Wide-band Dual Port Cross Slot Wearable Antenna for In-body Communications

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***Abstract*—Wearable antennas are commonly required for devices that operate within the Body Area Network. Depending on the application, the wearable antenna might be forming an off-body, on-body, or in-body link. Forming an in-body link is often more challenging due to reflection at the air-human body boundary and the path loss within the body. The performance of the antenna is going to be dependent on where it is located on the human body as the effective permittivity changes according to the dominant tissue. In order to improve the reliability or the data rate of the in-body link, multiple polarization and wide-band operation can be utilized. Here, a wide-band dual port wearable antenna is presented. The input bandwidth of the antenna is 1.52 GHz operating from 0.94 GHz to 2.36 GHz, a fractional bandwidth of 87%, on any tissue having a relative permittivity of 30 or more. The isolation between its ports is shown to be greater than 40 dB throughout the bandwidth.**

***Index Terms*—wearable antennas, in-body communications, wide-band antenna, dual port antenna, cross slot.**

I. INTRODUCTION

Wearable antennas are now commonly used for various applications which require different links to be formed: off-body, on-body, and/or in-body. The in-body link is dependent on the location of the wearable and the implant antenna. The wearable antenna is going to be detuned as the dominant tissue that it is facing and hence the effective permittivity changes. This issue can be overcome by using a wide-band antenna that is suitable for the permittivity range that human tissues take. Another parameter that heavily affects the performance of the link is the polarization match and the alignment between these antennas. One can utilize polarization diversity in order to mitigate this issue.

There are various multi-port antennas in the literature with wide-band characteristics [1]-[4] that are not wearable. [1] presents an array of two dielectric resonator antennas for MIMO communications with two ports. Although utilizing arrays is the conventional method to create a pattern or polarization diversity, one can reach this goal with a single radiator as well. [2] has proposed a dual port wide-band slot antenna achieving greater than 30 dB isolation. [3] proposed a cross slot antenna with two ports achieving outstanding decoupling performance. However, the antenna thickness is as large as a quarter wavelength. Similarly, in [4], a broadband dual-polarized sub-array of quarter wavelength deep cavity-backed slot antenna with two ports was presented. That is why these antennas are not suitable for wearable applications. [5] proposes a circularly polarized wearable antenna that achieves multi-port operation in a broadband frequency range. Similarly, [6] propose a button antenna which also is broadband and one port provides a pattern suitable for on-body while the other port is suitable for off-body communications. However, none of the above antennas are intended for in-body communications.

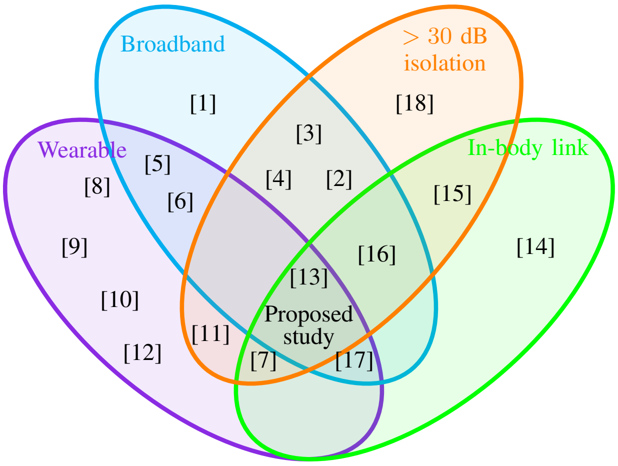


Fig. 1. A comparison of the proposed study with related antennas in the literature.

