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Study of Different Slotted UWB Antennas for Capsule Endoscopy Applications

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Abstract- In recent years, Wireless communications have played an important role in the advancement of medical treatment and diagnosis. Wireless capsule endoscopy (WCE) is one such example. It is a non-invasive method used extensively in the diagnosis of gastrointestinal tract diseases. However, its application is critically limited by various factors such as low data transmission rates, capsule size and lack of antenna propagation efficiency. Antennas play a major role in mitigating most of these issues. Hence, the design of a WCE antenna is explored in this paper. Three miniaturized UWB antennas are designed and optimized for WCE by exploring various optimization techniques, such as employing dielectric substrates with high permittivity and the lengthening of the current flow patch on the patch surface. The performanceis investigated by placing the antennas inside a homogeneous single layered phantom model. The antennas are also tested for specific absorption rate (SAR,) for compliance with the IEEE C95.1-1999 recommended health standards.

1. Introduction

Endoscopy is the traditional method for detecting abnormalities in the human gastrointestinal (GI) tractand it is used in the diagnosis and detection of a variety of diseases such as colon cancer, gastrointestinal bleeding, gastro-paresis, Crohn’s disease, etc. The primary requirement is a thin and long flexible tube, which on insertion through the oral cavity; gives real time images of the stomach, colon and rectum in high definition. This accounts for about 4 feet of the gastrointestinal tract. The remaining 20 feet GI tract remains undiagnosed. Hence, posing as a major disadvantage to the conventional method of endoscopy. This led to the development of WCE (wireless capsule endoscopy) with the swallowable-capsule concept first appearing 1957, when R.S. Mackay developed an endo radiosonde (ERS) based on a tunable Colpitts oscillator for measuring pressure within the GI tract for diagnosis [1]. It overcame the conventional drawbacks and allowed for a cable free visualization of the GI tract, including the small and large intestines [2]. Generally endoscope capsule consists of a wireless IC transceiver, LEDs, batteries, camera sensors, and an antenna. Due to limitations in capacity, the antenna is required to be physically diminutive, which leads to a heightened challenge for it to be matched to IC transceiver at specific frequencies [3-5]. Furthermore, the human body acts like a lossy dielectric material absorbing a number of waves and attenuating the receiving signal power, thus having a strong negative influence on microwave propagation.

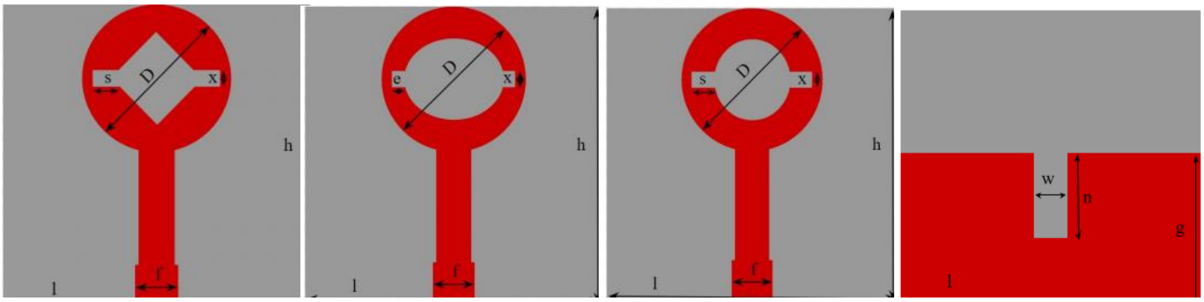
There are three major frequency bands; MICS (medical implant communication service), ISM (industrial, scientific and medical), and UWB (ultra-wideband) that are taken into consideration in the development of antennas for endoscopy [6-10, 17]. The MICS band allocated by the FCC basis in 1999, specifies the use of a frequency between 402-405 MHz for medical implant communication allowing for a bi-directional communication channel for electronic implants. In order to reduce the interference risk, the max power transmission is limited to 25 μW or -16 dBm. The (902–928 MHz, 2.40–2.48 GHz, 5.725–5.875 GHz) bands, constitute the ISM band. UWB signals are signals having a 0.2 fractional bandwidth or larger and a minimum bandwidth of 500 MHz. The UWB signals operate in the 3.1-10 GHz frequency band and an effective isotropic radiated power kept below -41.3 dBm/MHz. Based on these specifications, several different UWB based antennas have been proposed [8-16].

