LINEARLY POLARIZED HMSIW U-SLOT ANTENNA FOR OFF-BODY COMMUNICATION

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Abstract: In this paper, a linearly polarized U-slot half-mode substrate integrated waveguide (HMSIW) antenna for off-body communication is presented. It is based on a combination of a U–shaped slot etched in the HMSIW top wall and two shorts placed in this slot. The antenna operates at 5.8 GHz. In order to verify performance of the proposed antenna placed in the proximity of a human body, a three-layer phantom of the human body – a chest model – is used. The antenna placed in proximity of the phantom of the human body achieves simulated impedance bandwidth of 2.02 % and the gain of 7.23 dBi.

Keywords: Half–mode substrate integrated waveguide, slot antenna, human body model

1. INTRODUCTION

In these days, a wearable antennas designed at Industrial, Scientific and Medical (ISM) bands (2.4, 5.8 and 61 GHz) attract a lot of attention. These antennas could be exploited for in-body, on-body or off-body communication [1]. Several antennas for off-body communication at 5.8 GHz were reported in [2]-[4]. The HMSIW technology [5] could be successfully exploited for the antenna design. In [2], a dual-band diamond-shape HMSIW textile antenna has been presented. The antenna is comprised by the two slots. The small one is for the tuning of the resonate frequency in the higher frequency band. Enlarging this small slot decreases the resonance frequency of the second-order mode and provides larger bandwidth in the higher frequency band. The measured impedance bandwidth of the antenna is 4.9 % and 5.1 % in 2.4 GHz and 5.8 GHz band, respectively. The measured gain of the antenna is 4.1 dBi and 5.8 dBi, in 2.4 GHz and 5.8 GHz band, respectively. In [3], a textile dual band-band patch antenna was presented. The antenna is comprised by an inner patch, operating at 5.8 GHz, surrounded by a parasitic rectangular ring element resonating at 2.45 GHz. In [3], the authors focus on crumbling of the antenna. It was demonstrated, that heavy crumbling has negative influences on operating frequency, minimum of the reflection coefficient and radiation patterns. A multilayered C-shape slot antenna has been introduced in [4]. The antenna is comprised by two patches, where the largest patch resonates at 2.45 GHz and the smaller patch resonates at 5.8 GHz. The antenna achieves impedance bandwidth of 3.88 % and 6.90 % and efficiency of 91 % and 95 % for 2.45 GHz and 5.8 GHz, respectively. Other antennas for off-body communication at 2.45 GHz and 60 GHz were reported in [6] and [7]. Antennas for on-body communication at 2.45 GHz, 5.8 GHz and 60 GHz were reported in [8]-[10].

In this paper, a half-mode substrate integrated waveguide U-slot antenna radiating linearly polarized wave designed for the 5.8 GHz ISM band for off-body communication is presented [11]. The proposed antenna is placed in proximity of human body model and its parameters are studied.

2. ANTENNA DESIGN

The antenna is depicted in Figure 1. The dielectric substrate of the length *L*, the width *W*, and the height *h* with the relative permittivity ε_r, and the loss tangent tan(δ) is on its both sides covered by metal sheets. The HMSIW is created by a row of vias and both its ends are shorted. It operates in the fundamental mode $TE_{0.5,0}$. The radiating U-slot is etched in the top wall of the HMSIW at the distance L_{viaX} from its short end in the x-direction, and from the row of vias at the distance L_{viaY} in the y-direction. The outer dimensions of the slot are L_{SLOT-X} and L_{SLOT-Y}. The width of the slot is W_{SLOT}. The slot is shorted by the strips of the width W_{SHORT1} and W_{SHORT1}. The antenna is equipped by a HMSIW to GCPW (grounded coplanar waveguide) transition.

