Dual Band Slotted Patch Antenna for On/Off-body Communication

Morteza Nadi, Mohammad Hosein Fakheri, Ali Abdolali
Department of Electrical Engineering, Iran University of Science and Technology, Tehran, Iran,
m_nadi@elec.iust.ac.ir, mh_fakheri@elec.iust.ac.ir, Abdolali@iust.ac.ir
Corresponding author: Morteza Nadi

***Abstract-* Body Centric Wireless Communication (BCWC) has been topic of much research in recent years. In this manuscript, a novel low-cost microstrip patch antenna is designed for on-/off-body communication with a dual-band operation. The proposed structure exhibits a monopole-like radiation pattern at 2.45 GHz and a broadside radiation at 4.8 GHz, simultaneously. Lateral dimensions of 42 mm × 46 mm and a low profile foam substrate with thickness of 2.5 mm are considered for the dual-mode antenna presented. The proposed low-cost structure is fabricated and the stability of its performance under the human body effects is investigated through both simulation and measurement. The experimental results are in good agreement with the simulated ones.**

Index Terms- Body centric wireless communication (BCWC), on-/off-body communications, dual band patch antenna.

I. INTRODUCTION

The Body Centric Wireless Communication (BCWC) is an attractive topic in several areas of personal healthcare, this concept is about medical sensor systems which transmit biological signals such as temperature, pressure etc. [1]. Based on the position of transmitter/receiver antennas, there are on-body and off-body communication systems [2]. In order to link the on body antennas to each other, the radiation pattern should be end-fire, in such a way that the creeping waves could propagate on body surface, whereas a broadside radiation pattern is needed to communicate with an exterior device [3-7].

Some of the previous studies just deal with the on-body antennas to radiate over the body surface omnidirectionally. These papers attempt to make the antenna low-profile, highly efficient near the human body, easy to manufacture and be of compact size [2, 4, and 6]. However, in some medical applications, a dual-mode antenna with a simultaneous broadside and end-fire radiation pattern is required, [3] and [7-9]. For instance, in [3] a dual band antenna is proposed which operates at 1.9 GHz and 2.45 GHz for off-/on-body radiation. An acceptable efficiency and a routine gain in free space

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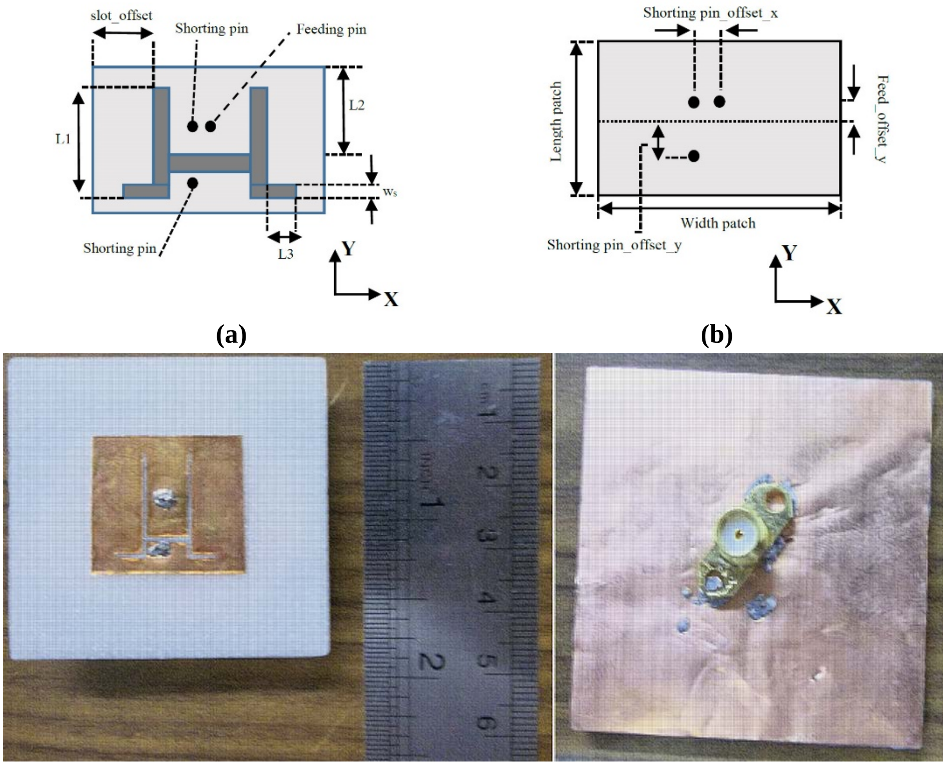


(c)

Fig. 1. (a) Top view and (b) bottom view of proposed antenna (c) fabricated antenna

scheme are achieved. A switchable radiation pattern in a dual mode antenna has been obtained in [7] at 2.45 GHz.

