2nd URSI AT-RASC, Gran Canaria, 28 May – 1 June 2018

A Quarter Mode SIW Antenna for Short Range Wireless Communications

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Abstract

A wearable textile antenna based on the fundamental mode of a quarter-mode substrate-integrated waveguide is presented for Short Range Wireless Applications. The antenna operates in the UHF frequency band, at 868 MHz, has a compact size, and requires minimal manufacturing complexity and a very low production cost. Moreover, it presents a very good isolation from the human body, and a significant robustness with respect to deformation. If compared with its SIW resonator counterpart, the proposed antenna size has been reduced of 75%, without degrading its performance. The proposed structure has been simulated using CST Microwave Studio, and its gain is around 4 dBi, with a broadside radiation pattern. All these features make it very promising for Short Range Wireless Communications.

1. Introduction

Short-range wireless applications, such as Bluetooth, WiFi, ZigBee, and RFID, typically require small transmitted power (mW or less) and operate in indoor environment, with a range of a couple of meters, and a limited bandwidth. Antenna size is a very important task to consider for the designer, and the challenge relies on making the antenna as small as possible to simplify its integration in modern wireless devices, without excessively degrading its electromagnetic performance. Antenna miniaturization for short-range wireless applications, can be achieved through two different approaches: geometry based miniaturization, and material based minaturization. Geometry-based miniaturization consists of designing antenna geometries capable to take the maximum profit of the available space, for example using space-filling geometries [1-2], while material-based miniaturization can be obtained using high dielectric materials (for example ceramics), which allow the required miniaturization [3]. Thanks to their miniaturization properties, space-filling based antennas can be designed as efficient, small, and multiband antennas, and several short-range antennas for wireless applications (such as wireless headsets, cellular handsets, Bluetooth USB, wearable electrionics, and serial Dongles) are already adopted in industry, showing that geometry plays an important role in the performance of a small antenna, in the same way of size and length.

Among the Short-range wireless applications, wearable electronics has gaining increasing interest due to the wide range of healthcare, security, sports, and military applications [4]. Antennas for wearable devices have to be mechanically robust, simple to manufacture, low-cost, and should have a minimal interaction with the human body, being at the same time as small as possible so as to be comfortable for the wearer. Moreover, wearable antennas must be able to operate in very different environments (humidity, wetness, heat, and so on) and have to be robust enough with respect to bending and flexibility. Such antennas are often based on conductive fabric [5-7], but recently also antennas based on substrate integrate waveguides (SIWs) have been implemented in textile materials, where the vertical vias forming the cavity are implemented through metallized eyelets [8], or embroidered conductive thread [9]. These SIW structures are particularly suitable components for wearable applications, because of their flexibility, and wideband/multiband [10-11] operation. Furthermore, SIW structures can be easily miniaturized by exploiting the symmetry of the field distributions of their resonant modes [11-12]. In this work an antenna based on quarter-mode substrate integrated waveguide (QMSIW) technology for short range applications in the UHF frequency band is presented. The proposed textile SIW antenna is very robust both with respect to the coupling with the human body and to flexibility, and can be realized with a very low cost procedure, since it requires minimal patterning and embroidery. Numerical simulations have been performed using CST Microwave Studio.

2. Antenna Design and Results

The proposed miniaturized SIW textile wearable antenna is designed for short range wireless communication in the UHF band, at the central frequency of 868 MHz (the typical frequency of Short Range Near Field UHF RFID Systems). A very common textile material has been selected as dielectric substrate for the SIW antenna, the cordura, which has a dielectric constant equal to 1.9, with a dielectric tangent tanδ= 0.0098. The thickness of the substrate is equal to 3 mm, but thin substrates can be chosen, which however will result in a consequent diminishing of the antenna radiation efficiency, and in a reduction of the impedance bandwidth.

The resulting antenna, shown in Fig.1, is very compact and can be easily adapted at several textile materials, commonly found in garments (which may be specific to the target application), and electrotextiles can be used to implement the conductive planes, thus obtaining a high versatility, and maximizing the wearability of the design.

