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A Wearable SIW Antenna for Lo-Ra Applications

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Abstract

A wearable textile antenna based on the fundamental mode of an eighth-mode substrate-integrated waveguide is presented, operating in the UHF frequency band, at 915 MHz. The proposed structure has a compact size, and presents a very good isolation from the human body. Compared to its SIW resonator counterpart, the proposed antenna size has been reduced by almost 87.5%, without degrading its performance. It has been simulated using CST Microwave Studio, with a broadside radiation pattern. All these features make this antenna very promising for Lo-Ra systems and applications, such as internet of things (IoT) applications.

1 Introduction

In the last years, driven by the recent progress in miniaturization of communicating devices and in design of smart networks, body area networks (BANs) and personal area networks (PANs) have become increasingly popular, owing to their very strong potential in applications relevant to military, personal healthcare, sport, space, entertainment, smart home, etc. In the next future, a person is likely to carry several devices and sensors, including sensors which constantly communicate with each other and the outside world. This functionality should be provided as unobtrusively and comfortable as possible, and a key technology able to achieve this goal is wearable electronics and antennas [1].

Typically, these smart applications require the transmission of very small data packet, therefore new technologies (such as LoRa [2]) have been recently proposed, enabling power efficient wireless communication over very long distances. These technologies are generally used to form LPWAN star networks, where devices communicate directly to a sink node, thus removing the need of constructing and maintaining a complex multi-hop network.

LoRa is a wireless standard for Low Power Wide Area Networks (LPWAN), consisting of a spread-spectrum modulation technique which allows transmitting data at extremely low data-rates (down to few bytes per second), and achieving extremely long ranges. LoRa applications operate in both 868 and 915 MHz ISM bands (preferred to the densely populated 2.4 GHz, with its high level of interference), with a typical bandwidth smaller than 5MHz, and this feature makes it appropriate for virtually any country. LoRa is particularly relevant in applications for wearable devices, where compact and low-profile antennas are required.

The main features that distinguish antennas for wearable devices from “classic” antennas, and which allow them to be efficiently integrated into a garment, are: mechanically robust, simple to manufacture, comfortable, compact, lightweight, flexible (but not deformable), unobtrusive (so that the user can move freely without obstacles), reliable in the vicinity of the human body, characterized by a minimal SAR (Specific Absorption Rate), low-cost. Moreover, wearable antennas must be able to operate in very different environments (wetness, cold, heat, and so on), and robust enough with respect to bending and flexing. All these requirements call for a suitable integration of these antenna elements within everyday clothing [3-6].

Recently, several antennas based on substrate integrate waveguides (SIWs) have been proposed [7-9], since they are particularly adequate components for wearable applications, because of their low profile, planar structure, and relatively high isolation with good radiation characteristics. Furthermore, SIW structures can be easily miniaturized by exploiting the symmetry of the field distributions of their resonant modes.

In this work, a wearable textile antenna based on eight-mode substrate integrated waveguide (EMSIW) technology for Low Power Wide Area Network (Lo-Ra) Applications is presented. The antenna is very compact and comfortable for the wearer, and requires minimal manufacturing complexity, and a very low production cost. The proposed antenna operates in the lower part of UHF frequency band, with a central frequency of 915 MHz, as requested by the Lo-Ra applications. An adequate antenna topology with an optimized cavity ground plane is adopted to mitigate the deterioration of the antenna performance, due to both the EMSIW configuration, and the body coupling effects. The results on the designed antenna show a very good isolation from the human body, and a significant robustness with respect to human body proximity, making the proposed SIW antenna very promising for Lo-Ra systems and applications, such as internet of things (IoT) applications. Numerical simulations have been performed using CST Microwave Studio.

2 Antenna Design and Results

The proposed miniaturized SIW textile wearable antenna is designed for Lo-Ra Applications in the UHF band, at the central frequency of 915 MHz, covering the widest of the two frequency bands used by LoRa (which uses the band 863-870 MHz in Europe, and the band 902-928 MHz in USA). A common cotton fabric was selected as dielectric substrate for the SIW antenna, with a dielectric constant equal to 1.6, and a loss tangent tanδ= 0.04, which is therefore a highly dissipative material. The metallic conductors have been implemented using copper. Due to the high dielectric tangent of the cotton, a relatively thick substrate has been selected to get acceptable antenna gain and efficiency. The thickness of the substrate was chosen equal to 5 mm. Thinner substrates can be used, at the cost of a reduced antenna radiation efficiency, and of a narrower impedance bandwidth.

Starting from a SIW cylindrical resonant cavity, operating in the TM010 mode at 915 MHz, we exploited the magnetic field symmetry of this TM010 mode to reduce the size of the cavity to obtain the eighth-mode SIW resonator (EMSIW) of Figure 1.