To achieve this goal, a switching signal is used to alter the antenna between two conditions which makes it complicated. But all the mentioned studies have relatively large antenna dimensions and are not suitable for wearable applications. To overcome this issue, a Hilbert curve fractal antenna is proposed at 2.45GHz ISM and 5.5GHz WLAN (wireless local area network) bands in [10]. The designed antenna has a compact lateral size and an acceptable directivity at broadside whereas its end-fire radiation main lobe is not directed along the body surface. Also, the presented antenna suffers from having a thick profile, which limits its functionality in some applications.

In this paper, a novel highly efficient microstrip patch antenna for on-/off-body communication is proposed. This antenna is designed and fabricated at low cost and presents a dual band operation. The proposed structure benefits from two shorting pins which provide a monopole-like radiation pattern at 2.45 GH ISM (Industrial, Scientific and Medical) band for on-body communication. A broadside radiation at 4.8 GHz (with no frequency interference) is used to transmit signals with the external devices. The proposed antenna is simulated by CST MICROWAVE STUDIO 2014 and the measurement results validate the simulation ones. In the following, the antenna design and its characteristics are illustrated in section II. Section III presents the results, and finally section IV concludes the paper.

Table I. The geometric parameters of the proposed antenna of Fig. 1

Components	**Unit(mm)**
slot_offset	4.75
feed_offset_y	1
Shorting pin _offset_x	1
Shorting pin _offset_y	7.4
Length patch	21
Width patch	23
L1	15.5
L2	13
L3	3
w_s	1
Length ground	42
Width ground	46

II. ANTENNA DESIGN AND CHARACTERISTICS

The proposed antenna, an antenna with a ground plane and a monopole disposed in the dielectric part is described in this section. To study the effect on the reflection coefficient and radiation pattern, the antenna must be designed with consideration of human body, this means that, tissue layers with different thickness and relative permittivity must be considered in the time of antenna design.

Fig. 1 (a) shows the schematic of the proposed dual band antenna. It has lateral dimensions of 42 mm × 46 mm and is composed of a low loss foam substrate with the thickness of 2.5 mm. The thickness of the metallic structure is 0.02 mm. The antenna is excited using a probe of diameter 1.2 mm. The substrate is topped with a slot in which two shorting pins connect the patch to the ground plane. Other geometric parameters of the antenna are given in Table I.

The slot is used to have a dual band operation for both on-body and off-body communication. The surface current distribution of the antenna at 2.45 GHz and 4.8 GHz for the on and off body mode is shown in Fig. 2 (a) and (b), respectively. From the current distribution it can be seen that for 2.45 GHz the current is mostly distributed on the feeding post and the adjacent shorting pins. Therefore, the antenna radiates with a null in the broadside while for 4.8 GHz the highest surface current distribution is found surrounding the slots as discussed also in [11]. Considering the whole patch, the dominant mode TM10 can be identified shifted to the right part of the patch, consequently generating broadside radiation pattern.

The two shorting pins are used to force null in the electric field between the patch and ground element. So, the shorting pins are used to match the input impedance of the antenna close to 50 Ω and achieve a monopole-like radiation pattern at the resonant frequency of 2.45 GHz.