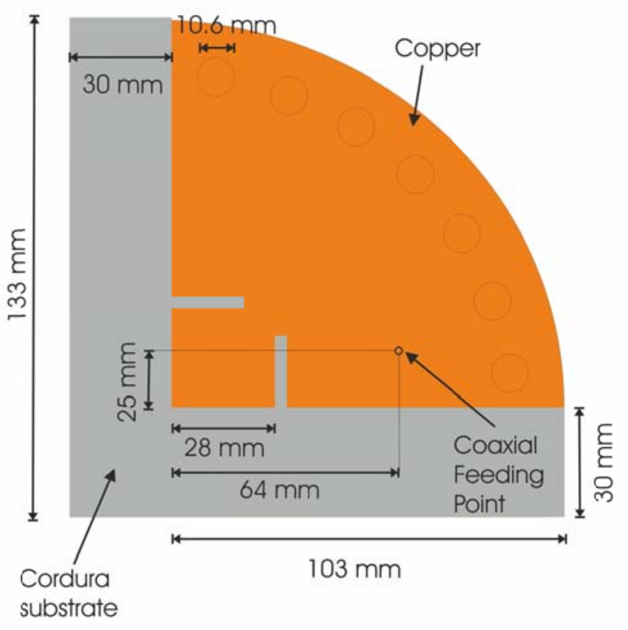

Figure 1. Layout of the designed SIW antenna.

First of all we designed a circular resonating cavity, which operates at its fundamental mode at the design frequency of 868 MHz, following the formulas for SIW given in [13]. Then, exploiting the symmetry of the magnetic field, the cavity size is reduced of 75%, and operates at quarter mode, radiating through the open side walls. It is worth noting that, in order to achieve a better antenna behavior, we keep a suitable ground plane extension both in vertical and horizontal directions (see Fig.1). The two slots, cut on the top patch, allow to lengthen the current path, and help to further reduce the antenna size. The offsets and size are the same for both slots, and their 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 structure is fed by a coaxial probe, whose position can be chosen to easily match the antenna to the input impedance of 50 OHM.

In Fig. 2 the distribution of the electric and magnetic energy density within the antenna cavity at the design frequency of 868 MHz is shown.

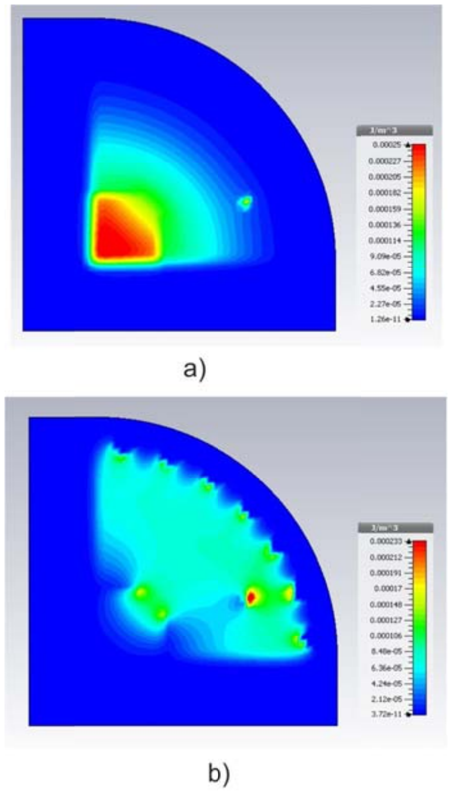

Figure 2. a) Electric energy density distribution within the antenna substrate for the antenna in free space. **b)** Magnetic energy density distribution within the antenna substrate for the antenna in free space.

In Fig. 3, the frequency response of the designed SIW antenna in free space is shown, referred to an input impedance of 50 OHM, with a -10 dB bandwidth equal to 15 MHz, from 860 to 875 MHz (2%). Fig.4 shows the input impedance of the antenna in free space, which has the typical behavior of a real resonator with losses. The SIW antenna is linearly polarized, and its radiation pattern in free space is shown in Fig. 5, with a broadside behavior. The maximum gain in the broadside direction is equal to 4 dBi, with a radiation efficiency of 70%.

