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Original Article

Characterization of Microstrip Patch Antenna for Endoscopy Application

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Abstract - *Compared to standard endoscopy, wireless capsule endoscopy with non-invasive antennas has gained more attention. Since the transmitting antenna of a Wireless Capsule Endoscope (WCE) is located inside the body as opposed to the receiving antenna, which is located outside of it, designing the transmitting antenna is a difficult challenge. Simultaneously achieving high data rates, small size, omni-directionality, acceptable Specific Absorption Rate (SAR), and large bandwidth in telemetry systems are major hurdles faced by these antennas. This is because many parts of the gastrointestinal tract have different dielectric constants and thicknesses. To overcome these obstacles, antennas must be characterized for WCE. With a modified partial ground plane, the suggested antenna is a small planar slotted microstrip patch antenna. It is a miniature ingestion-capable Ultra-Wide Band (UWB) antenna. The substrate material for the antenna is Rogers TMM 13i. An environment that roughly represents the full human Gastrointestinal (GI) tract, including surrounding tissues, is created using the High Frequency Structure Simulator (HFSS 13.0). The performance of the antenna is evaluated by placing it in the middle of the various GI tracts. The suggested antenna's dimensions are 40 mm^3 (10 mm × 10 mm × 0.4 mm) and are a mere 1.26 percent of the capsule's volume. About 4.3 GHz and 6.7 GHz, with a -3 dB bandwidth of about 20.4 MHz and 950 MHz, respectively, are the resonant frequencies. The advantage of having multiple resonant frequencies is that the proposed single antenna can be used for the GI tract, although the dielectric constant varies over the entire GI tract. The existing literature needs different antennas for different GI tracts. In the biological model, the radiation pattern is circularly polarized and omnidirectional. The maximum radiation efficiency of 95.65% has been observed. For the purpose of biocompatibility analysis, the SAR value in the GI tract is also calculated and is well limited.*

Keywords - *Circular polarization, Miniaturization, Specific absorption rate, Ultra wide band, Wireless capsule endoscopy.*

1. Introduction

Most importantly, capsule endoscopy allows physicians to see inside the small intestine, an area that is difficult to access with more conventional endoscopy procedures. A vitamin-sized capsule is inserted into the patient's digestive tract and used to take pictures of the digestive tract using a wireless camera. In a traditional endoscopy, a patient has a long, flexible tube with a video camera sent down their throat. As a result, this method became uncomfortable and unpleasant and caused sore throats and infections.

All of these shortcomings in the conventional approach led to the development of Wireless Capsule Endoscopy (WCE), a non-invasive endoscopic procedure. The main challenges of the WCE antenna are size miniaturization, choosing a non-toxic substrate, achieving an omnidirectional radiation pattern, and maintaining the allowable SAR and wide Bandwidth.

So, the main objective will be to achieve a low profile, wide bandwidth endoscopy antenna with allowable SAR. In order to reduce SAR, frequency needs to be reduced as frequency is related to power. Reduction in frequency increases the size of the antenna. Another way to reduce SAR is by reducing transmitting power, which may result in a low data rate. Therefore, one has to achieve a tradeoff between SAR, data rate and miniaturization. The objective is to have an omnidirectional radiation pattern. So that the antenna can transmit the information regardless of the position and the direction of the capsule. In comparison to the existing antennas, the proposed antenna for endoscopy application is very small in size, 40 mm^3, and gives the required omnidirectionality with a gain of 1.6 dBi and permissible SAR. Characterization of the proposed antenna is done with respect to input power requirement, dielectric selection, Gain, and Bandwidth point of view. The existing literature needs different antennas for different GI tracts. So, there is a need to design an antenna with multiple resonant frequencies in order to use it for the GI tract, although the dielectric constant varies across the entire GI tract.

2. Wireless Capsule Endoscopy

The WCE capsule is made up of a microstrip antenna, battery, camera lens, and LEDs. Designing a transmitting antenna for WCE is a more challenging task than designing a receiving antenna because it is placed inside the capsule. As the capsule's orientation is unpredictable, the transmitting antenna for WCE must have an omnidirectional radiation pattern.

To satisfy the demands of high data rates for transmitting high-resolution images, another design problem is wide bandwidth. It also aids in withstanding the fluctuating environment of the digestive tract [1]. Thus, the transmitting antenna should have characteristics like high bandwidth (BW>500 MHz), enhanced antenna efficiency, and the ability to transmit data at a high data rate (10 Mbps) [2]. It should have a small (< 26 x 11 mm^2) size so that it can use less space within the capsule cavity [3].