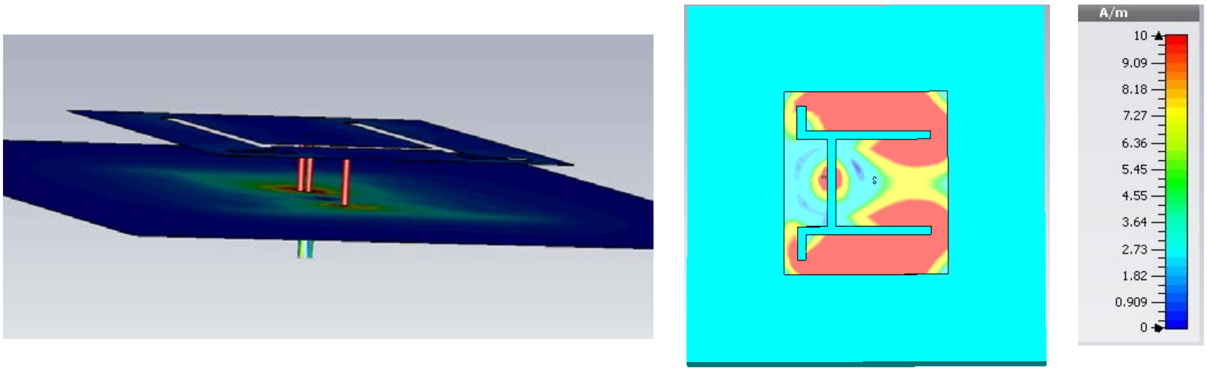


Fig. 2. Surface current distribution of the antenna in the (a) on body mode (b) off body mode

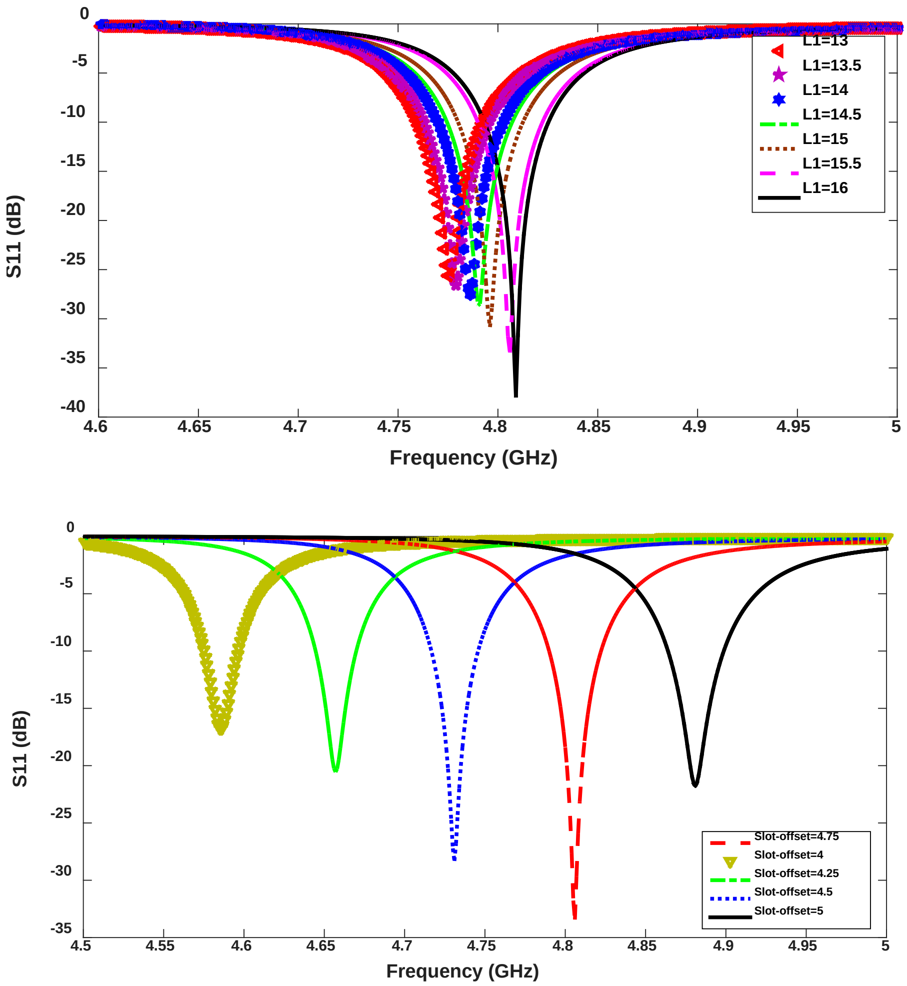


Fig. 3. Variation of resonance frequency depending on (a) stub length L1 and (b) slot offset

Also, the upper resonant frequency for off-body communications is determined by the employed slot size without affecting the impedance matching to excited mode (TM10). This is done by considering the current distribution computed by the full wave analysis, as is depicted in Fig. 3. It is shown that by adjusting the slot offset and slot length, the resonance frequency can be tuned. The proposed antenna with optimum dimensions has been fabricated and shown in Fig.1 (c).

