rms, 1 g) [W/Kg]	0.507495 W/Kg	1.21299 W/Kg U.S & AU limit: 1.6 W/Kg
Max. SAR (rms, 10 g) [W/Kg]	0.266098 W/Kg	0.417621 W/Kg Europe limit: 2 W/Kg

V. CONCLUSION

An efficient dual band and dual pattern square patch antenna with strip line feed is proposed for on-body and off-body communication modes. The proposed antenna presents much improved gain with one truncated square radiating element than the previous works of the compact dual band and dual mode antennas. Simulated and measured performances of the antenna in free space were shown and the effects of presence a human around the antenna on the radiation characteristics were also investigated by modeling a human body. The antenna showed a horizontal pattern over the body surface at 5.4 GHz for the on-body mode with 7.2 dB gain and a directive radiation pattern at 2.468 GHz for the off-body mode with 6 dB gain at the presence of the human model. The results show that this antenna does not experience significant frequency detuning from the free space resonance at both frequency bands when simulated on the human body model due to shielding provided by the ground plane.

Simulations indicate that localized SAR values of 1 gr are 0.5 W/Kg for lower band and 1.21 W/Kg for the upper band being compatible with the basic restrictions for the general public.

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Seiran Khaledian received the B.S. degree in Electrical Engineering from Khaje Nasir University of Technology and M.S degree in Communication Engineering from Tarbiat Modares University, Tehran, Iran, respectively. She is currently a Ph.D. student at University of Illinois at Chicago (UIC). Her research interests include the design of antennas, Microwave and RF circuits.

Zahra Atlasbaf received the B.S. degree in Electrical Engineering from the University of Tehran, Iran, in 1993, and the and Ph.D. degrees in Electrical Engineering from the University of Tarbiat Modares, Tehran, Iran, in 1996 and 2002, respectively. She currently is an Associate Professor with the Faculty of Electrical and Computer Engineering, Tarbiat Modares University. Her research interests include numerical methods in electromagnetics, theory and applications of metamaterials, and microwave and antenna design.