The main feature is that it should possess a permissible SAR value. According to IEEE and ICNIRP guidelines, the maximum safety limit of SAR is 1.6 W/kg for 1 g of tissue and 2 W/kg for 10 g of tissue [4] [5]. The primary limitation of the Medical Implant Communication Service (MICS) frequency range (402–405) is its limited bandwidth.

A considerable path loss occurs at higher frequencies in the 2.45 GHz Industrial Scientific and Medical (ISM) band despite its support for a wide bandwidth. In order to overcome these limitations, the UWB frequency band (3.1- 10.6 GHz) is preferred due to its large bandwidth, low power consumption and simplicity [6]. It is also critical to minimise the amount of power that enters the human body for medical reasons.

Ultra Wide Band (UWB) communication is a natural choice since using a large channel bandwidth is one technique to get a larger data throughput without raising the transmission power [7]. In order to meet the 1-g and 10-g SAR requirements, the permitted transmitter power values are 3.9 mW and 31.9 mW respectively [8]. The power requirements for several WCE instrument types are displayed in Figure 1.

Trade-offs between SAR, data rate, and miniaturization must be made in order to meet all of these objectives. Because increasing frequency is necessary to attain wide bandwidth, an increase in frequency also increases the SAR value. SAR frequency must be decreased, yet doing so results in enormous sizes. Reducing transmit power, which could lead to a poor data rate, is another strategy to lessen SAR. Consequently, a trade-off between SAR, data rate, and miniaturization must be made. This paper deals with the trade-off between miniaturization, omnidirectional radiation pattern and SAR.

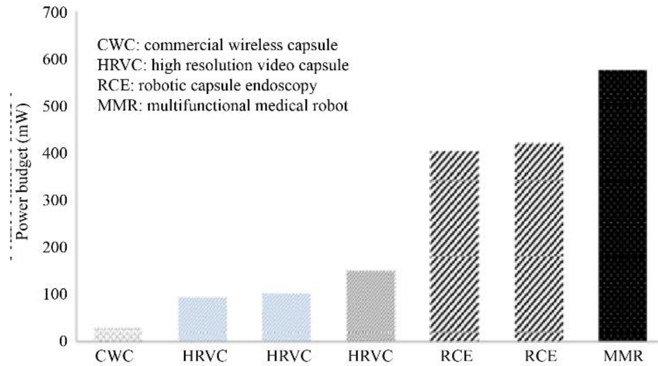


Fig. 1 Power requirements for various WCE instrument types [8]

3. Characterization of Patch Antenna

The essential characteristics of the well-known microstrip patch antenna are its low cost, straightforward construction, ease of fabrication, and ease of integration with other electrical devices. The next step involves designing and developing a patch antenna with an omnidirectional radiation pattern, high gain, wide bandwidth, miniaturization, and high efficiency for wireless capsule endoscopy. The primary disadvantage of the patch antenna, however, is that it has low bandwidth and low strength. It is, therefore, possible to enhance the patch antenna's properties by characterizing it using several techniques, such as meandering lines, slots, shorting pins, and metamaterial. WCE transmitting antenna needs are mostly determined by the physical characteristics of the antenna, such as its height, width, dielectric constant, length, etc. Therefore, the only purpose of characterization is to investigate how an antenna's physical attributes affect its performance metrics for various antenna design approaches. Characterization of patch antenna helps to achieve the desired requirement of antenna depending upon the application. It basically studies the effects of the physical parameters of the antenna on enhancement techniques. This is summarized in Table 1.

The GI tract is mainly divided into different parts: the esophagus, small intestine, large intestine (colon), and stomach. All these parts have different dielectric properties and, hence, will affect the antenna response differently. So, it is necessary to know about the various body properties and their effects on the performance of the antenna.