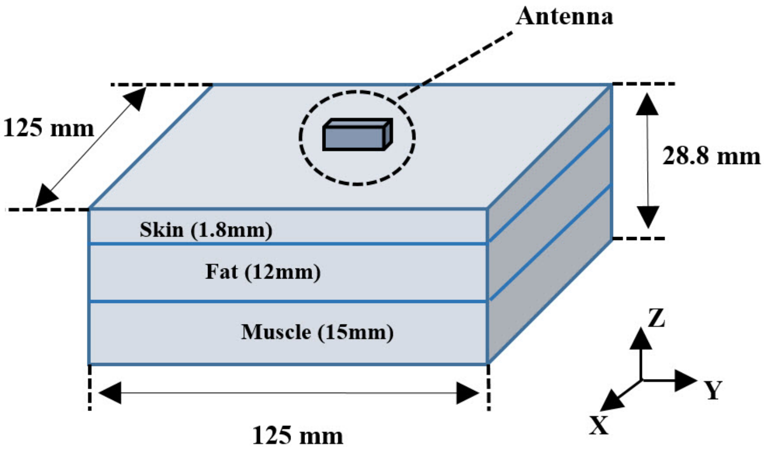


Fig. 4. Human phantom with its dimensions used for simulation

Table II. Electrical properties of human body tissues at frequency 2.4 and 4.8 GHz [12].

	2.4 GHz		4.8 GHz	
Tissue	ε_r	σ(S/m)	ε_r	σ(S/m)
Skin	38.06	1.44	35.93	2.90
Fat	5.28	0.10	5.04	0.22
Muscle	52.79	1.70	49.80	3.82

III. RESULTS AND ANALYSIS

Human body is not an ideal medium for radio frequency wave transmission. It consists of materials of different dielectric constants, characteristic impedances and thicknesses. Therefore, depending on the frequency of operation, the human body can lead to high losses caused by power absorption, central frequency shift, and radiation pattern destruction. The performance of the proposed antenna is investigated through the simulation. A simple configuration, as illustrated in Fig. 4, has been used to clarify the antenna operation under the near field human effects. A lossy dispersive phantom is chosen with 125 mm × 125 mm × 28.8 mm dimension to resemble the human tissue. The details of the electromagnetic properties of the employed phantom i.e skin layer (with thickness 1.8 mm), fat layer (with thickness 12 mm), and muscle layer (with thickness 15 mm) at 2.4 GH and 4.8 GHz are given in Table II. Due to the back feed the antenna is placed at 10 mm away from the body both in the simulations and measurmeant.

The reflection coefficient of the antenna is simulated and measured in free space and on-body situation at 2.4 and 4.8 GHz. As depicted in Fig. 5, the value of return loss is 21 dB at the lower frequency of 2.45 GHz and 26 dB at for the higher frequency band of 4.8 GHz in free space simulations, respectively. The measured 10 dB fractional bandwidth for 2.45 GHz and 4.8 GHz are 2.4% and 7.2%, respectively.

