Design of a PIFA antenna integrated in the watchstrap for smart watch application in the 2.4 GHz Bluetooth band

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***Abstract*—This paper presents a Planar Inverted-F Antenna (PIFA) design for a smartwatch application, optimized to operate on the 2.4 GHz Bluetooth frequency band, on the proximity of the human forearm. The PIFA antenna is mounted on the watchstrap that is used as the antenna substrate. The antenna is fed in a singular way, since a coplanar wave-guide (CPW) transmission line is used to excite the antenna. The antenna is integrated in the watchstrap, curved over the phantom forearm and simulated along with the watchcase. A return loss of –20 dB is obtained at 2.4 GHz, and an efficiency of -5 dB, which represents a good efficiency taking into account the effect of the human forearm.**

***Keywords*—PIFA antenna, on-body application, smartwatch, Bluetooth.**

I. Introduction

In recent years, research into wearable antenna applications has gained a growing attention due to its potential applications in areas such as E-health systems, home care, security, and entertainment. The smart watch is a promising wearable device for mobile communication. Its rapid growing has attracted huge attentions from industries and public. However, due to the limited space within the wearable device, and its proximity to the human body, the design of an operating antenna at the Bluetooth band presents various challenges.

The antenna is to be lightweight, low cost, and maintenance-free, to meet the requirements of the application and the market. Considering the miniaturization and stable performance close to the human body, the planar inverted-F antenna (PIFA) can be considered a good candidate [1].

Typically, commercial smart watches integrate the antenna inside the watchcase, which makes the antenna highly influenced by the presence of the battery, the screen and the PCB circuitry. In this paper, we propose to integrate the antenna in the watchstrap, in order to increase the available space and decrease the effect of the watch components.

The structure proposed is a conventional PIFA optimized to operate at 2.4 GHz, conformed on the watchstrap, along with a CPW transmission line, that connects the antenna with the watchcase. The watchstrap is made of a flexible material, which will constitute the substrate on where the antenna is mounted.

The simulation take into account the curving effect of the antenna, the substrate used as the watchstrap, the watchcase, the feeding technic, and the human body effect, to have a more closer view to the behavior of the antenna in a real case user.

Finally, the antenna reflection coefficient, efficiency and the pattern radiation are evaluated with CST 2020, taking into account the whole watch structure in the presence of the human forearm phantom. A comparative table between the proposed antenna and other existing antenna will be presented as well.

II. Geometry of the Antenna

The proposed antenna is a Planar Inverted-F antenna, optimized to operate at 2.4 GHz band. The main advantage of using a PIFA is its reduced electric length and folded structure. Moreover, the impedance matching of the PIFA can be obtained by optimizing the space between feed and shorting pins. The main idea designing a PIFA is not to use any extra lumped components for matching network, and thus avoid any losses due to those elements [2]-[3].

Fig. 1 shows the geometry of the antenna. The length and width of the ground plane (bottom plate) are respectively **Lg** and **Wg**. The gap between the radiating plate and the ground plane is **H**. For the radiating plate (top plate), the length and width are respectively, **Lu** and **Wu**. Two shorting pins located at the antenna edge connect the upper radiating plate, with the bottom plate. Using two shorting pins instead of a shorting wall facilitate the connection of the feeding CPW transmission line, besides having an easy fabrication. The 50 Ω CPW line transmits the power from the watchcase to the antenna. Six shorting pins are placed on both sides of the CPW line to connect the ground plane of the CPW line with the antenna ground plane, as shown in Fig 1(a). The CPW has the dimensions **Wcpw**, and **g**. The CPW feeds the radiating plate at a distance of **fx** from the shorted edge of the antenna. The substrate used is rubber. The antenna element and CPW transmission line are made of cupper of a thickness of 0.35 µm.

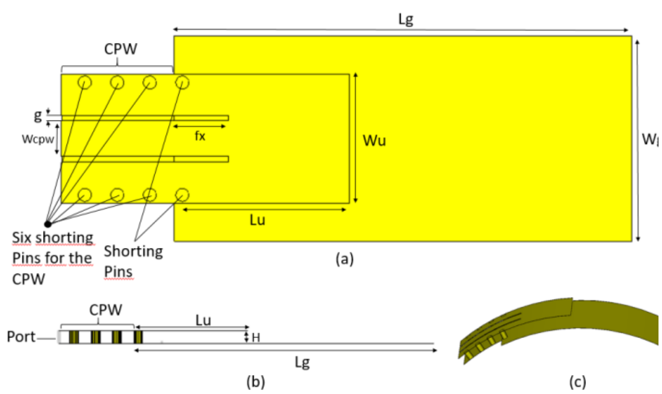

Fig. 1. Geometry of the proposed PIFA antenna fed by a CPW transmission line (a) Top view, (b) Side view and (c) General view of the curved antenna.