An appropriate ground plane and substrate extension must be kept in proximity of each virtual magnetic wall to achieve a better antenna behavior. Therefore, a suitable extension has been chosen all around the final cavity of the EMSIW, both in diagonal, vertical, and horizontal directions (see the parameters LG1, LV1, LV3 and LD of Fig.1). The slot, cut out of the top patch, allows to lengthen the current path, thereby further reducing the antenna size. Its main function is antenna miniaturization, since a larger slot size will reduce the operating frequency, which can be further modulated by varying the slot offset. The coaxial probe position is optimized to easily match the antenna to the input impedance of 50 Ω.

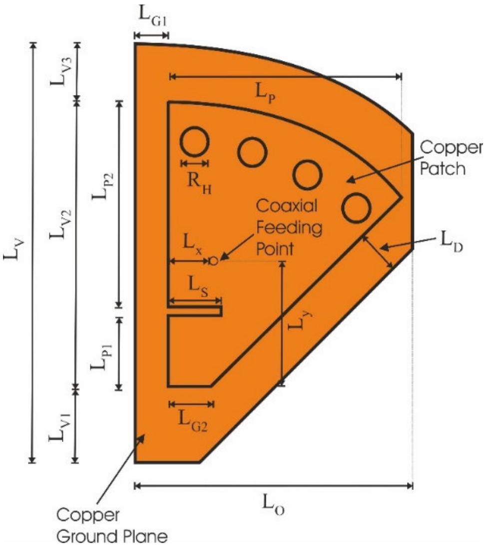

Figure 1. Layout of the designed SIW antenna. L_O=85.4mm, L_V=126.9mm, L_{V1}=19.2mm, L_{V2}=87.7mm, L_{V3}=20mm, L_P=72.33mm, L_{P1}=37.8mm, L_{P2}=47.17mm, L_{G1}=10mm, L_{G2}=14.59mm, L_D=10mm, L_S=24.48mm, L_x=5.78mm, L_y=44.22mm, R_H=9.6mm.

In wearable antennas, the antenna electromagnetic performance is strongly influenced by the proximity of the human body, acting as a lossy, non-homogeneous material. Therefore, a very important requirement for a wearable antenna is its robustness. Since the distance between body and antenna randomly changes during antenna operation, the antenna specifications should be satisfied both for deployment in free space and on the human body. A numerical phantom has been added to the simulation scenario (Fig. 2), in order to analyze the body-antenna coupling, and to verify that the antenna performance is still acceptable in close proximity to the human body. We have chosen a three-layer human body model [10, 11], with dimensions 400x400x200 mm, whose dielectric parameters are reported in Fig.2. Since the antenna will be integrated into clothes, we decided to use a large dielectric substrate for the SIW antenna (being 400x400x5 mm), which equals the size of the body phantom, as indicated in Fig.3. This choice will result in a larger value of the dissipation and losses, with lower values for the efficiency and gain of the SIW antenna, but will provide more realistic simulated results.

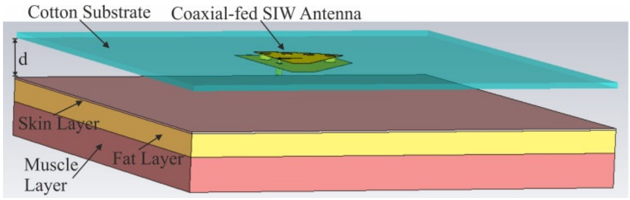

Figure 2. Designed antenna on the three-layers phantom model used to perform the numerical investigation of the antenna robustness to the body proximity. The size of the dielectric layers and of the antenna substrate is equal to 400x400 mm in the horizontal plane, while the thickness of the layers is 5 mm for the cotton substrate, and 1.5 mm for the skin (ε_r=41.34, σ=0.85 S/m @915MHz), 20 mm for the fat (ε_r=5.46, σ=0.05 S/m @915MHz), and 30 mm for the muscle layer (ε_r=55, σ=0.93 S/m @915MHz), respectively.

In Fig. 3, the distribution of the electric and magnetic energy density within the antenna cavity at 915 MHz is shown when the antenna radiates in free space, while Fig.4 shows the same energy distribution when the antenna is attached to the body phantom.

In Fig. 5, the frequency response of the designed antenna is shown for the antenna both operating in free-space and attached to the human body, referred to an input impedance of 50 Ω, with a -10 dB bandwidth equal to 34 MHz, from 900 to 934 MHz (4%). Fig.6 reports the input impedance of the antenna in free space and adherent to the body phantom, and finally Fig.7 shows the radiated fields in the E-Plane and H-Plane, which are broadside for both cases. The results in Figs. 3-7 show a very good isolation of the designed antenna with respect to the human body, with a behavior very close to the free-space case.