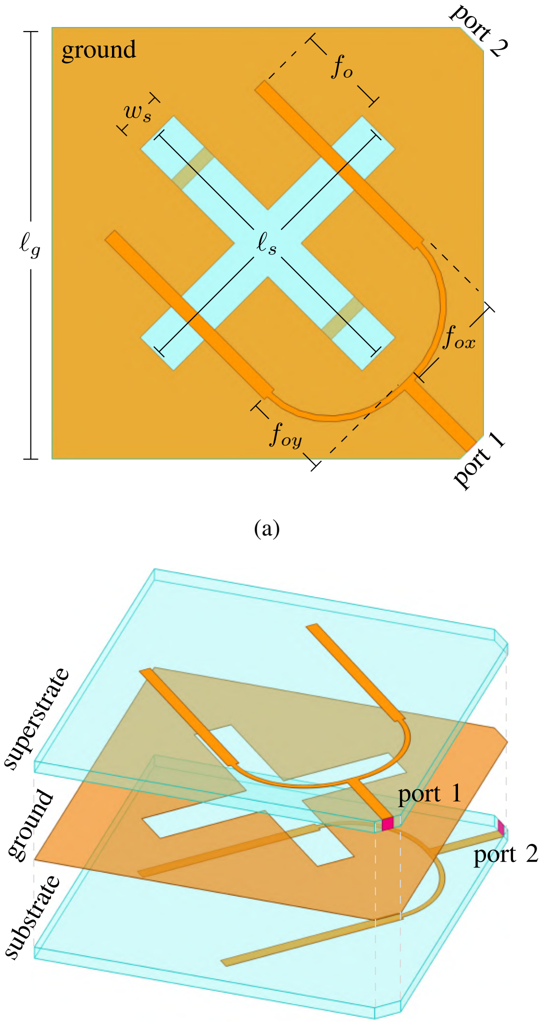
On the other hand, there are various multi-port wearable antennas that are not wide-band [7]-[12]. As seen in Fig. 1, [8]-[12] have low isolation performance. [7] presents an antenna that forms an in-body link with high isolation performance; however, it is narrowband. [14]-[16] are antennas that achieve multi-port operation and are intended for in-body communications; however, they are implant antennas.

As seen in Fig 1, only [13] and [17] satisfies all the requirements that we would like to achieve here, being wearable antennas intended for implant communications and having broadband characteristics. The isolation performance of the antenna proposed in [17] is below our target. On the other hand, the antenna proposed in [13] achieves good isolation between 381 MHz and 990 MHz on human muscle. Here, we propose a cross slot antenna that fulfills the aforementioned requirements between 0.91 GHz to 2.43 GHz on any tissue with a relative permittivity of 30 and higher. In addition, our proposal is a magnetic antenna that achieves better in-body link performance since the human body tissues have real permeability and no magnetic losses [19].

The rest of the paper is organised as follows. The antenna design is presented in Section II. Section III discusses the results and Section IV concludes the paper.

II. ANTENNA DESIGN

The cross slot is modelled on RO6010 ($\varepsilon_r = 10.2$ and $\tan\delta = 0.0023$) with a thickness of 1.91 mm for miniaturization purposes. Note that a wearable antenna should either be flexible or have a small form factor for user acceptability. Here, miniaturization is chosen over flexibility which is not favored due to the complications encountered in feeding.



(a)

(b)

Fig. 2. The geometry of the antenna. Assembled (a) and exploded (b) views. $\ell_g = 55$ mm, $\ell_s = 40$ mm, $w_s = 4$ mm, $f_{ox} = 13.5$ mm, $f_{oy} = 11$ mm, $f_o = 12$ mm.

Fig. 2 demonstrates the antenna model on which parameterized dimensions are labelled. The slot is sandwiched between two micro-strip fork feeds which are perpendicular to each other. Each feed excites the cross slot in one diagonal. Since the diagonals are orthogonal to each other, the isolation between the ports is low. The wide-band behaviour is achieved by utilizing wide slots and fork feeds. One feed network consists of a 50 Ω microstrip line divided into 70.7 Ω lines which are connected to open-circuited stubs. The offset of the stubs, f_o, and the separation between the arms of the feed, f_{ox}, control the input impedance of the structure while slot length, ℓ_s, and slot width, w_s are dominant in tuning the operating frequency.