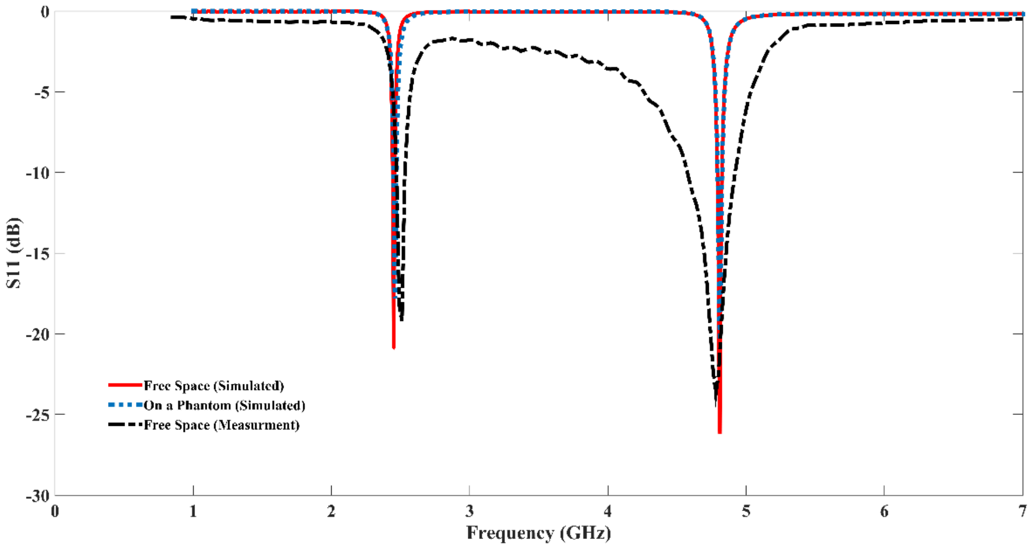


Fig. 5. Simulated and measured reflection coefficient of the proposed antenna in free space and on a phantom.

Table III. Comparison of simulated and measured antenna characteristics in free space and on a phantom.

	Simulated				Measured	
Parameter	Lower Band		Higher Band		Lower Band	Higher Band
	Free Space	On Body	Free Space	On Body	On Body	On Body
Resonant frequency f_c (GHz)	2.45	2.46	4.8	4.8	2.6	4.7
Return Loss (dB)	21	18	26.22	20.39	19	23
Gain (dBi)	1.42	1.29	8.93	8.13	1.1	7.8
Efficiency	93%	75%	99%	98%		

The radiation pattern of the fabricated antenna is measured at resonant of frequencies of 2.45 and 4.8 GHz, and compared with the simulation results in the free space and close to the phantom which are depicted in Fig. 6. In the x-y plan, the maximums simulated and measured gain is 1.42 dBi and 1.1 dBi, respectively at lower frequency band and in the x-z plane the maximum simulated and measured gain is 8.93 dBi and 7.8 dBi, respectively at higher band frequency in free space.

Fig. 6 (b) shows that there is a -8 dBi null normal to the patch surface, minimizing radiation in the off body direction and the maximum gain can be achieved in x-y plane at θ = 90° in which the radiation pattern has an omnidirectional behavior, similar to monopole radiation. Also the radiation patterns at 4.8 GHz illustrated in Figs. 6 (c) and 6 (d), show that it is directed towards off the body. Fig. 6 (c) shows that the maximum gain is -6 dBi, minimizing radiation in the on body direction. So, it has a good performance for communication with external devices. The results are summarized in Table III.