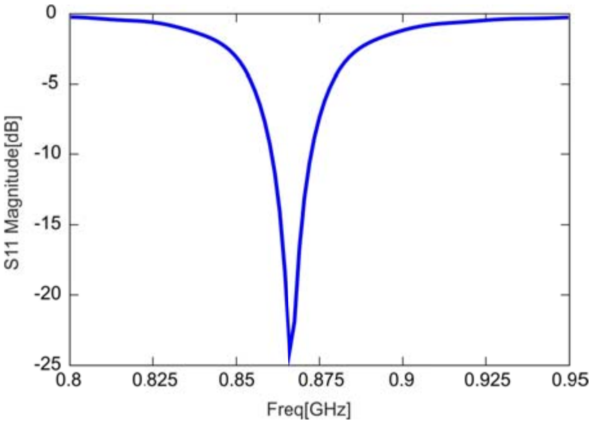

Figure 3. Frequency response of the designed SIW antenna in free space.

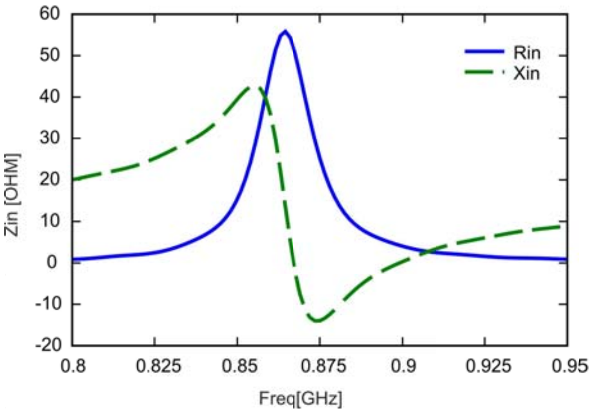

Figure 4. Input impedance of the designed SIW antenna in free space.

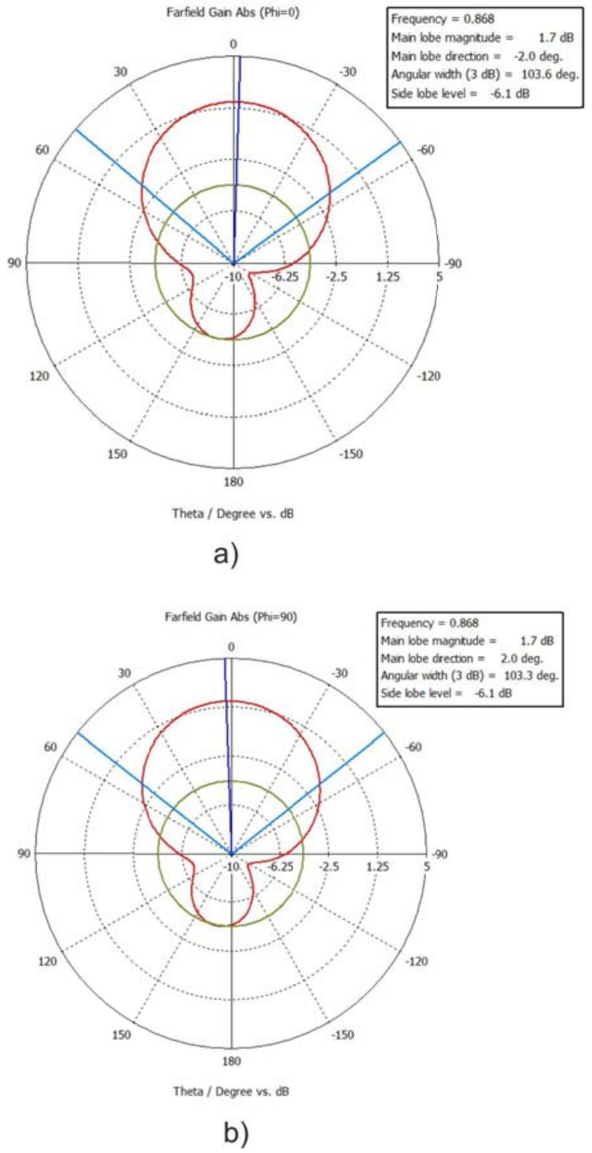

Figure 5. Far field plots for the antenna in free space: a) Phi=0° cut; b) Phi=90° cut.