Chavez-Santaigo et.al [8] have presented results on the ultra-wide capsule endoscope. Thotahewa et.al [10] have initially explored the implications of electromagnetic power absorption of the human abdomen from IR-UWB based WCE devices. This was followed up by Thotahewa et.al [10] research on propagation, power absorption, and temperature analysis of UWB WCE devices operating in the human body. Subsequently, Thotahewa et.al [11] have devised a UWB WCE device. Arifin and Saha [12] have introduced the design of a miniaturized UWB ingestible antenna for WCE. Yazdandoost [13] has also designed an antenna for wireless capsule. Wang el.al [14] have explored the use of UWB planar antennas for WCE. Yun et.al [15] have proffered an outer-wall loop antenna for UWB capsule endoscope system. Suzan et.al [16] have proposed an UWB conformal loop antenna for ingestible capsule endoscope system.

This paper presents the design and simulation of three slotted UWB antennas that can be used for wireless capsule endoscopy. The antennaswere optimized with various geometric slots with impedance bandwidth below -10dB reflection coefficient within the ultra-wideband region while maintaining a small footprint overall. The SAR analysis of the proposed antennas were performed in order to keep the value within the IEEE set limits. The paper is organized as follows. In Section IIdiscusses the studied antenna geometries. Section III elucidates on the phantom body model used for simulations. The Antenna performance analysis is then discussed in section IV.Finally,section V gives the author’s concluding remarks followed by the references.

2. Studied Antenna Geometries

The main criteria for antenna design is the reduction of antenna size such that the capsule can easily be ingested by the human subject. The designed antennas operates in the UWB frequency range and are designed on a Roger R03010 substrate which is typically used in the manufacture of implantable patch antennas in the field of biomedical telemetry. The substrate specifications are as follows, relative permittivity ε_r = 10, and lostan = 0.0023. The high-permittivity dielectric helps in the miniaturization of the antennas because of the effective wavelength shortening.



(a) Antenna #1 (Front-view)(b) Antenna #2 (Front-view) (c) Antenna #3 (Front-view)(d) Back-view

Fig.1. Studied Antenna Geometries.

A comparison is made by employing different antenna geometries in order to select the geometry with the best results over a range of criteria. The first antenna design (Antenna #1) is a microstrip antenna with a square-slot of side-length 2 mm. This is a modified version of the antenna given in [12]. The second and third antenna designs (Antenna #2 and Antenna #3) are created by replacing the square-slot with an elliptical-slot (semi major axis = 1.5 mm, semi minor axis = 1 mm) and circular-slot (radius = 1 mm), respectively. The optimizations taken for Antenna #2 and Antenna #3 are the final optimized versions of them too.

Table 1. Dimensions of the optimized Antenna

Parameter	Value (mm)
Length of substrate (h)	9.0
Width of substrate and ground (l)	10.0
Length of ground (g)	4.5
Thickness of ground	0.4
Width of ground notch (w)	1.0
Length of ground notch (n)	2.5
Diameter of circular patch (D)	5.0
Thickness of patch	0.25
Width of horizontal slots in circular patch (x)	0.5
Length of horizontal slots in circular patch (e) [Antenna #2]	0.5
Length of horizontal slots in circular patch (e) [Antenna #1 and Antenna #3]	1.0
Width of feed line (f)	1.3

The Circular antenna patch is fed by a 50 Ω microstrip feed (1.20 mm × 1.60 mm wide). The circular patch is connected to the feed by a strip of width 1mm. The antennas also have two identical slots of length 1.0mm and width 0.5mm cut horizontally from the circular patch. A rectangular notch is also introduced on the top of the ground in order to improve the antenna's impedance. All the parameters are realized using CST microwave studio.The optimized dimensions of the studied antennas are presented in Table I.

