Flexible PIFA antenna design for wireless sensor networks in wearable healthcare applications

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Abstract- In this work a flexible wearable PIFA antenna has been designed in order to operate according to the Bluetooth v4 standard (2400-2483.5 MHz) in healthcare applications designed for wireless sensor networks. The substrate design includes the textile and human skin effects as well as the antenna flexible substrate (Pyralux). The return losses results show a strong detuning (36.8 %) of the operation frequency of the antenna due to the outfit and human skin presence, instead of air, and therefore a redesign of the antenna dimensions has been done (42.2% of miniaturization of the antenna layer). Some antenna performance changes are observed in terms of the radiation pattern and gain reduction due to the body proximity.

1. INTRODUCTION

Narrowband flexible printed circuit board (F-PCB) antennas play an important role in the design of wearable electronics for applications such as body area networks (BAN), wireless personal area networks (WPANs) and medical sensor networks [1-2]. Microstrip technology is typically used due to its low cost, planar conformability, small factor and ease manufacture. Concurrently, in recent years, the Wireless Sensor Networks (WSNs) [3] have emerged as a communication technology to address applications such as health care monitoring, environmental sensing, industrial monitoring, etc. The WSNs consist of small communication nodes containing a sensing part, a microcontroller, communication components and a battery. Wearable WSN healthcare applications require compact size and optimized radiation patterns [4] and, therefore, the antenna design play a fundamental role in customized designs. The planar inverted-F antenna (PIFA) is a common antenna for portable devices because of its excellent balance between low-profile, low-cost and performance [5]. Obviously, since the human body is composed of a large variety of tissues types (with different dielectric properties) the substrate design of the wearable antennas must include their effects, specifically to take into account the overall dielectric constant of the device and losses.

In this work an optimized F-PCB PIFA including the textile and human skin effects has been designed and simulated for wearable WSN healthcare applications operating under the Bluetooth v4 standard. The return loss impact, radiation pattern and antenna gain have been analysed and compared. Section 2 addresses the PIFA design and final geometry, whereas Section 3 is focused on the antenna performance. Finally in Section 4, the main conclusions are summarized.

2. F-PCB PIFA DESIGN AND GEOMETRY

The proposed PIFA has been designed by means of the commercial *Keysight Advanced Design Systems and Momentum* software. Fig. 1 shows the proposed substrate based on the implementation of the flexible PIFA in the commercial Pyralux (dielectric constant ε_{rP}=4.6, thickness h_P=50 µm). A textile layer (ε_{rT}=2, h_T=1 mm) has also been considered to emulate the outfit impact on the antenna. Finally, the human skin has been included as the lowest layer in the substrate (ε_{rS}=39, h_S =1.5 mm) [6]. The antenna has been designed to operate under the Bluetooth v4 standard (2400-2483.5 MHz). The original F-PCB meandered antenna has been designed in a single Pyralux dielectric and it is illustrated in Fig. 2(a). A rectangular inset fed at 2.45 GHz with 50 Ω input impedance has been considered for matching condition. The final geometry corresponds to the following parameters: Original Antenna: W_A = 0.6 mm ; L_{A1} = 16.6 mm ; S_{A1} = 1.4 mm ; Ground plane: W_G = 20.6 mm ; L_G = 14.6 mm ; Via: Φ=0.3 mm. The total dimensions of the PIFA correspond to 20.6x26.0 mm^2. Since the impact of the textile and skin effect increases the effective dielectric constant of the substrate, a reduction in the original antenna frequency operation is expected. Therefore, a redesign of the F-PCB is required in order to guarantee the specifications. The optimized PIFA including textile and human skin impact is depicted in Fig. 2(b), where most dimensions remain constant, except: L_{A2} = 9.6 mm ; S_{A2} = 0.4 mm, which implies a PIFA area reduction of 42.2%.