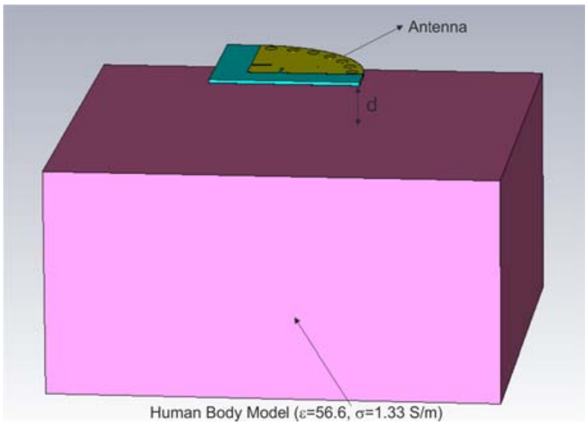

Figure 6. Designed antenna on the phantom model used to perform the numerical investigation of the antenna robustness to the body proximity (the electrical parameters in the figure are those used at 868 MHz).

The antenna electromagnetic performance is strongly influenced by the proximity with the human body, 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. 6), in order to analyze the body-antenna coupling, and to verify that the antenna performances are still acceptable when it works close to the human body. We have chosen a single-layer human body model, with a size 400x400x200 mm, whose dielectric parameters are reported in Fig.6. The robustness of the antenna with respect to the human body proximity can be improved by suitably choosing an adequate ground plane extension (see Fig.1). In our case, an extension of 30 mm is a good compromise between antenna size and performance. As a matter of fact, enlarging the ground plane increases the antenna dimensions, resulting in less confortable antennas, but a too small ground plane (or, even worse, a ground plane with no enlargement) leads to an antenna strongly influenced by the human body, with a degradation of both impedance matching, radiation efficiency, and resonance frequency, furthermore increasing the body absorption (SAR level).

In Fig. 7, the simulated frequency response of the designed SIW antenna for different distances from the human phantom is shown. These results confirm a very good robustness of the proposed antenna, since the curves are very similar while varying *d*, with a stable resonance frequency, with negligible frequency shift.

Finally, in order to test the robustness of the proposed structure with respect to flexibility, in Figure 8 the frequency response of the antenna is shown for different values of the curvature angle θ (from 15° to 45°). The frequency response is very stable for all the tested bendings, with a slight shift of the resonant frequency with respect to the planar case reported in Figure 3, which increases with the curvature angle. The far field pattern remains broadside for all the working frequencies, with only a slight deterioration due to the bending of the radiating structure. These results confirm very good robustness of the proposed antenna, which can be successfully used also as a conformal antenna, with no modification on the geometry of the non-conformal (i.e., planar) structure, whose dimensions are reported in Fig. 1.

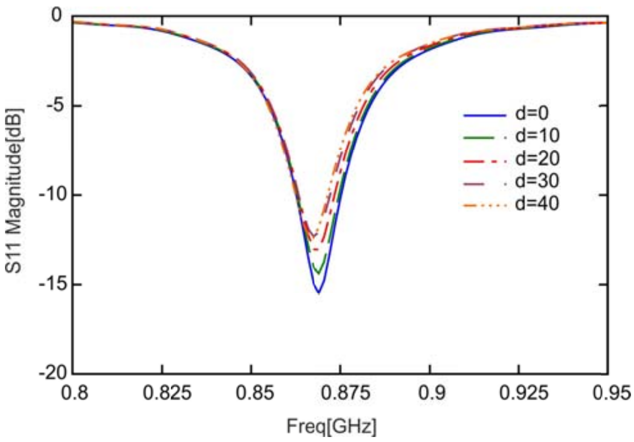

Figure 7. Frequency response of the designed SIW antenna for different distances from the human phantom.

