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Implantable slot antenna with substrate integrated waveguide for biomedical applications

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ABSTRACT

This work presents a new design of capsule slot antenna with substrate integrated waveguide (SIW) for wireless body area networks (WBANs) operating at the range of (2.5-4 GHz) which is located in the body area networks (BAN) standard in IEEE802.15.6. The proposed antenna was designed for WBANs. The substrate is assumed to be from Rogers 5880 with relative permittivity of 2.2, and thickness of 0.787 mm. The ground and the patch are created from annealed copper while the capsule is assumed to be a plastic material of medical grade polycarbonate. The antenna designed and summited using computer simulation technology (CST) software. A CST voxel model was used to study the performance of SIW capsule antenna and the ability of the band (2.5-4 GHz). Results indicated a wide bandwidth of 1.5 GHz between the range of (2.5-4) GHz at 3.3 GHz as center frequency, with return loss with more than -24.52 dB, a gain of -18.2 dB, voltage standing wave ratio (VSWR) of 1.17, and front-to-back ratio (FBR) of 10.07 dB. Through simulation, all considerable parameters associated with the proposed antenna including return loss, bandwidth, operating frequency, VSWR less than 2, radiation pattern were examined. Regarding size, gain, and frequency band, the proposed antenna is located with the standards of implantable medical devices (IMDs).

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1. INTRODUCTION

The approaches of in-body communications (IBCs) are utilizing the human body as a transmission medium to interconnect devices in the biomedical wireless body area networks (WBANs). Such devices might be either in-body or on-body devices and communicate with each other and also with a central device via low-data rate and low-power consumption channels [1], [2]. Currently, decreasing the size of implantable medical devices (IMDs) requires a small implantable antenna for embedded applications. Therefore, a lot of implantable antennas that were suggested for various wireless communications and biomedical applications might not be excellent candidates for the WBAN implantable medical devices due to the fairly relatively large size [3], [4]. The human body as a propagation channel is not an adequate way of transferring radio waves since it can be specified as one of the obstacles affecting the transmission system's performance. It is a difficult task to design a good performance antenna to be used with a high lossy medium [5].

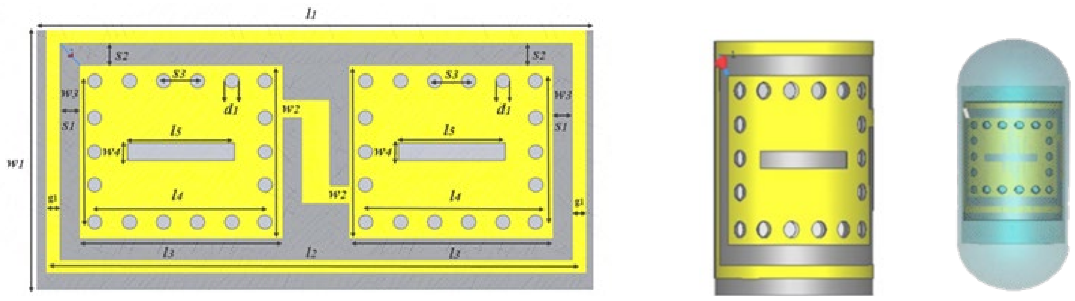
Antennas that have been aimed for applications of the capsule antenna were researched in many different works; such works indicated that conformal form is the extremely significant type and therefore was used by a lot of designers [6]-[13]. In [6]-[9], antenna's conformal form has adequately large bandwidth since they were printed on the capsule's outer wall. The capsule antennas indicated in [10], [11] were created on the capsule's inner wall, thus avoid direct contact with the human tissues. Yet, such antenna's bandwidth has been majorly extremely narrow. A simulated 8.99% bandwidth has been achieved via differential feeding [12]. A meandering dipole is loaded with a strip was suggested and reached bandwidth (37.8%) [13]. The important antenna is a component in the IMDs and requires to be small in size, providing enough bandwidth, and must have an omnidirectional radiation pattern to transmit signals. Recent research on IMDs antennas has shown embedded [14], [15] and conformal structures [16], [17] to be a promising antenna type.

In this work, a new capsule antenna with substrate integrated waveguide (SIW) is proposed. It operates (2.5-4 GHz) band performance for biomedical applications. The Ultra-wideband performance shows the characteristic with-10 dB impedance matching from (2.5-4 GHz) helps antennas in resisting the frequency shift as well as providing a guarantee for the high-speed data transmissions. Therefore, this work is focusing on Enhance performance which is related to the subcutaneously implanted antenna with effective wideband antenna efficient implanted for medical capsule systems. Furthermore, the proposed antenna has a nearly omnidirectional radiation pattern. Because of its small size, support of Ultra-Wideband, and omnidirectional radiation pattern, it can meet the requirements for IMDs systems.