3.1. Dielectric Properties Human Body

To create electromagnetic phantoms, biological tissues must have certain dielectric characteristics. Constructing an antenna for biomedical telemetry requires research into the materials and propagation characteristics inside the body. In free space, radio wave propagation takes on unique characteristics due to the altered environment. Different permittivity and conductivity of the various tissues that make up the human body, resulting in varying dielectric characteristics. An electromagnetic viewpoint divides materials into three categories: conductive, semi-conductive, and dielectric media. The electromagnetic properties of materials and their propagation properties are frequently frequency-dependent. The substance of the body is dielectric. The human body is described by the Federal Communications Commission (FCC) as an averaged homogeneous medium, and measurements are made using a human phantom in order to examine the properties of antennas for capsule endoscopes [9]. The official FCC website provides information on the UWB body tissue dielectric properties. The dielectric characteristics of human body tissues at 4.3 GHz and 6.7 GHz, respectively, are displayed in Table 2 and Table 3 [10].

Table 1. Effects of physical parameter of antennas on the requirements of WCE transmitting antenna

Physical parameters of antenna	**Effects on the requirements/performance parameters of WCE antenna**
Resonant frequency (f_r)	**Miniaturization** Frequency depends on the relative permittivity of the antenna. Biological tissues increase the effective dielectric permittivity ε_r^{eff} of an antenna. Thus, the electrical length of an antenna increases by decreasing the *fr* value, which deteriorates the radiation efficiency and slightly increases the reflection losses. $$f_r < \frac{c}{4\Pi a\sqrt{\varepsilon_r^{eff}}}$$ Where, a - radius, $C = 3 \times 10^8\ m.\ s^{-1}$ is the speed of light
Length and width (*l* and *w*)	**Bandwidth and radiation efficiency** The *l* and *w* of the patch are inversely proportional to the square root of ε_r. Therefore, surface wave excitation increases and results in lower BW as well as a decrease in radiation efficiency [6]. By increasing the width of the patch antenna, resonance frequency and input impedance value decreases.
Dielectric constant ($\mathcal{E}_r$)	**Miniaturization and efficiency** when the substrate permittivity ($\mathcal{E}_r$) is smaller, the frequency shift is higher, so it helps to minimize the antenna structure [6] $$C' = \frac{c}{\sqrt{\varepsilon_r}}$$ A low value of $\mathcal{E}r$ for the substrate will increase the fringing field of the patch and, thus, the radiated power. The low dielectric constant materials increase efficiency and bandwidth and are better for radiation.
Loss tangent ($\tan\delta$)	A high loss tangent ($\tan\delta$) increases the dielectric loss and, therefore, reduces the antenna performance.
Substrate thickness (*h*)	**Bandwidth, efficiency and return loss** The thickness of the substrate is used to maximize radiation efficiency and to achieve a wide BW. The BW is increased at the cost of degradation in the impedance matching [2] As the height of the substrate increases, higher modes excite and due to this modes result in the degradation of the return loss and bandwidth [6]

3.2. Effect of the Body Properties on the Performance of Antenna

The endoscopic capsule's intended application is within the human anatomy. As a result, it is evident that tissue surrounds it and that this may have an impact on antenna effectiveness. The environment of the human body contains many losses, which is why the antenna's efficiency and gain are declining more so than the air. As such, consideration of the human body's effects is essential during the design phase. Notably, the literature review points out that the findings are merely guidelines because human morphology, posture, size, and weight vary greatly [11]. Two primary outcomes of antenna implantation within the human body are a reduction in the size of the implanted resonant antenna and a loss of gain [12]. This is due to the high conductivity and dielectric permittivity of bodily tissues. Due to the difference in the effective dielectric constants of the body material (K=56, σ = 0.8) and air (K=1, σ = 0), the resonant frequency shifts towards the left. The phantom and real organs have differing effective dielectric constants as well. Real digestive organs have empty interiors to provide room for food. Consequently, the real organs' effective dielectric constant is smaller than the phantom's. As a result, in genuine organs, the resonance frequency increases [13].

Anatomical models of a 34-year-old adult (height 1.74 m, weight 70 kg) and a 6-year-old boy (height 1.17 m, weight 19.5 kg) are compared in the study [14]. The SAR value is dependent on the dielectric properties of the organs surrounding the Tx antenna. SAR is maximum in the organs surrounding the Tx when their conductivity is high. SAR of child > adult since a child's muscle and fat layers are thinner than an adult's. Implantable antennas lose some of their radiated efficacy due to electromagnetic absorption in biological tissues.

The extremely lossy medium distorts radiation patterns, affects antenna performance, and changes behaviour. Consequently, as electromagnetic waves travel through the human body, they experience numerous reflections and significant attenuation. It is, therefore, necessary to develop effective antenna designs and novel methods to get around the lossy media effects and enhance implanted antenna performance [15].