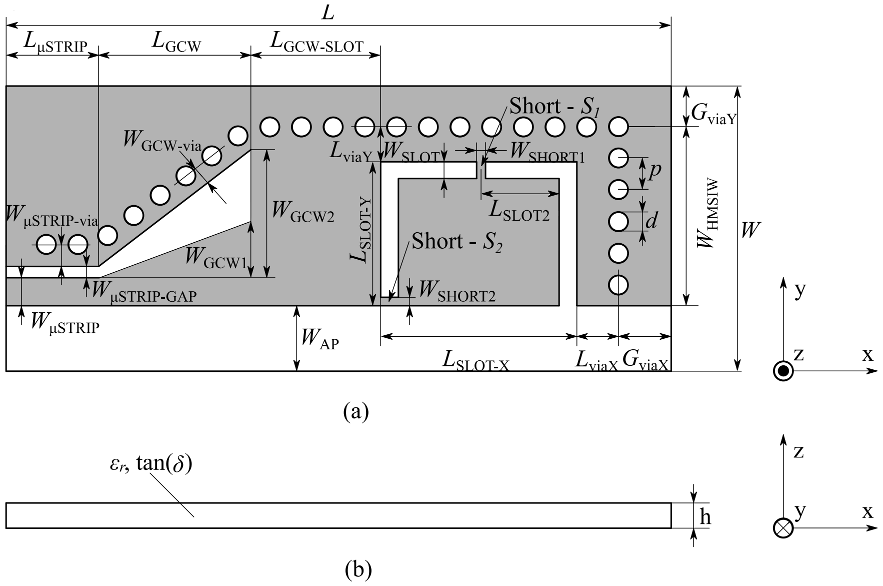


Figure 1: Top (a) and side (b) view of HMSIW U-shape slot antenna.

3. HUMAN BODY MODEL

The human body model used for simulations is composed from three layers – a skin, a fat, a muscle. From the viewpoint of the propagation of electromagnetic waves, all the described layers are lossy dielectrics of specific thicknesses and complex permittivity. The skin is a planar organ which plays the role of an external surface of organism and protects organism against surrounding environment. The thickness of the skin is between 0.4 mm and 4.0 mm. The fat is a reservoir of the energy and a heat insulator. The thickness of the fat layer is impossible to determine because everyone has unique anatomy. Muscles are tissues with elastic properties. Muscles are able to contract and relax. The layer of muscle has various thicknesses which depend on the type of muscle and the location on the body.

The configuration of the multilayer model (the phantom) of a chest is shown in Figure 2. The parameters of the phantom are summarized in Table 1 [12]. The phantom is a block of base 200 mm × 200 mm. The height of the phantom is given by the thicknesses of the layers representing the skin, the fat and the muscle. The distance *d* between the human body model and the antenna is 1 mm.

	ε_r	tan(δ)	σ (S/m)	thickness [mm]
Dry skin	35.114	0.32807	3.7170	2
Fat	4.955	0.18335	0.29313	10
Muscle	48.485	0.31715	4.9615	28

Table 1: Parameters of chest phantom.

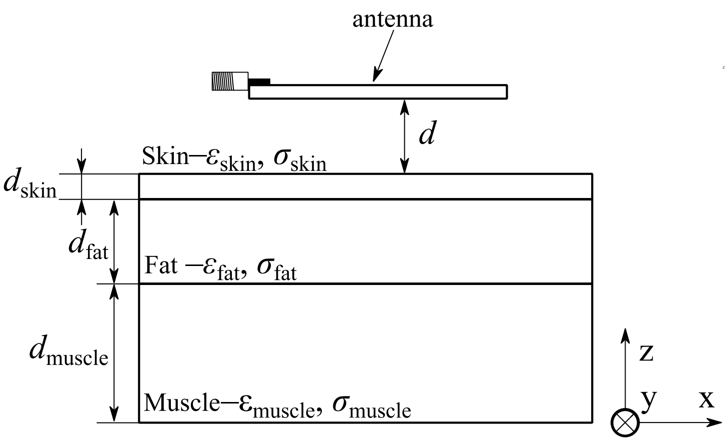


Figure 2: The chest phantom.

4. ANTENNA DESIGN AND SIMULATED RESULTS

The antenna was designed with the help of the time domain solver of CST Microwave Studio (CST MWS), where local optimization procedures Trust Region Framework and Nedler Mead Simplex Algorithm were used, for the operating frequency of 5.8 GHz on the dielectric substrate ARLON CuClad 217 with relative permittivity $\varepsilon_r = 2.17 \pm 0.02$, tangent loss tan(δ) = 0.0009, and height h = 1.524 mm. The resultant dimensions of the antenna are summarized in Table 1.

	[mm]		[mm]		[mm]
L	59.06	W	22.5	W_{AP}	3
$L_{\mu STRIP}$	8.76	$W_{\mu STRIP}$	2.34	W_{HMSIW}	16.98
L_{GCW}	8.77	$W_{\mu STRIP\text{-}GAP}$	1	G_{viaX}	9.57
$L_{GCW\text{-}SLOT}$	9.09	$W_{\mu STRIP\text{-}via}$	3.862	G_{viaY}	2.52
$L_{SLOT\text{-}X}$	20.95	W_{GCW1}	2.98	h	1.524
$L_{SLOT\text{-}Y}$	13.69	W_{GCW2}	9.99		
L_{SLOT2}	8.38	W_{SLOT}	1.687		
L_{viaX}	3.62	W_{SHORT1}	0.64		
L_{viaY}	3.29	W_{SHORT2}	0.64		

Table 2: Dimensions of designed antenna (Figure 1).