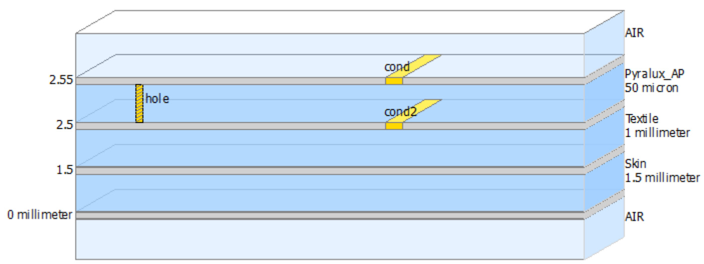

Fig. 1. Substrate definition including F-PCB, textile and skin effects.

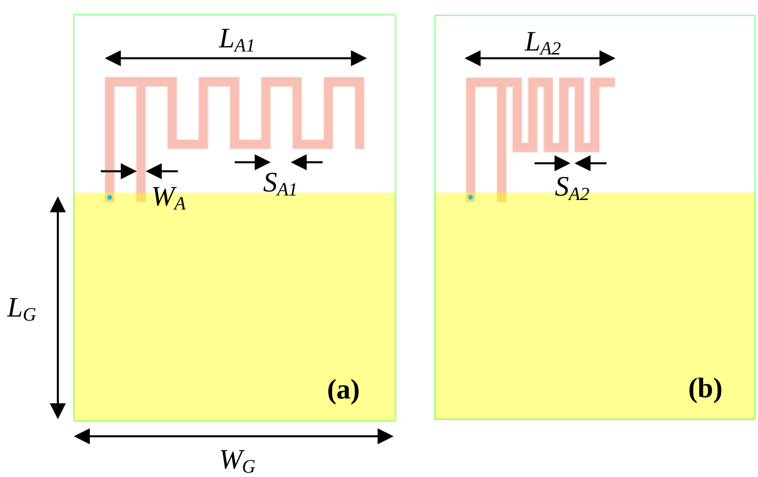

Fig. 2. Geometry of the (a) original and (b) redesigned meandered PIFA antenna.

3. F-PCB PIFA PERFORMANCE

The antenna return losses (S11) for several steps with regard to the optimization design process are depicted in Fig. 3. An original PIFA meandered antenna has been designed at the operation frequency in Pyralux substrate. A S11=-14.2 dB is obtained with a fractional bandwidth of BW=3.5% (at S11=-10 dB). The impact of the textile reduces the operation frequency of the original PIFA a 8.5%, with S11=-13.5 dB and the fractional bandwidth remains almost constant (BW=3.3%). Finally, the combination of textile and skin effect implies a frequency detuning of 36.8%, with S11=-22.7 dB and BW= 6.8%. Obviously, the introduction of the textile and skin layers increases the overall dielectric constant and, therefore, a reduction in the radiation frequency is expected. The redesigned antenna (substrate described in Fig. 1) performance correspond to 300 MHz bandwidth (BW=12.5%) and a maximum return losses of S11=-18dB. The original antenna designed with Pyralux and air substrate shows an excellent radiation pattern, as depicted in Fig. 4(a). The redesigned antenna shows a radiation pattern reduced (2 dB in the maximum radiation direction), as expected due to the body proximity impact and attenuation. It is also observed that the angle of maximum radiation is also modified from ϕ=141º to ϕ=177º. Moreover, the directivity of the wearable antenna is increased, whereas the gain is reduced from 1.5 dBi (original antenna) to -7 dBi.

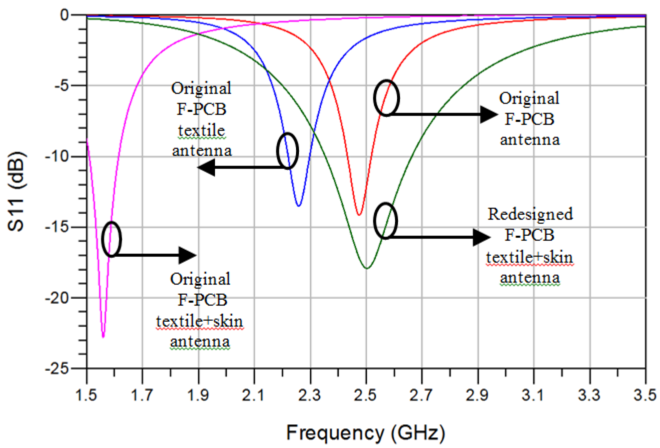

Fig. 3. Return loss of the original and redesigned PIFA antennas.