Thus, creating a capsule antenna that operates steadily while it passes through various organs like the stomach, esophagus, small and large intestines, rectum, and anus has proven to be a difficult task.

Human esophageal, stomach, small intestine, and large intestine models have been developed for simulation to investigate the impact of anatomical features on the transmitting antenna's performance.

The antenna is placed in the center of the four GI tract models, as shown in Figure 2, and the accompanying simulated outcomes are continued into the subsequent section. The esophagus has been modelled by a circular cylinder.

Similarly, the stomach, large intestine, and small intestine have been modelled as spears, rectangular boxes, and circular cylinders. For ease of use and quicker processing times, the four models' small dimension values have been selected [16].

Table 2. Human body tissue dielectric properties at 4.3 GHz [10]

	Conductivity [S/m]	Relative Permittivity	Loss Tangent
Fat	0.21784	5.067	0.168
Muscle	3.6162	50.058	0.2823
Skin Wet	3.2126	40.105	0.3130
Stomach	4.6126	58.585	0.3076
Large Intestine	4.1198	50.357	0.3197
Small Intestine	5.2848	50.635	0.40785
Esophagus	5.2848	50.635	0.4078

Table 3. Human body tissue dielectric properties at 6.7 GHz [10]

	Conductivity [S/m]	Relative Permittivity	Loss Tangent
Fat	0.38729	4.8302	0.20017
Muscle	6.7225	46.592	0.36022
Skin Wet	5.7972	36.9	0.39223
Stomach	8.5178	53.953	0.39415
Large Intestine	7.4382	46.241	0.40159
Small Intestine	8.6239	46.412	0.4639
Esophagus	8.5178	53.953	0.39415

4. Antenna Design for Endoscopy Application

An Ultra-Wide Band (UWB) monopole ingestible capsule antenna that is miniature is designed and presented in this research. It is evident that the monopole antenna emits radiation in an omnidirectional manner, which enables it to capture photos of the exterior of the body as well as any capsule movements that are random within the digestive system [17]. With a -3 dB fractional bandwidth of 1.8%, the resonance frequency is around 4.3 GHz and the fractional bandwidth ranges from 4.25 GHz to 4.33 GHz. Similarly, -3 dB fractional bandwidth for 6.7 GHz resonant frequency is 9.56 %, ranging from 6.39 GHz to 7.03 GHz. In order to ensure reliable communication with the external receiver while lowering polarisation mismatch and multipath loss, the Circularly Polarised (CP) capsule antenna can be more appealing [18].

The reason for using Rogers TMM 13i substrate is its high relative permittivity and loss tangent values ($\varepsilon r = 12.85$, $\tan\delta = 0.0019$), which reduce the antenna's effective wavelength and aid in antenna miniaturisation. It is placed between the patch and the ground. In order to improve the radiation property, a partial ground plane is used.

The upper corners of the ground are eliminated in order to improve impedance matching and expand bandwidth. An additional plus (+) form slot is added to the patch's center. To increase the bandwidth and maximise the resonant frequency, a split ring resonator is positioned around the slot. The antenna's feed is received by a waveguide port. A matching piece of 1.6 mm width is employed as a feed line to supply the circular patch. The following Equations (1) and (2) [16] were used to calculate the conducting circular patch with a radius of 2.5 mm:

$$a = \frac{F}{\left\{1 + \frac{2h}{\pi \varepsilon_r F}\left[ln\left(\frac{\pi F}{2h}\right) + 1{,}7726\right]\right\}^{\frac{1}{2}}} \quad (1)$$

$$F = \frac{8.791 \times 10^9}{f_r \sqrt{\varepsilon_r}} \quad (2)$$

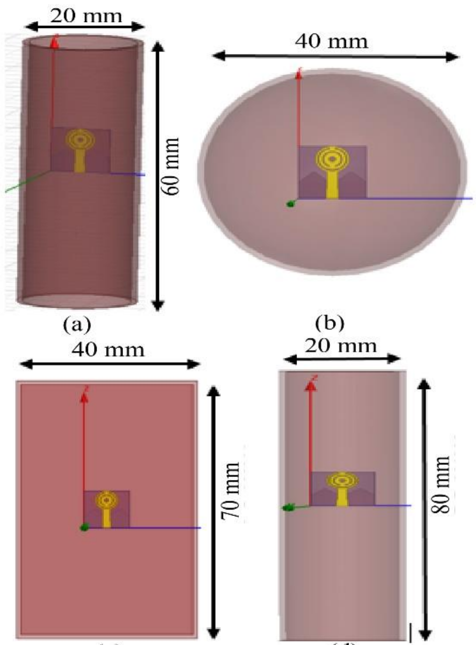


Fig. 2 The suggested antenna with GI tract models in (a) Esophagus, (b) Stomach, (c) Large intestine (d) Small intestine