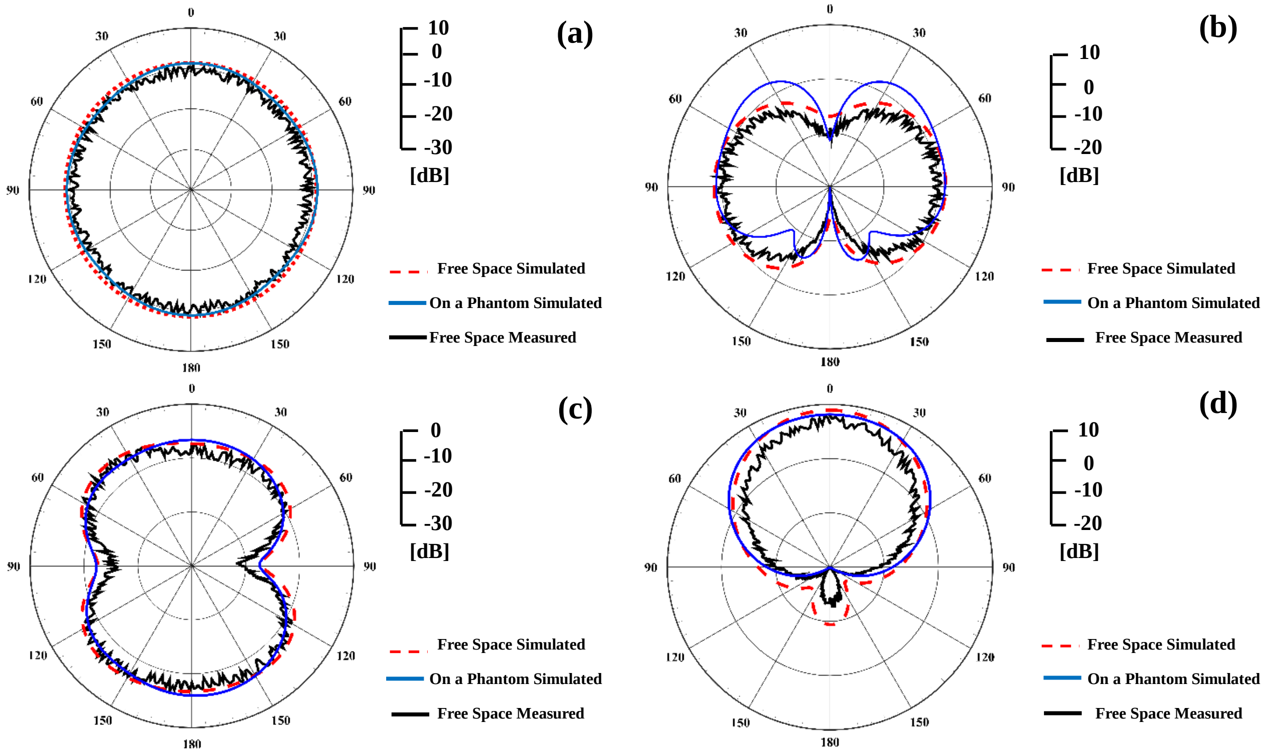
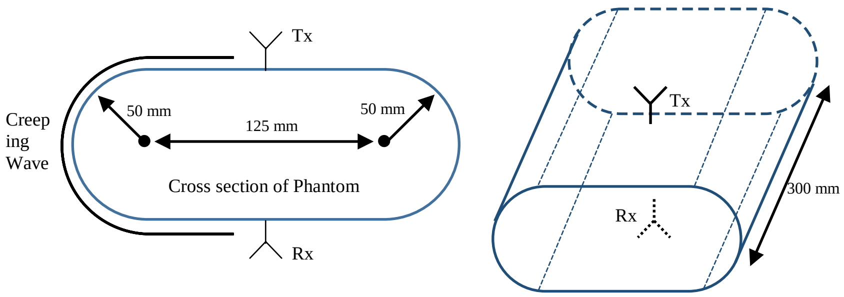


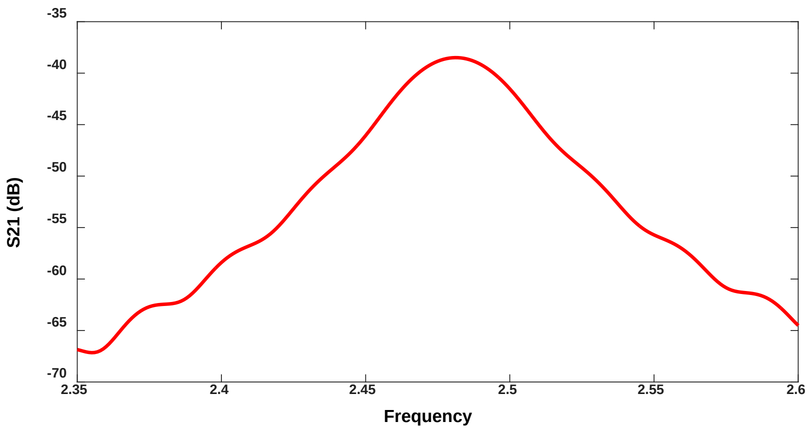
Fig. 6. The simulated radiation patterns in free space and on a phantom at 2.45 GHz (a) x-y plane (b) x-z plane.
4.8 GHz (c) x-y plane (d) x-z plane.