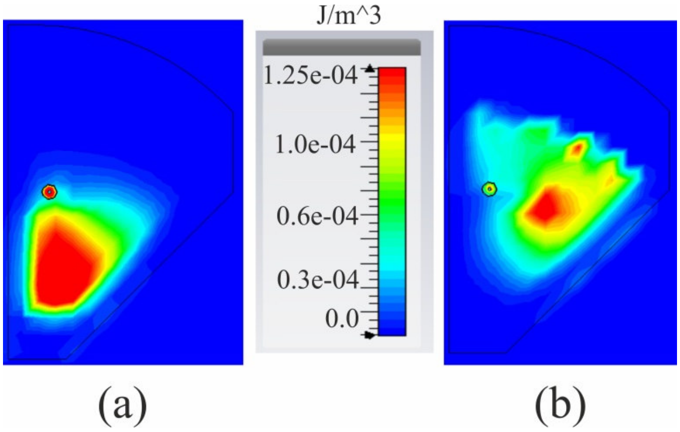

Figure 3. a) Electric energy density distribution within the antenna substrate for the antenna in free space. b) Magnetic energy density distribution within the antenna substrate for the antenna in free space.

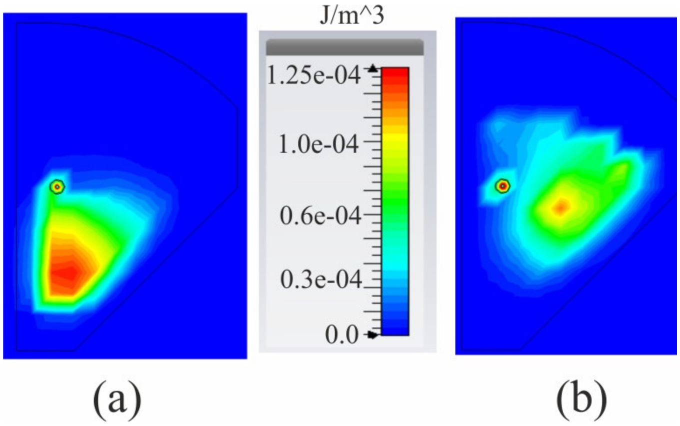

Figure 4. a) Electric energy density distribution within the antenna substrate for the antenna attached to the body model. b) Magnetic energy density distribution within the antenna substrate for the antenna attached to the body model.

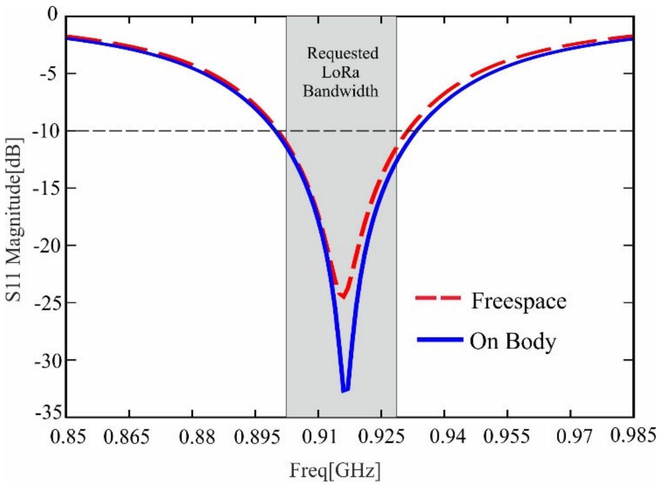

Figure 5. Frequency response of the designed SIW antenna fed by a coaxial cable shown in Figure 1.

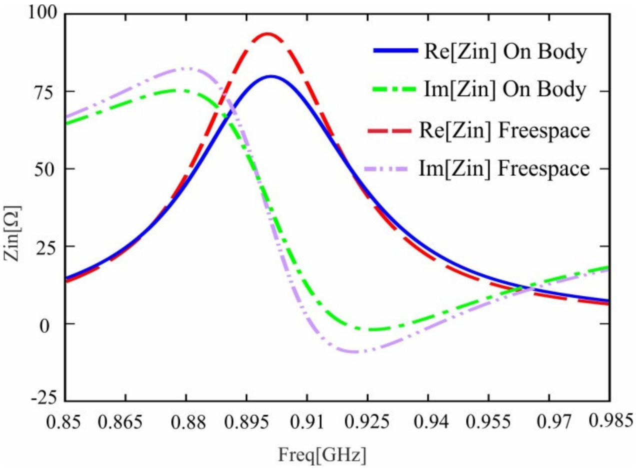

Figure 6. Input impedance of the designed SIW antenna.