3. Phantom Body Model

A simple single layered tissue model is selected as it is very simple to model and projects exceptionally fair and accurate results as proof of concepts while displaying snappy computational times on comparison to more complex tissue models (e.g. anatomical tissue models). Hence a homogeneous human muscle model is integrated for the performance analysis of the antenna. The tissue model is cubic in shape with a dimensions of 40mm x 40mm x 40mm along with a relative permittivity (ε_r) = 45.007, conductivity (σ) = 8:2903 S/m and a lostan (δ) = 0:3962 at 8.36 GHz [12, 18]. The model material is customized with the parameters mentioned above on the CST microwave studio and the antenna is placed at the center as shown in Fig. 2.

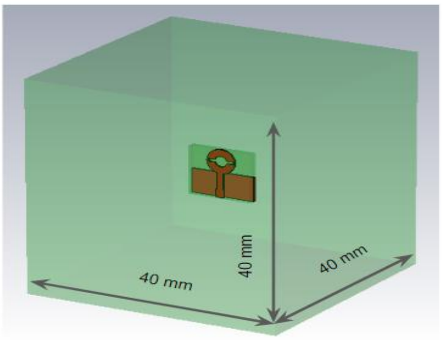


Fig.2. Phantom Body Model

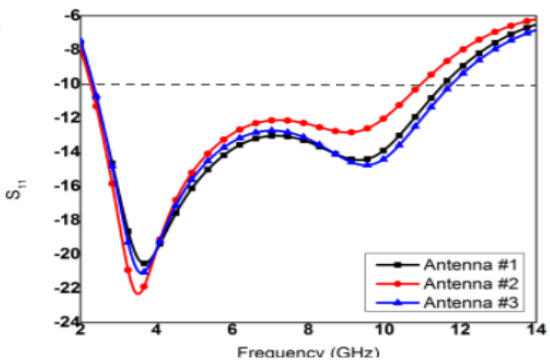


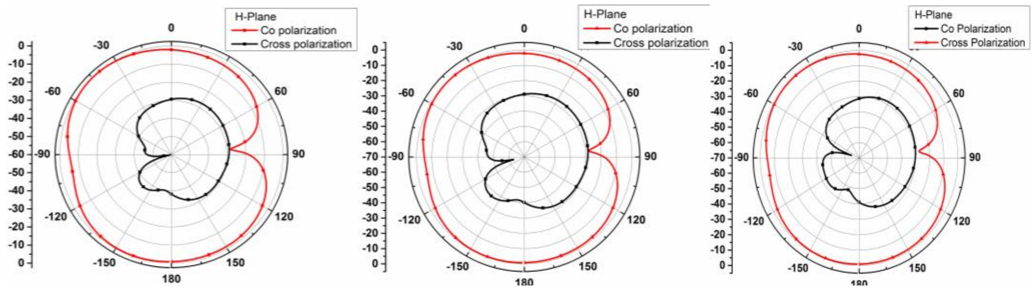
Fig.3. S_{11} Values inside the Phantom Model

4. Performance of the Studied Antenna

4.1 S-parameter Analysis (reflection coefficient)

The S_{11} frequency response of the studied antenna placed inside the phantom model is shown Fig.3. It can be seen that Antenna #1 and Antenna #3 exhibit almost identical plots with reflection coefficients S_{11} of -20.5 dB and -21 dB and -10dB bandwidths of 9.27 GHz (2.30 to 11.573 GHz) and 9.45 GHz (2.33 to 11.78 GHz), respectively. Antenna #2 has a better reflection co-efficient value of -22.35 dB, but has a smaller -10dB bandwidth of 8.711 GHz (2.265 - 10.976 GHz).