The distribution of the electric field in the substrate at the frequency 5.8 GHz is depicted in Figure 3. Thanks to the short S_1, the electric field at the slot is cutted into two halves and the linearly horizontally polarized wave in the far field is obtained.

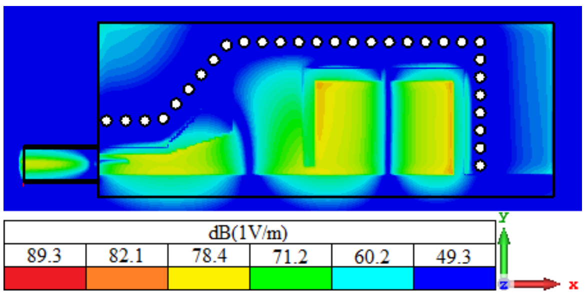


Figure 3: Distribution of electric filed intensity at 5.8 GHz in substrate (magnitude).

The simulated reflection coefficient of the antenna in the free-space and in the proximity of the chest phantom is depicted in Figure 4. The simulated reflection coefficient of the antenna achieves impedance bandwidth about 2.05 % and 2.02 % for the antenna placed in the free-space and in the proximity of human body, respectively. The minimum of the reflection coefficient of the antenna placed in proximity on human body is slightly shifted about 25 MHz to lower frequencies due to the influence of the phantom.

The normalized simulated radiation patterns in two orthogonal cutting planes in the free-space and in the proximity of the phantom at the frequency 5.8 GHz are depicted in Figure 5. It can be observed that the co-polarizations are in good agreement at the boresight direction in both cutting planes. The level of the cross-polarization at the boresight direction reaches higher level due to the influence of phantom in comparison to the cross-polarization of the antenna placed in the free-space. The simulated antenna peak gain is 6.49 dBi and 7.23 dBi for the antenna placed in the free-space and in the proximity of the phantom, respectively.

Simulated total efficiency at operating frequency f = 5.8 GHz of the antenna is 96 % and 82 % in the free-space and in proximity of the phantom of human body model, respectively.

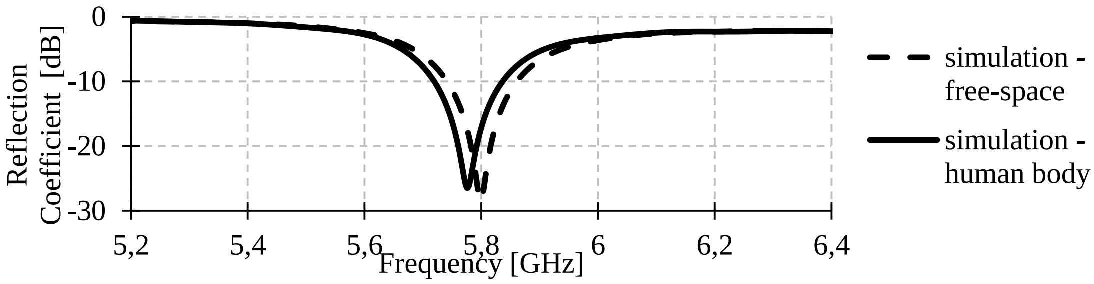
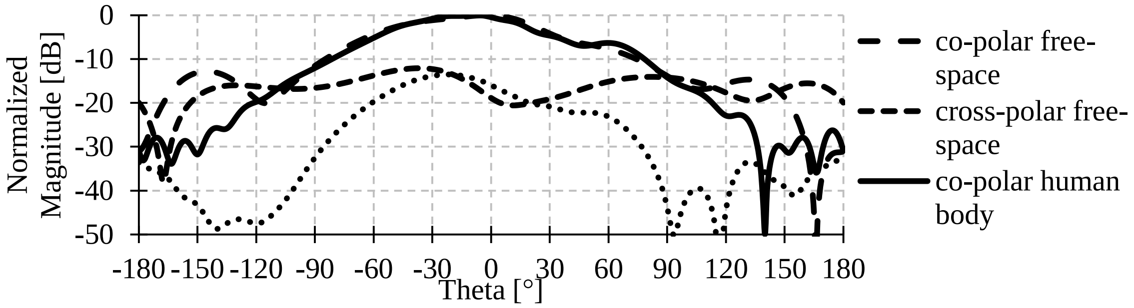
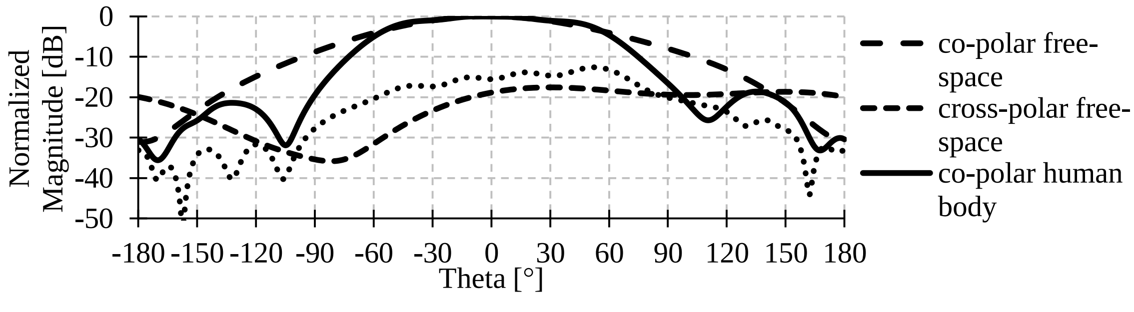