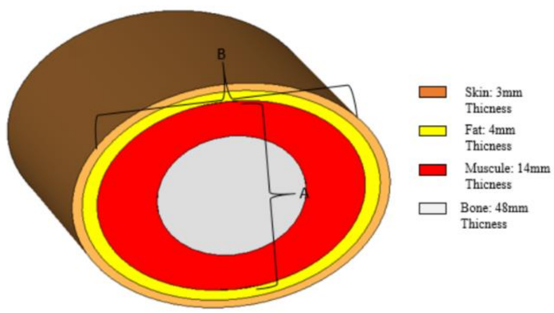

Fig. 2. Human forearm model dimensions.

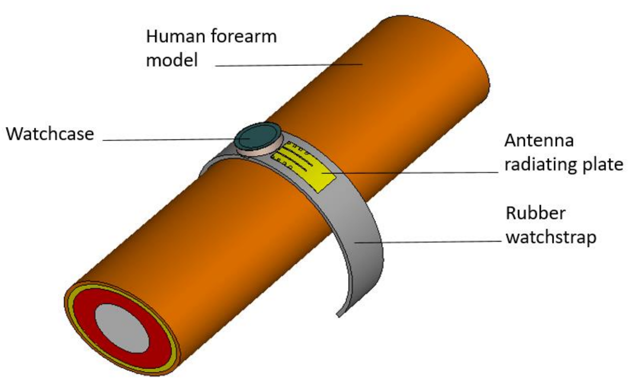

Fig. 3. Human forearm phantom, with the PIFA antenna mounted on the rubber substrate of the watch case.

TABLE I. DIMENSIONS OF THE ANTENNA AND CPW (UNITES IN MM)

Lg	**Wg**	**H**	**Lu**	**Wu**	**Wcpw**	**g**	**Fx**
45.3	18.97	1.84	16.2	11.97	3.3	0.5	4.85

TABLE II. CHARACTERIZATION OF BIOLOGICAL MATTER IN THE PROPOSED FOREARM MODEL

Matter	**Components**		
	Dielectric constant	***Loss tangent***	***A × B***
Skin	38.007	0.28262	45 × 64
Fat	5.2801	0.14524	42 × 60
Muscule	52.729	1.7388	38 × 54
Bone	18.548	0.80517	24 × 30

Fig.3 shows the antenna mounted on the watch strap, modelled with a flexible substrate. The watch strap has standard dimensions: Ls=200 mm, Ws=20 mm and thickness Hs=1.84 mm. The substrate, which is the watchstrap, is made of rubber, with a dielectric constant of 3 and loss tangent 0.001. The watchcase is modelled by three elements: an external case made of polycarbonate dielectric constant of 2.9 and a loss tangent of 0.1, a battery made of PEC and a top cover made of glass. Fig.2 present the geometry of the human forearm model used for this simulation, and table.2 the component. the human forearm phantom has four layers [4]: The skin, fat, muscle and bone.

III. RESULTS AND DISCUTION

In this section, the proposed antenna, mounted on the watchstrap, along with the watchcase and the human forearm phantom, is simulated and evaluated.

A. *Reflection coefficient*

The antenna's reflection coefficient (S_{11}) simulated from 1 GHz to 4 GHz is depicted in Fig. 3. The reflection coefficient is -20.6 dB at the 2.4 GHz. The matching bandwidth for a -10 dB reference goes from 2.38 GHz to 2.43 GHz.

B. *Radiation efficiency and total efficiency*

The total efficiency (green curve) and radiation efficiency (red curve) are shown in Fig. 4. As observed, at 2.4 GHz, the total efficiency is -5.17 dB, and the radiation efficiency is -5 dB.

C. *Radiation pattern*

The simulated radiation pattern at 2.4 GHz is shown in Fig.5. As can be observed the radiation is mainly focused in the broadside direction as desired, opposite to the forearm.

D. *Comparison of the proposed antenna with other existing antenna for the smart watch application*

Table.3 shows a comparison between the proposed antenna and three other existing antenna operating in the 2.4 GHz for smartwatch application.

The first antenna is a microstrip antenna 30x40x7 (mm^3), integrated in the watchcase. It present a 5% bandwidth and an efficiency of -5dB. Comparing with our antenna, we have a better efficiency and a relatively smaller dimension; moreover, the antenna we proposed is integrated in the watchstrap rather than the watchcase, which leaves more space in the watchcase and less interaction with the watchcase components [5].

The second antenna consist of a dipole of dimension 145x40 (mm^2), integrated in the watchstrap. It present a 31% bandwidth, and an efficiency of -8dB. The main advantage of our antenna is its relatively small dimension and its efficiency working at the proximity of the human body [6].

The third antenna is a compact uniplanar tri-band antenna. The antenna present a better behavior and cover a wider frequency band in free space compared to the antenna we proposed, but when tested in a user case, it deteriorate its performance due to the proximity of the human forearm [7].

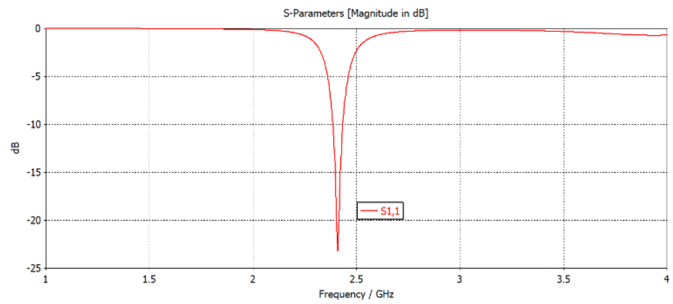

Fig. 4. Simulated reflection coeficient of the antenna described in Fig. 2.