4.2 Radiation Pattern Analysis



(a) Patterns of Antenna #1 (b) Patterns of Antenna #2 (c) Patterns of Antenna #3

Fig.4. Cross- and Co-polarization patterns for Proposed Antenna Geometries

Fig.4. shows the 2D co- and cross-polarization patterns for Antenna #1, Antenna #2 and Antenna #3 obtained upon simulation. From the 2D co-polarization pattern, the main lobe magnitude, direction, and angular width of Antenna #1, Antenna #2 and Antenna #3is indicated in Table 2.

Table 2. Far-field Parameters (Co-pol) for Proposed Antenna Geometries

Far-field Parameters (Co-pol at θ = 90°)	**Antenna #1**	**Antenna #2**	**Antenna #3**
Main lobe magnitude	2.45 dBi	2.49 dBi	2.18 dBi
Main lobe direction	-44^0	-44^0	-45^0
Angular width (3dB)	102.4^0	100.7^0	88.7^0

It can be seen that the Antenna #1 and Antenna #2 display almost identical field patterns with a minute 0.04 dBi difference between the two (Antenna #2's 2.49 dBi vs. Antenna #1's 2.45 dBi) and also the angular width (3dB) value showcases a minute difference of 1.7^0 (Antenna #1's 102.4^0 vs. Antenna #2's 100.7^0). Antenna #3 on the other hand has a much larger deviation in terms of main lobe magnitude and angular width values with 2.18 dBi and 88.7^0, respectively.

From the 2D cross polarization patterns, the main lobe magnitude, direction, and angular width and side lobe level of Antenna #1, Antenna #2 and Antenna #3 which is indicated in the Table 3.

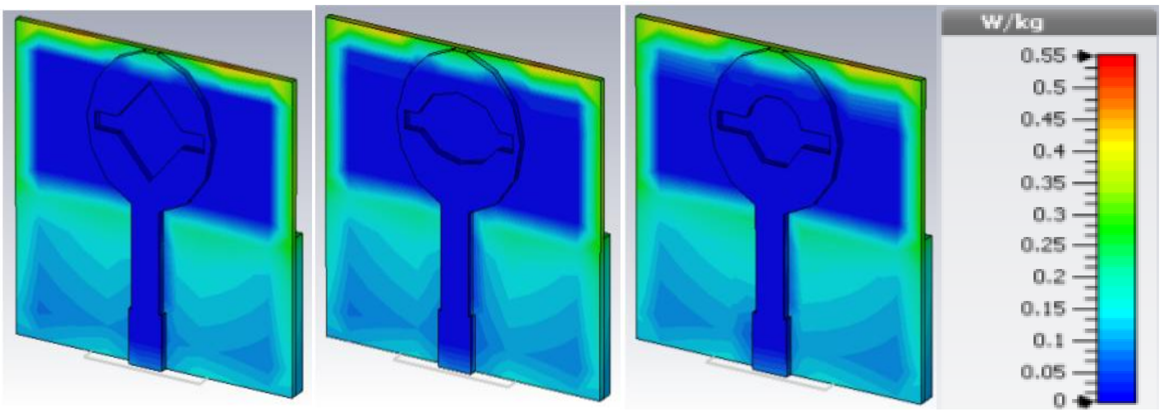
Table 3. Far field Parameters (Cross-pol) for Proposed Antenna Geometries

Far-field Parameters (Cross-pol at θ = 90°)	Antenna #1	Antenna #2	Antenna #3
Main lobe magnitude	-24.9 dBi	-24.5 dBi	-25.7 dBi
Main lobe direction	35^0	35^0	39^0
Angular width (3dB)	118.3^0	116.2^0	96.6^0
Side lobe level	-9.3 dB	-9.7 dB	-15.0 dB

Again, it can be seen that the Antenna #1 and Antenna #2 display almost identical field patterns with a main lobe magnitude of -24.9 dBi and -24.5 dBi respectively while Antenna #3 shows a magnitude of -25.7 dBi.