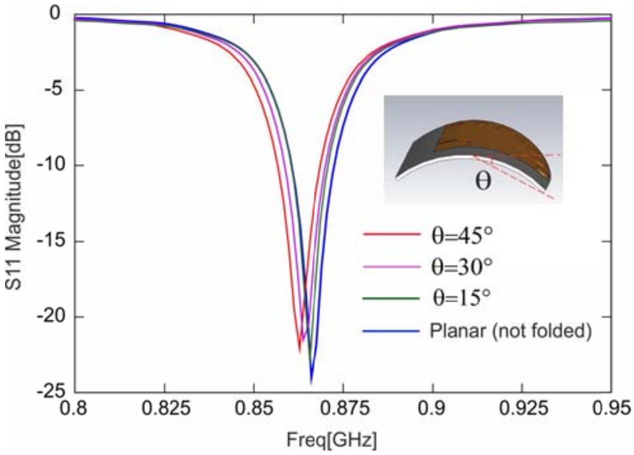

Figure 8. Frequency response of the designed antenna shown in Figure 1 for different curvature angles.

3. Conclusions

A Quarter-Mode Substrate Integrated Waveguide textile antenna is presented for Short Range Wireless Applications in the UHF frequency band. The designed antenna has a compact size, and requires minimal manufacturing complexity and a very low production cost, since only minimal patterning and embroidery should be used during antenna realization. In addition, it has very good free-space and on-body performance, and is very robust also with respect to deformation. This great versatility and robustness makes the antenna particularly suitable for Short Range Wireless Communications.

4. References

1. S. R. Best, “A comparison of the resonant properties of small space-filling fractal antennas,” *IEEE Antennas and Wireless Propagation Letters*, vol. 2, pp. 197–200, 2003.
2. S. R. Best and J. D. Morrow, “The effectiveness of space-filling fractal geometry in lowering resonant frequency,” *IEEE Antennas and Wireless Propagation Letters,* vol. 1, pp. 112–115, 2002.
3. K. L. Wong, Planar Antennas for Wireless Communications, Wiley-Interscience, New York, NY, USA, 2003.
4. N. H. M. Rais, P. Soh, F. Malek, S. Ahmad, N. B. M. Hashim, P. Hall, "A review of wearable antenna", Proc. LAPC, pp. 225-228, 2009-Nov.
5. I. Locher, M. Klemm, T. Kirstein, G. Troster, "Design and characterization of purely textile patch antennas", *IEEE Trans. Adv. Packag.*, vol. 29, no. 4, pp. 777-788, Nov. 2006.
6. L. Zhang, Z. Wang, D. Psychoudakis, J. Volakis, "E-fiber electronics for body-worn devices", Proc. 6th EuCAP, pp. 760-761, 2012-Mar.
7. T. Kaufmann, I.-M. Fumeaux, C. Fumeaux, "Comparison of fabric and embroidered dipole antennas", Proc. 7th EuCAP, 2013-Apr.
8. R. Moro, S. Agneessens, H. Rogier, and M. Bozzi, “Wearable textile antenna in substrate integrated waveguide technology,” *Electron. Lett.,* vol. 48, no. 16, pp. 985–987, Aug. 2012.
9. T. Kaufmann and C. Fumeaux, “Wearable textile half-mode substrate-integrated cavity antenna using embroidered vias,” *IEEE Antennas Wireless Propag. Lett.*, vol. 12, pp. 805–808, 2013.
10. S. Lemey, F. Declercq, and H. Rogier, “Dual-Band substrate integrated waveguide textile antenna with integrated solar harvester,” *IEEE Antennas Wireless Propag. Lett.*, vol. 13, pp. 269–272, 2014.
11. S. Agneessens and H. Rogier, “Compact half diamond dual-band textile HMSIW on-body antenna,” *IEEE Trans. Antennas Propag.*, vol. 62, no. 5, pp. 2374–2381, May 2014.
12. C. Jin, R. Li, A. Alphones, and X. Bao, “Quarter-mode substrate integrated waveguide and its application to antennas design,” *IEEE Trans. Antennas Propag.*, vol. 61, no. 6, pp. 2921–2928, Jun. 2013.
13. M. Bozzi, A. Georgiadis, and K. Wu, “Review of substrate-integrated waveguide circuits and antennas,” *Microw., Antennas Propag.*, vol. 5, no. 8, pp. 909–920, Jun. 2011.