The antenna is placed above a 150 mm × 150 mm × 70 mm muscle block with an air gap of 1 mm as seen in Fig. 3. The reflection and transmission coefficients of the antenna of which optimized dimensions are given in Fig. 2 can be seen in Fig. 4. The radiation pattern of the antenna can be seen in Fig. 5.

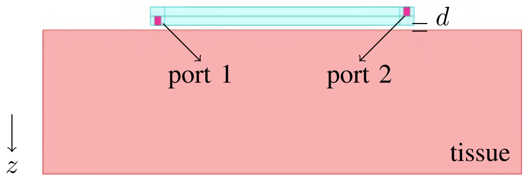


Fig. 3. The simulation model to test the performance of the antenna for different target tissues.

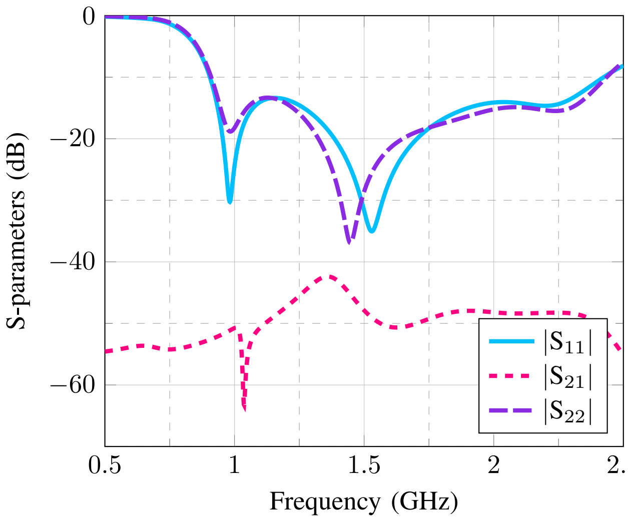
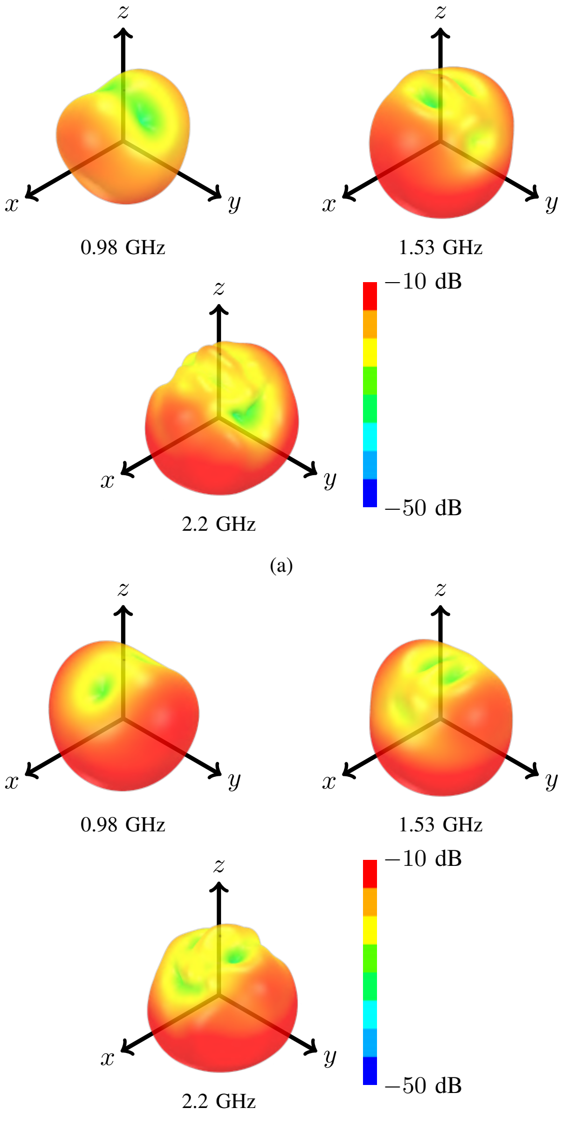


Fig. 4. The reflection and transmission coefficients of the optimized antenna on human muscle with an air gap of 1 mm.