Figure 4: Simulated reflection coefficient.



(a)



(b)

Figure 5: Simulated radiation patterns of the antenna placed in free-space and in proximity of human body (phantom): (a) E-plane and (b) H-plane.

In comparison to antenna proposed in [2], the presented antenna has a higher gain, higher total efficiency and smaller size.

5. CONCLUSION

In this paper, a linearly polarized half-mode substrate integrated waveguide U-slot antenna operating at the frequency of 5.8 GHz in the proximity of a human body model (a chest phantom) has been proposed. The simulated results of the antenna placed in the proximity a human body achieves impedance bandwidth of 2.02 % and gain of 7.23 dBi. The antenna is suitable for off-body communication. The will be experimentally verified and the results will be presented at the conference.

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REFERENCES

[1] P. S. Hall, "Antennas challenges for body centric communications," *in Proc. Int. Workshop Antenna Technol., Small Antennas Metamater. Appl.*, Mar. 2007, pp. 41–44.

[2] S. Agneessens, and H. Rogier, "Compact Half Diamond Dual-Band Textile HMSIW On-Body Antenna," *IEEE Transactions on Antennas and Propagation*, 2014, vol. 62, no. 5, pp. 2374–2381.

[3] Q. Bai, and R. Langley, "Crumpled textile antennas," *Electron. Lett.*, vol. 45, pp. 436–438, 2009.

[4] A. R. Chandran, and W. G. Scanlon, "Dual-band low profile antennas for body-centric communications," *International Workshop on Antenna Technology (iWAT)*, pp. 1 – 4, 2010.

[5] W. Hong, B. Liu, Y. Wang, Q. Lai, H. Tang, X. X. Yin, YIN, Y. D. Dong, Y. Zhang, and K. Wu, "Half Mode Substrate Integrated Waveguide: A New Guided Wave Structure for Microwave and Millimeter Wave Application," *Joint 31st International Conference on Infrared Millimeter Waves and 14th International Conference on Terahertz Electronics*, 2006, pp. 219.

[6] P. Salonen, and L. Humre, "A novel fabric WLAN antenna for wearable applications," *in Proceedings of the IEEE Antennas and Propagation Society International Symposium*, Jun. 2003, vol. 2, pp. 700–703.

[7] L. Panzin, and Y. Leviatan, "A compact 60-GHz tapered slot antenna printed on LCP substrate for WPAN applications," *IEEE Antennas and Wireless Propagation Letters*, vol. 9, pp. 272–275, 2010.

[8] I. Kahn, L. Yu, Y. I. Nechayev, and P. S. Hall, "Space and pattern diversity for on-body communication channels in an indoor environment at 2.45GHz," *in Proceedings of The Second European Conference on Antenna and Propagation (EUCAP 2007)*, Nov. 2007, pp. 1-6.

[9] I. Khan, and P.S. Hall, "Multiple Antenna Reception at 5.8 and 10 GHz for Body-Centric Wireless Communication Channels," *IEEE Transactions on Antennas and Propagation*, Vol. 57. No. 1, January 2009.

[10] S. S. Hsu, K. C. Wei, C. Y. Hsu, and H. R. Chuang, "A 60-GHz millimeter-wave CPW-fed Yagi antenna fabricated by using 0.18-μm CMOS technology," *IEEE Electron Devices Letters*, vol. 29, no. 6, pp. 625–627, Jun. 2008.

[11] P. Hubka, and J. Lacik, "Linearly polarized HMSIW U-slot antenna, " *In Proceedings of Conference on Microwave Techniques (COMITE)*, Pardubice (Czech Republic)," April 2015, pp 1-3.

[12] C. Gabriel, "Calculation of the Dielectric Properties of Body Tissues in the frequency range 10 Hz – 100 GHz. IFAC. [online]. 1997 [cit. 2016-06-03]," Available at: http:// http://niremf.ifac.cnr.it/tissprop/htmlclie/htmlclie.php.