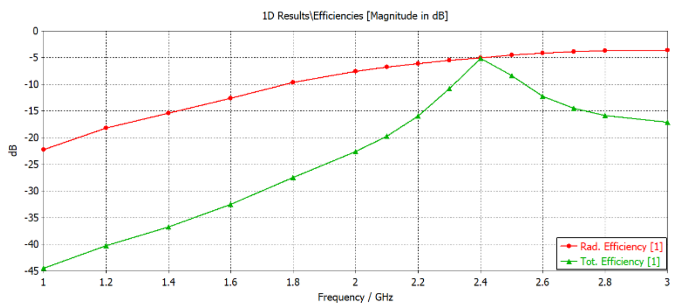

Fig. 5. Simulated total efficiency (green curve) and radiation efficiency (red curve) of the proposed antenna considering the human forearm and the complete watch.

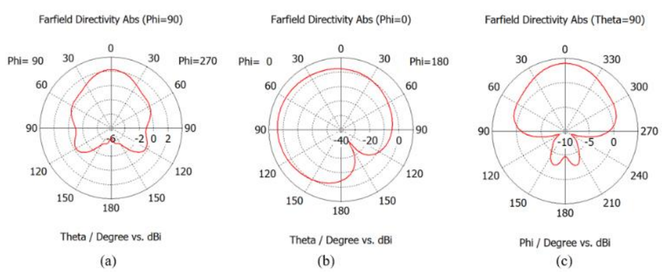

Fig. 6. Radiation pattern of the proposed antenna at 2.4 GHz: (a) Phi= 90º, (b) Phi=0º and (c) Theta=90º.

TABLE III. COMPARISON BETWEEN THE PROPOSED ANTENNA AND OTHER EXISTING ANTENNAS SPECIFICATION AT 2.4 GHZ, IN THE USER CASE.

References	**Parametric performance**			
	Size (mm)	***Bandwidth***	***Frequency band***	***Efficiency at 2.4GHz (in dB)***
[5]	Microstrip antenna 30×40×7 mm³	5%	2.39–2.51 GHz	-5.5
[6]	Planar antenna dipole 145×40mm²	28%	2.1–2.8 GHz	-8
[7]	Compact Uni-lateral triband antenna 38×38×0.8mm³	4%	2.4 GHz	(no efficiency provided for user case)
Proposed	PIFA antenna 45.3×18.97×1.84 mm³	3.3%	2.37–2.45 GHz	-5

IV. CONCLUSION

A compact PIFA antenna designed for smartwatch application, on the Bluetooth frequency band has been presented. The antenna is mounted on a rubber watchstrap to increase the available space inside the watch case. The effect of the human body has been taking into account and a realistic technique to feed the antenna using a CPW transmission line has been proposed. The simulated results confirm that the antenna is a good candidate for the smartwatch application. A prototype of the antenna will be fabricated to validate the simulated results and the Specific Absorption Rate (SAR) will be calculated.

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REFERENCES

[1] G. Gao, C. Yang, B. Hu, R. Zhang and S. Wang, "A Wide-Bandwidth Wearable All-Textile PIFA With Dual Resonance Modes for 5 GHz WLAN Applications," in IEEE Transactions on Antennas and Propagation, vol. 67, no. 6, pp. 4206-4211, June 2019, doi: 10.1109/TAP.2019.2905976.

[2] Wong Kin Lu. Planar antennas for wireless communication, John Wiley & Sons, New York, 2003.

[3] *David M. Pozar, Microwave Engineering. Hoboken, NJ :Wiley, 2012.*

[4] H. A. Damis, R. Mirzavand, H. Chung and P. Mousavi, "Flexible printed square loop antennas for wearable applications," *2016 17th International Symposium on Antenna Technology and Applied Electromagnetics (ANTEM)*, 2016, pp. 1-2, doi: 10.1109/ANTEM.2016.7550212.

[5] R S. Lin, Y. Lin, J. Peng and Y. Tuan, "Microstrip antennas for smart watch," *2016 IEEE 5th Asia-Pacific Conference on Antennas and Propagation (APCAP)*, 2016, pp. 109-110, doi: 10.1109/APCAP.2016.7843122.

[6] K. Zhao, Z. Ying and S. He, "Antenna designs of smart watch for cellular communications by using metal belt," *2015 9th European Conference on Antennas and Propagation (EuCAP)*, 2015, pp. 1-5.

[7] A. Shafqat, F. A. Tahir and H. M. Cheema, "A Compact Uniplanar Tri-band Antenna for Wearable Smart Watches," *2018 18th International Symposium on Antenna Technology and Applied Electromagnetics (ANTEM)*, 2018, pp. 1-3, doi: 10.1109/ANTEM.2018.8572966.