III. RESULTS

The antenna is designed to operate on the human body. The effects of the parameterized dimensions are presented in Section III-A. There are two main variations that are inevitable in real life and affect the performance of the antenna. The first one is the target tissue variation. In other words, the antenna might be located on the chest, the head, or the abdomen which is going to change the effective permittivity of the medium that the antenna radiates into. The second variation is the separation between the antenna and the human body. The effects of these variations are detailed in Section III-B and III-C. Both target



(a)

(b)

Fig. 5. The radiation pattern of the antenna when port 1 (a) and port 2 (b) are excited.

tissue and separation analysis are conducted by locating the antenna on a 150 mm × 150 mm × 70 mm tissue block as seen in Fig 3.

A. Parametric Analysis

The effects of w_s and ℓ_s on the reflection and transmission coefficients of the antenna can be seen in Fig. 6 and Fig. 7. As w_s increases, the resonant frequency of the dominant mode decreases. The transmission coefficient also increases since it affects the cross-polarization level. Similarly, ℓ_s controls the resonant frequency.

B. Target Tissue Analysis

For this analysis, the relative permittivity of the tissue block is swept from 10 to 70 covering most of the tissues that exist in the human body. Note that the conductivity of the block is kept constant 0.5 S/m since its effect is limited to near-field loss. As the permittivity of the target tissue changes, the reflection coefficient of the on-body antenna changes as seen in Fig 8. It can be observed that the antenna operates well between the intended frequency range for tissues of which relative permittivity value is greater than 30. The reason why the antenna is immune to detuning is that the radiator is sandwiched between the microstrip feeds and faces the low-loss dielectric substrate.

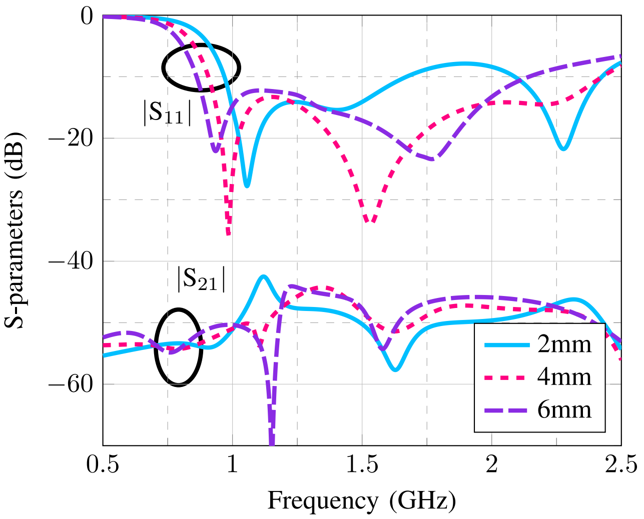


Fig. 6. The effect of w_s on the reflection and transmission coefficients of the antenna.

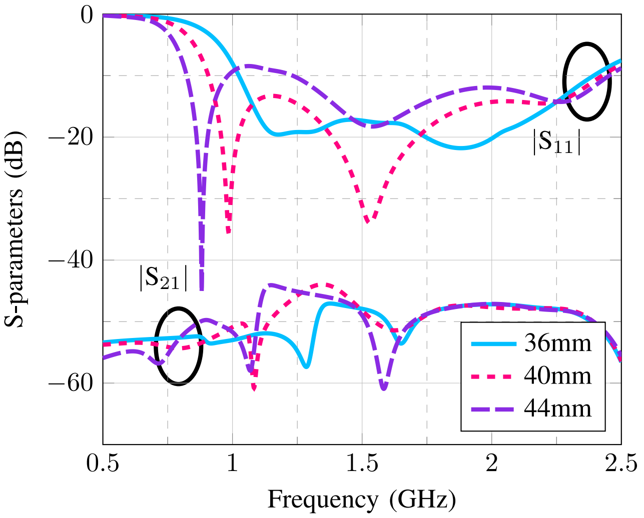


Fig. 7. The effect of ℓ_s on the reflection and transmission coefficients of the antenna.