Where, a is the patch's radius, ε_r is the substrate's dielectric constant, and f_r is the resonant frequency.

With a volume of 40 mm^3, or 10 mm × 10 mm × 0.4 mm, the planned microstrip patch antenna only makes up 1.26 percent of the capsule volume. Table 4 lists the recommended antenna's dimensions. Figure 3 shows the proposed antenna's structure. We use the high-frequency structure simulator (HFSS 13.0) for both the antenna design and simulations. The recommended antenna's reflection coefficient (|S11|) and 3D far field polar plot are shown in Figures 4 and 5, respectively. The figure shows that the antenna resonates at 4.6 GHz and 7.2 GHz. The suggested antenna's magnitude of reflection coefficient (|S11|) is -15.87 dB and -23.79 dB, respectively. A -3 dB bandwidth corresponds to 60 MHz at 4.64 GHz and 900 MHz at 7.2 GHz. The suggested antenna has a maximum gain of -21.25 dB. The antenna's 2-D far-field radiation pattern in the E-plane and H-plane, respectively, at the resonant frequencies of 4.6 GHz and 7.2 GHz, is shown in Figures 6 and 7. The radiation pattern shows that both planes of the antenna exhibit an omnidirectional radiation pattern.

Table 4. The proposed antenna's dimensions [16]

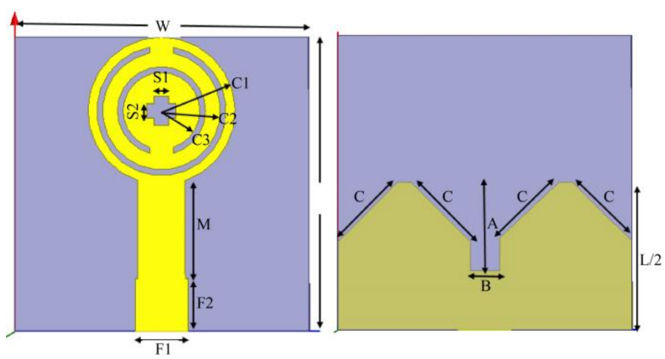
Parameters	Values (mm)
Substrate	length = 10, Width (W)= 10, Thickness = 0.4,
Patch	C1 = 2.5; C2 = 1.5; C3 = 1.3, S1 = 1; S2 = 0.5; Thickness = 0.25
Feed line	Thickness = 0.25, M = 3.2, F1 = 1.8; F2 = 1.8
Ground	Thickness = 0.25, A = 3; B = 1; C = 2.8283

5. Result Analysis

The following section discusses the antenna's functionality and safety measures when it operates inside the human body, i.e., the GI tract.

5.1. Esophageal Influence on Antenna Performance

Figure 8 displays the reflection coefficient (|S11|) of the ingestible capsule antenna located in the middle of the esophagus in the GI tract tissue models. The diagram clearly shows that the antenna resonates inside the esophagus at frequencies of 4.3 GHz and 6.7 GHz.