4.3 SAR Analysis of Studied Antenna Geometries

The Specific absorption ratio (SAR)is also made for the optimized geometries. It can be defined as the measure of energy absorbed on exposure to radio frequency (RF) or electromagnetic (EM) field per unit mass by the human body. The IEEE C95.1-1999 sets concise restrictions on the maximum permissible value of SAR form commercially used devices calculated over 1g of a cube of tissue and is set to 1.6 W/Kg. For the studied geometries,the SAR is evaluated by applying a post processing SAR template and the computed results give a maximum reading of 0.5509W/Kg, 0.55W/Kg and 0.553W/Kg, averaged over an input power of 1 W per unit gram of tissue,for three antenna geometries, respectively. The proposed three antenna geometries exhibit quite identical SAR readings [Fig. 5] which fall well inside the set standards.



(a) Antenna #1 (b) Antenna #2 (c) Antenna #3

Fig.5. SAR Analysis of Proposed Antennas

4.4 Comparisons of the Selected Slot Geometries

Antenna #1 and Antenna #3 exhibited nearly identical results in terms of S_{11} parameters and -10 dB bandwidth, while the Antenna #2 provided a trade off by having the best reflection coefficient of the three (-22.35dB vs. Antenna #1's -20.5 dB and Antenna #3's -21 dB), but also had the worst -10dB bandwidth (Antenna #1's 9.27 GHz (2.30 to 11.573 GHz) and Antenna #3's 9.45 GHz (2.33 to 11.78 GHz) versus Antenna #2's 8.711 GHz (2.265 - 10.976 GHz)) of the three in return.9.45 GHz (2.33 to 11.78 GHz).

The SAR analysis of the three antennas also yielded acceptable but identical results of 0.5509W/Kg, 0.55W/Kg and 0.553W/Kg for Antenna #1, Antenna #2 and Antenna #3, respectively which albeit, fall well inside the mandatory IEEE health standard of 1.6W/Kg.

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So it finally comes down to the complexity of the antennas and the ease of implementation in all the three cases. The 90^0 tilt of the square in Antenna #1 and the 0.5mm×0.5mm identical side patches as well as both the major and minor axis considerations of Antenna #2; makes both them complex and slightly harder to realize in real world scenarios. Whereas the geometry of Antenna #3 is relatively simple with 1mm radius and 1mm× 0.5mm side slots, making it easier to realize in a real world scenario. Hence, Antenna #2 has the least complex geometry and hence presents a greater ease of implementation amongst the three.

5 Conclusion

Three small slotted microstrip antennas have designed and tested by enclosing them in a phantom tissue model for wireless capsule endoscopy (WCE). Several techniques have been explored in order to minimize the occupied volume and to realize the complete UWB band. A comparison has also been made amongst the three antennageometries and found to exhibit similar results, but Antenna #3 has exhibited similar results while maintaining a relatively simple geometry. The Antenna #3 has a circular slot and resonates at 3.6 GHz frequency with an ultra-wide -10 dB bandwidth of 9.45 GHz and a reflection coefficient of $|S_{11}|$ of -21 dB.The antenna has been designed to comply with the standards set in IEEE C95.1-1999 and ensures that the antennas work well within the acceptable SAR guidelines with a peak value of 0.553 W/Kg.

The relatively small size of this Antenna #3 and its ultra-wideband characteristics makes it optimum for use in very small capsules along with support for high data rates. Additionally, the observed omnidirectional radiation pattern of the antenna guarantees data reception regardless of capsule orientation inside the GI tract. The manufacture and testing of the antenna along with the received data rate, signal quality and its integration in a capsule endoscope can be the scope of the future work.

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