C. Antenna-Human Body Separation

Fig. 9 shows how the reflection coefficient change as the air gap increases. In a similar fashion to the target tissue analysis, the antenna is found to be immune to detuning with separation.

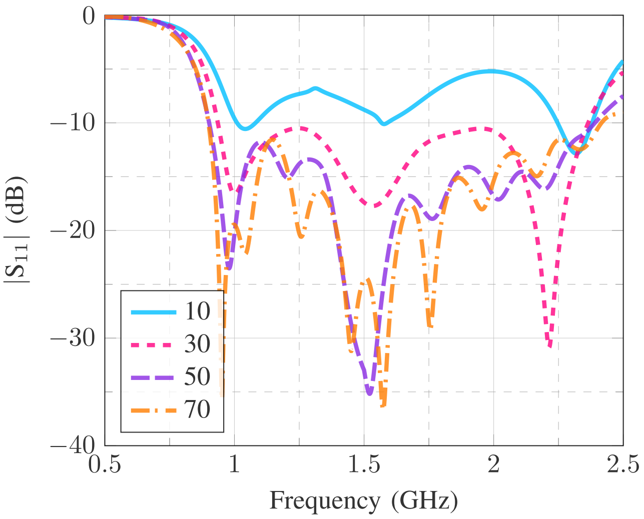


Fig. 8. The effect of the relative permittivity of the target tissue on the reflection coefficient of the antenna.

The magnitude of the reflection coefficient however changes as the air gap increases.

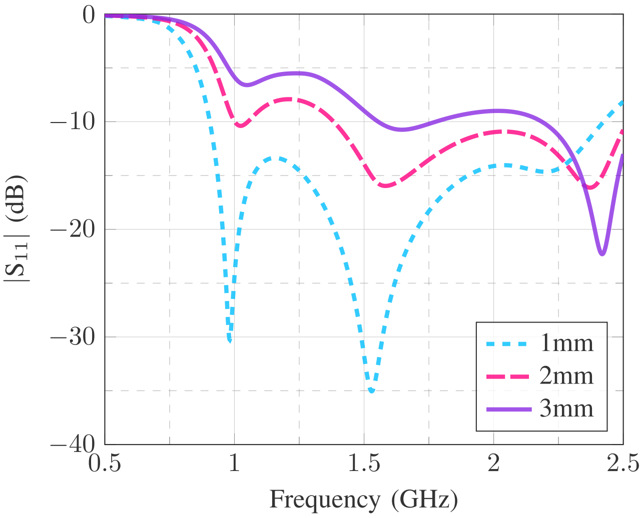


Fig. 9. The effect of d on the reflection coefficient of the antenna.

The prototyped antenna can be seen in Fig. 10.

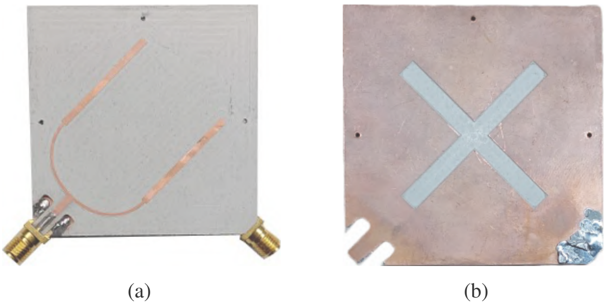

(a) (b)

Fig. 10. The microstrip (a) and ground (b) of the fabricated antenna.

IV. CONCLUSION

Here, a wearable antenna is presented which is suitable for in-body communications. The antenna is dual port with good isolation between its ports providing polarization diversity to mitigate misalignment between the wearable antenna and the implant antenna. It can operate over a wide band. Finally, the proposed antenna stands out compared to its counterparts in the literature by its outstanding performance on various tissues. The antenna can be used at different locations on the human body since the change in its S-parameters is minimal if the effective permittivity of the medium that it faces is more than 30.

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