(a) **(b)**

Fig. 3 (a) Top view and (b) Bottom view of the microstrip patch antenna

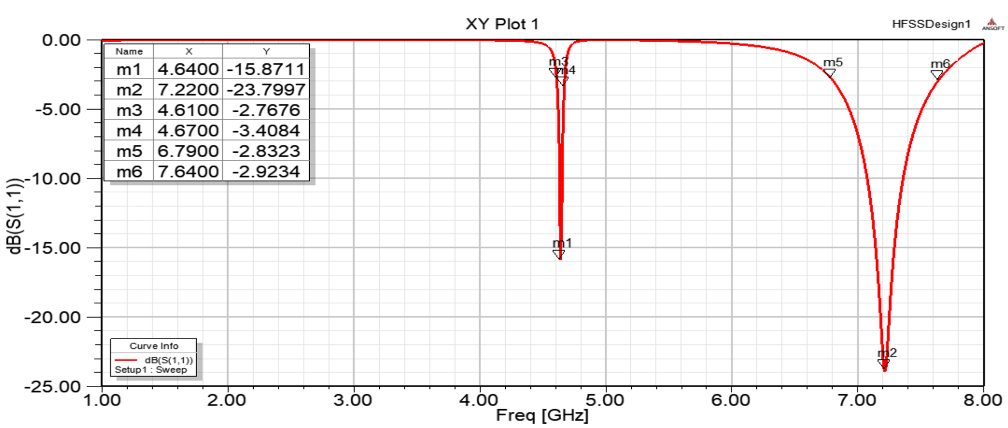
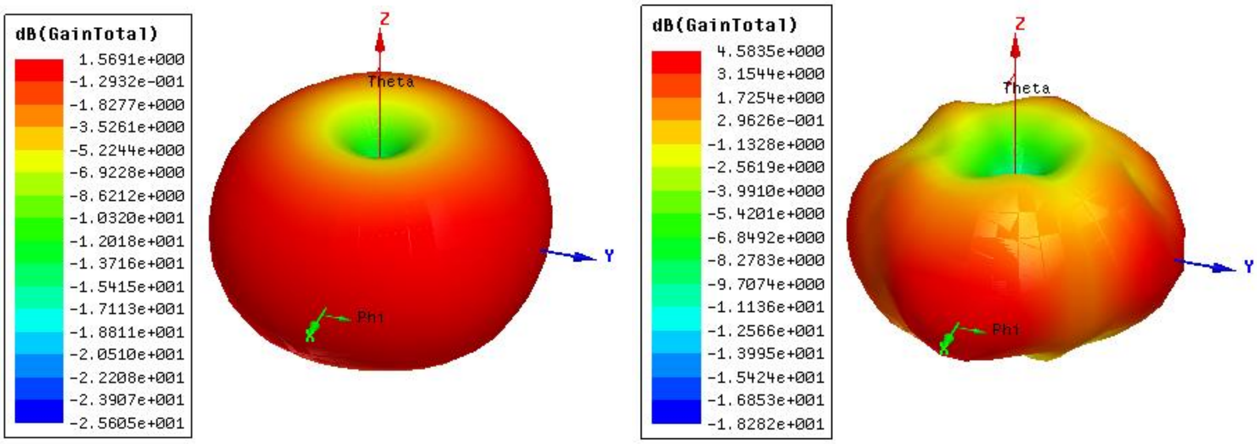
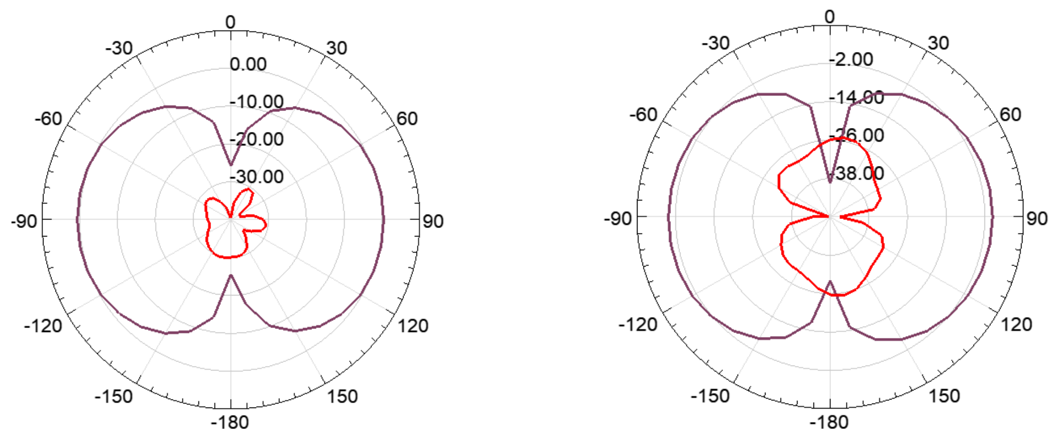


Fig. 4 Simulation result of reflection coefficient (S_{11})