2. RESEARCH METHOD

2.1. Antenna configuration

The configuration of the proposed antenna with SIW structure has been implemented with the use of Rogers 5880 substrate with permittivity, εr of 2.2, and loss tangent of 0.0004. The height of the substrate is 0.787 mm as in [18], [19] which is suitable for bending and wrapping around the capsule. The patch and ground are using Copper are used as conducting material. It is wrapped with plastic material of medical grade polycarbonate with 10x20 mm size (inside diameter, lengths) diameter. It includes two rectangular identically sized, each one is connected with a rectangular patch slot capsule antenna with the vias SIW structure prior to the wrapping process prior to and post its wrapping has been illustrated in Figure 1 and detailed parameters have been provided in Table 1.



(a) (b) (c)

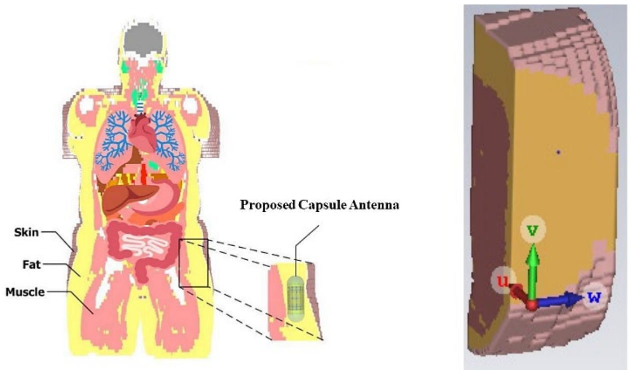
Figure 1. The proposed slot antenna with SIW; (a) before, (b) after bending, and (c) proposed capsule antenna

Table 1. Dimensions of the proposed capsule antenna

Parameter	Dimension (mm)	Parameter	Dimension (mm)
l1	31.5	w1	15.00
l2	30.40	w2	10.00
l3	11.50	w3	8.20
l4	8.40	w4	1.00
l5	6.00	g1	0.80
s1	1.05	ws1	32.00
s2	1.05	Ws2	20.00
d1	1.00	Ls	10.00

2.2. Voxel models

In this study, a simulated environment for the implanted antenna is a voxel model. Amongst which anatomical voxel models, Gustav has been selected, as can be seen in Figure 2. Gustav represents a normal-weight man with an of 2.08×2.08×2 mm resolution [20]. The voxel models thigh area cross-section, a 3-layered model of the human body (skin, fat, and muscles) has been utilized for the sub-cutaneous implanted antennas. The voxel models' cross-section thigh region, z-oriented capsule antenna has been located at the fat center. It has to be mentioned that the capsule's internal environment. The suggested antenna has been simulated with the use of the computer simulation technology (CST)-MW.



(a) (b)

Figure 2. (a) Anatomical voxel model Gustav, (b) Cross-cut of the thigh area presenting the subcutaneous and visceral fat

3. RESULTS AND DISCUSSIONS

The proposed antenna has been anticipated for operating on (2.5-4 GHz) band simulated by CST microwave software. In addition to that, this antenna has been applied to a variety of locations in the tissue for observing its properties and response face to the human tissues. At implantation depth, d=5 mm, the S11 of the coefficient reflection is -24.52 dB at 3.3 GHz and the bandwidth of the main structure is 1.5 GHz started from 2.5-4 GHz. Figure 3 illustrates the results of the simulation for the properties of the return loss of the proposed antenna versus the Frequency. The voltage standing wave ratio (VSWR) is the parameter describing the antenna response. Figure 4 it can be seen that the VSWR value of 1.17 at 3.3 GHz. The simulated gain proposed antenna inside the body Figure 5 indicates that the maximum gain achieved -18.5 dB at 3.3 GHz, and it is usually for the wireless-capsule antenna. Figure 6 shows the measured frequency dependence of the front-to-back ratio, which always exceeds the level of 10.07 dB at 3.3 GHz. The radiation pattern simulated of the proposed antenna at 3.3 GHz is illustrated in Figure 7. From the perspective of patient safety, the average specific absorption rate (SAR) per 1 gram of tissue should not exceed 1.6 W/kg according to the IEEE C95.1-1999 standard [21]. When the input power of the proposed antenna is set to 1W, the simulated average SAR value in fat tissue is 122.7 W/kg at 3.3 GHz. Therefore, the input power must be decreased to 4.42 mW. Table 2 summarizes the simulated results. Table 3 shows a comparison between the proposed designs with other work.