To examine the antenna coupling performance in the on-body operational mode, a worst case scenario is considered: an environment with signal propagation with non-line of sight propagation path, propagating waves traveling over a lossy curved surface (which results in significant diffraction and attenuation). Two antennas are mounted about 282 mm apart on both sides of the column phantom as depicted in Fig. 7 (a). The permittivity and conductivity of the phantom are chosen to represent muscle tissue at 2.4 GHz (ε_r = 52.79, σ = 1.7 S.m^{-1}). A phantom thickness of 100 mm is chosen to effectively eliminate signal penetration through the structure and hence isolate the creeping surface wave propagation mode.

The simulated path loss $(|S_{21}|)$ is shown in Fig. 7 (b). By means of creeping wave between two antennas the on-body communication could be done with a peak $|S_{21}|$ of -38.5 dB at 2.48 GHz.



(a)



(b)

Fig. 7. (a) $|S_{21}|$ simulation setup (b) $|S_{21}|$ path loss for on-body antennas

IV. Conclusion

A low-cost dual-band patch antenna was introduced in this manuscript for on/off body communication. Using a novel slot for the metallic patch and two shorting pins, a monopole-like radiation pattern at 2.45 GHz and a broadside radiation pattern at 4.8 GHz were obtained. The proposed antenna has lateral dimensions of 42 mm × 46 mm and a low profile foam substrate with the thickness of 2.5 mm. Also, the human body effects on the antenna have been studied and the stability of its performances has been discussed through both simulation and experimental results. Therefore, the proposed antenna is an appealing candidate for the on-/off-body communications.

References

[1] P. S. Hall and Y. Hao, "Antennas and propagation for body centric communications," 2006 *First European Conference on Antennas and Propagation*, Nice, 2006, pp. 1-7.

[2] G. O. Chia-Hsien Lin, K. Saito, M. Takahashi, and K. Ito, "A Compact Planar Inverted-F Antenna for 2.45 GHz On-Body Communications," *IEEE Transactions on Antennas and Propagation*, vol. 60, no. 9, pp. 4422-4426, Sept. 2012.

[3] M. Khan, M. Rahman, M. Talha, and T. Mithila, "Wearable Antenna for Power Efficient On-Body and Off-Body Communications," *Journal of Electromagnetic Analysis and Applications*, vol. 6, pp. 238-243, 2014.

[4] G.A. Conway and W.G. Scanlon, "Antennas for Over-Body-Surface Communication at 2.45 GHz," *IEEE Transactions on Antennas and Propagation*, vol. 57, no.4, pp.844-855, April 2009.

[5] B. Rabih, R. Mohamed, and V. Patrick, "Optimizing the monopolar wire-plate antenna for communications WBAN," in *13th Mediterranean Microwave Symposium*, pp.1-4, 2-5 Sept. 2013.

[6] A.R. Chandran, G. A. Conway, and W. G. Scanlon, "Compact slot-loaded patch antenna for 868 MHz wireless body area networks," *Loughborough Antennas and Propagation Conference*, LAPC 2008, pp.433-436, 17-18 March 2008.

[7] A.R. Chandran, G. A. Conway, and W. G. Scanlon, "Pattern Switching Compact Patch Antenna for On-body and Off-body Communications at 2.45 GH," *European Conference on Antennas and Propagation*, ECAP 2009.

[8] J-X. Niu, "Dual-band dual-mode patch antenna based on resonant-type metamaterial transmission line," *Electronics letters*, vol. 46, no. 4, pp. 266-268, 2010.

[9] P.J. Soh, G.A.E. Vandenbosch, S.L. Ooi, and M.R.N. Husna "Wearable dual-band Sierpinski fractal PIFA using conductive fabric," *Electronics Letters, vol.* 47, issue 6, March 2011.

[10] S. A. Saputro and J.-Y. Chung, "Hilbert curve fractal antenna for dual on- and off-body communication," *Progress In Electromagnetics Research Letters*, vol. 58, pp. 81-88, 2016.

[11] M. Darvish and H. R. Hassani. "Multiband Slot Loaded Uniplanar CPW-fed Monopole Antenna with Asymmetrical Arms," *Journal of Communication Engineering*, vol. 2, issue 1, pp. 43-53, winter-Spring 2013.

[12] [Online]. Available: http://niremf.ifac.cnr.it/tissprop/htmlclie/htmlclie.php