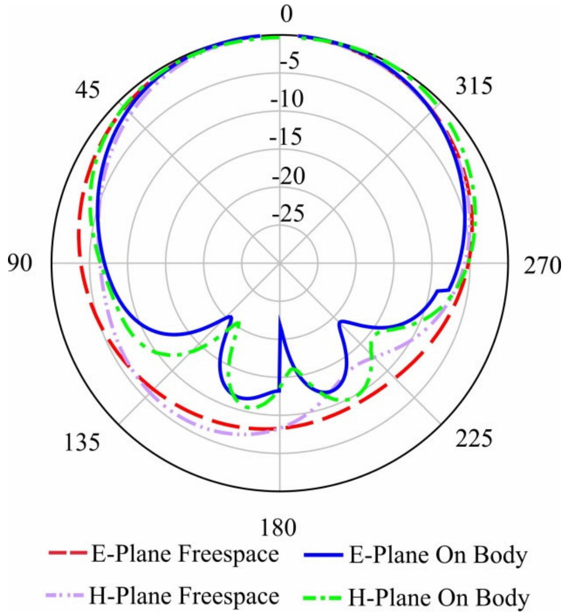

Figure 7. Simulated Far field plots for the designed SIW antenna at 915 MHz.

Antenna performance and robustness with respect to the human body proximity are both strongly influenced by the ground plane extension (see Fig.1) [10-13]. In our case, we tried to minimize this extension, aiming for a good compromise between antenna size and performance, selecting a 10 mm enlargement toward the horizontal (LG1) and diagonal (LD) directions and a 30 mm enlargement toward the vertical direction (LV1 and LV3). In fact, enlarging the ground plane increases the antenna dimensions, resulting in less comfortable antennas, but a too small ground plane (or, even worse, a ground plane with no enlargement) may lead to unacceptably high antenna coupling to the human body, with antenna detuning, reduced radiation efficiency, and increased body absorption (SAR level).

The antenna robustness is confirmed by the results shown in Fig. 8, where the simulated frequency response of the designed SIW antenna is shown for different distances d from the human phantom. The S11 curves are very similar while varying d (Fig.2), and the resonance frequency always remains at 915 MHz, while the -10dB bandwidth maintains substantially the same (with only a negligible decrease for increasing distances): for d=50mm it is 32.5 MHz, instead of the 34 MHz when the antenna is adherent to the body phantom.

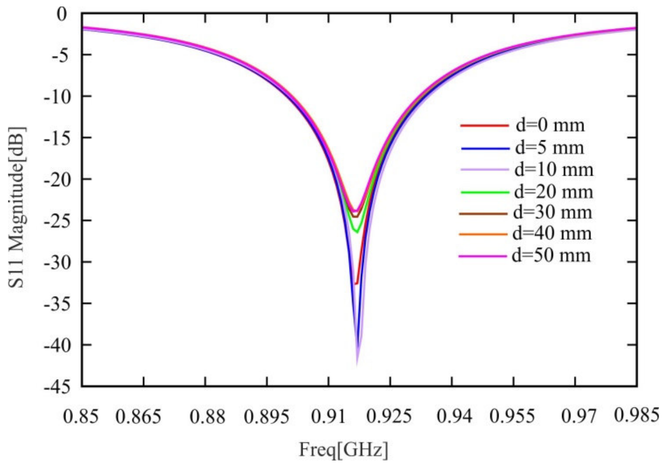

Figure 8. Frequency response of the designed antenna shown in Figure 2 for different distances from the body phantom

In Table I, the Directivity, Gain and efficiency of the SIW antenna are reported at 915 MHz, in the broadside direction, for different values of d. The efficiency is only around 20% due to the high dissipation of both (large) dielectric substrate and human body, but the Gain is still satisfactory, considering also the antenna size and its operating frequency.

Table I

Directivity, Gain and Efficiency of the SIW antenna for different distances from the human phantom at 915 MHz.

d [mm]	Dir [dB]	Gain [dB]	Eta
0	4.72	-2.36	20%
10	5.84	-1.56	18%
20	5.43	-2.50	16%
30	5.34	-2.51	16%
40	5.50	-2.00	18%
50	5.87	-1.30	19%

3 Conclusions

An eight-mode substrate integrated waveguide (EMSIW) wearable textile antenna has been designed in the UHF frequency band for Lo-Ra Applications. It results very compact and comfortable for the wearer, and can be realized with a very low cost procedure, since it requires minimal patterning and embroidery. Antenna robustness both with respect to the coupling with the human body and to flexibility has been successfully tested, making the proposed SIW antenna very promising for Lo-Ra systems and applications, such as internet of things (IoT) applications.

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