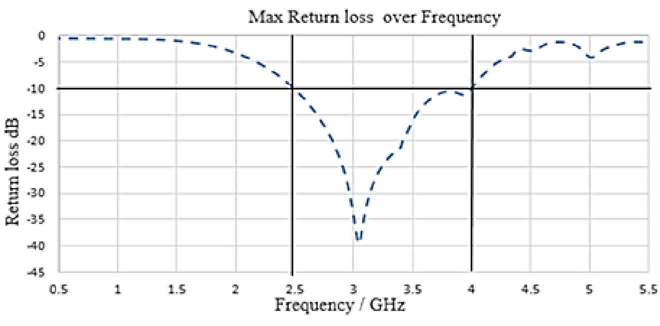


Figure 3. The Simulated return loss (S11) with bandwidth of proposed antenna

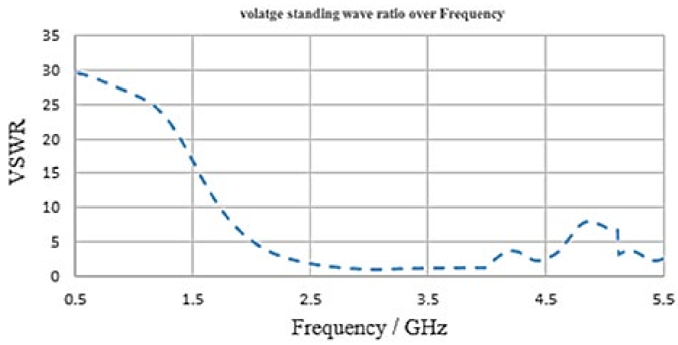


Figure 4. The simulated VSWR of proposed antenna

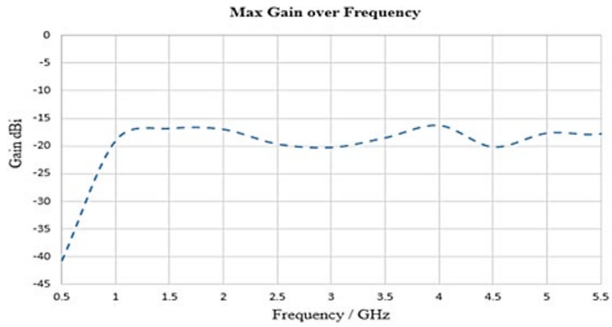


Figure 5. The Simulated gain of the proposed antenna

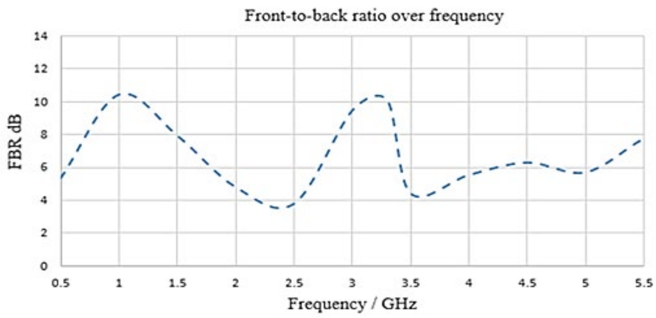
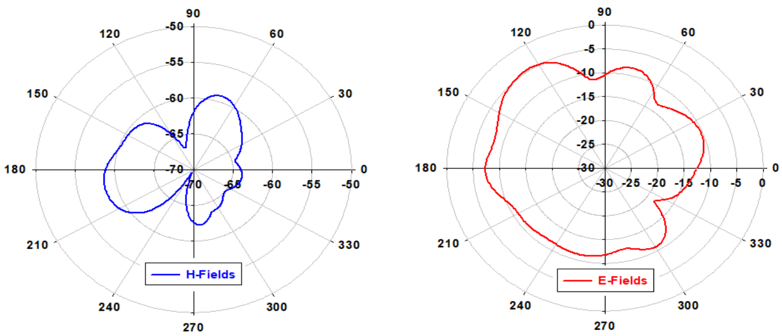


Figure 6. The simulated front-to-back ratio (FBR) of the proposed antenna



(a) (b)

Figure 7. The radiation pattern of the proposed antenna; (a) E-plane and (b) H-plane

Table 2. The simulated results of the proposed antenna at 3.3 GHz

Parameter value	Parameter value
Gain	-18.5 dBi
VSWR	1.17
Reflection coefficient	-24.56 dB
FBR	10

Table 3. Comparison of reported capsule antennas with the proposed antenna in this work

Ref	Antenna type (conformal)	Freq. (GHz)	Band. (MHz)	Gain (dBi)
[22]	outer-wall loop	0.403	541	-31.5
[23]	outer-wall loop	0.433	795	-35
[24]	inner-wall loop	2.45	4900	-22.7
[25]	inner-wall dipole	2.45	150	-19.5
[26]	inner-wall dipole	0.4	31	-31
[27]	inner-wall patch	0.915	81	-21
[28]	inner-wall ifa	1.4	150	-25.2
[29]	inner-wall ifa	0.433	753	-9.2
This Work	inner-wall siw	3.3	1500	-18.5

4. CONCLUSION

In this work, the new capsule antenna with substrate integrated waveguide (SIW) operated at 2.5-4 GHz bandwidth with a center frequency which is equal to 3.3 GHz, based on the standard of IEEE 802.15.6. The performance of the implant proposed antenna inside the human body has been assessed using voxel and multi-layer models. Results and analysis indicate that the proposed antenna achieved satisfactory bandwidth and exhibited obvious advantages in gain over other previous antennas. In addition to that, its property of the impedance matching has quite high stability. On other hand, its impedance matching property has quite high stability in addition to a comparatively high insensitivity to the variations of the ambient environment, which is highly desirable since the operating environment of the capsule can differ drastically. The aim is for the results to be beneficial as references for the designers who are engaged in developing a similar type of capsule for the implant antenna.

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