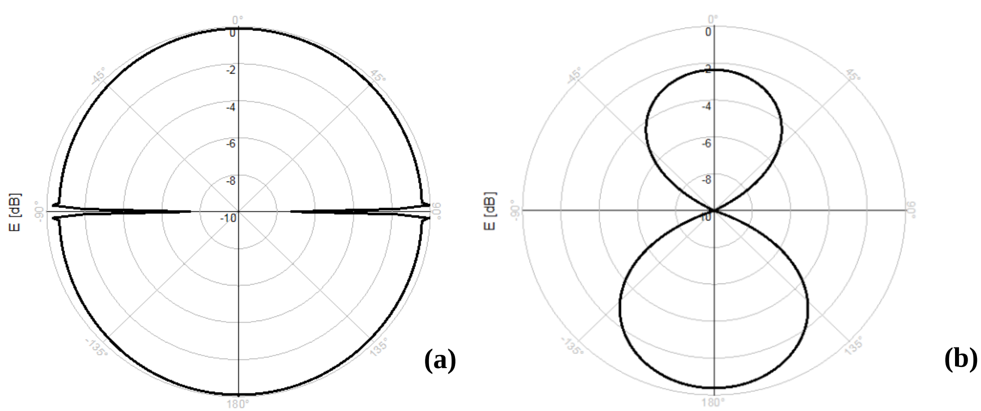

Fig. 4. Normalized radiation pattern for the maximum radiation level case at 2.45 GHz for the (a) original (ϕ=141º) and (b) redesigned meandered PIFA antenna (ϕ=177º).

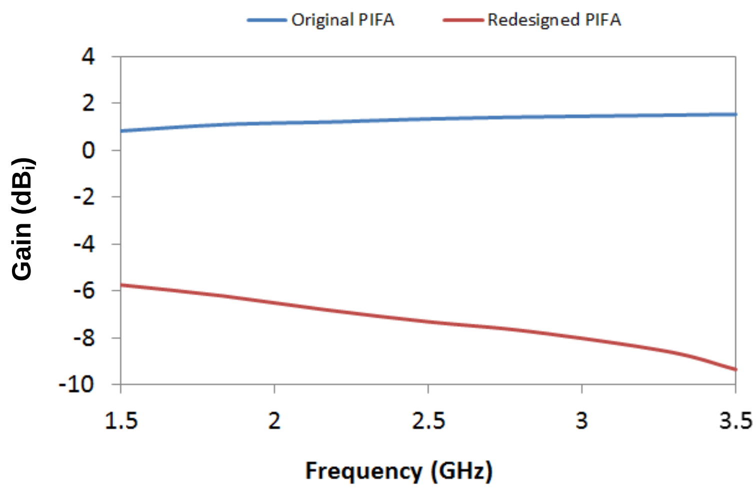

Fig. 5. Antenna gain for the (a) original and (b) redesigned meandered PIFA antenna.

4. CONCLUSIONS

A flexible wearable PIFA antenna developed for wireless sensor networks has been healthcare applications has been designed under Bluetooth v4 standard. Analytical results from method of moments simulation have been presented and discussed. The textile and human skin effects have been studied in terms of the antenna operation frequency, radiation pattern and gain. The human body proximity provokes certain degradation in the antenna performance (reduction of the efficiency and gain), as expected. Research is in progress in order to confirm experimentally the previous results, and to extend the analysis to other kind of F-PCB microstrip and coplanar antennas.

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