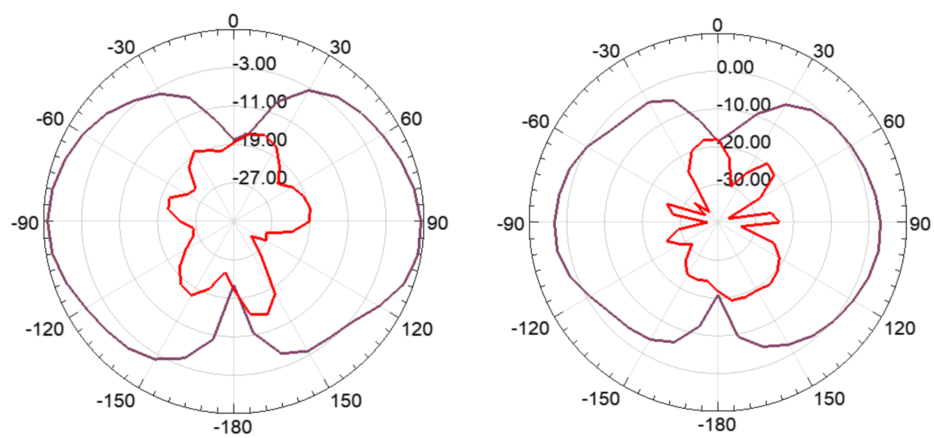
(a) **(b)**

Fig. 5 The proposed antenna's 3-D radiation pattern at (a) 4.3 GHz and (b) 6.7 GHz.



(a) **(b)**

Fig. 6 The proposed antenna's 2D far-field radiation pattern at 4.3 GHz (a) E-plane and (b) H-plane



(a) **(b)**

Fig. 7 The proposed antenna's 2D far-field radiation pattern at 6.7 GHz (a) E – Plane and (b) H – Plane

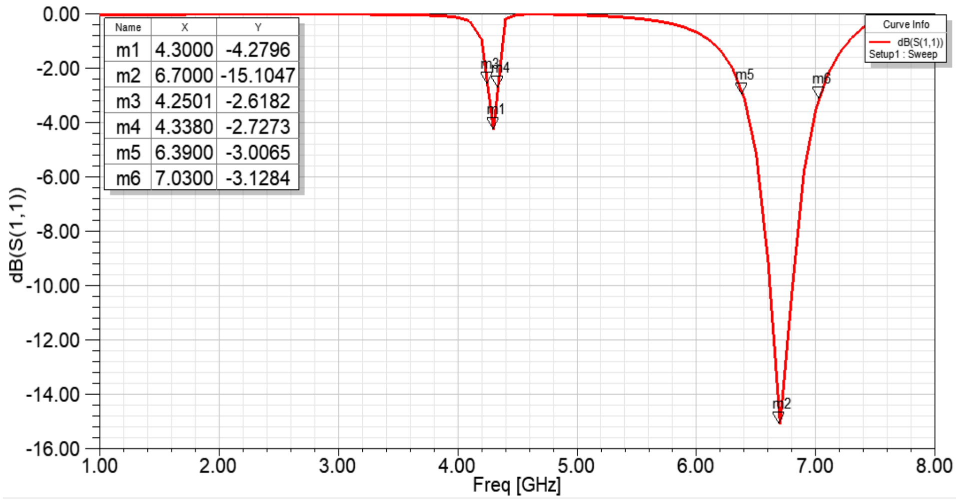


Fig. 8 Frequency responses of the antenna's reflection coefficient in the esophageal model

The ingestible antenna's magnitude (|S11|) reflection coefficient is -4.27 dB and -15.10 dB, respectively. -3 dB bandwidth at 4.3 GHz is 80 MHz, and at 6.7 GHz is 640 MHz. A three-dimensional polar map inside the esophageal tissue model is shown in Figure 9. The highest gain is roughly -18 dB. The two-dimensional far-field radiation pattern of the antenna at resonance frequency in the E- and H-planes is depicted in Figures 10 and 11. The radiation pattern shows that both planes of the antenna exhibit an omnidirectionality.

When the WCE is inserted inside the esophageal model, the simulated distributions of local SAR averaged across 10 g tissue are displayed in Figure 12. The standard limitations for IEEE C95.1-2005 are 2 W/Kg for 10g average SAR and 1.6 W/Kg for 1g average SAR, in compliance with IEEE C95.1-1999 standards. The maximum SAR is calculated as follows: 0.145 W/kg at 4.3 GHz and 0.198 W/kg at 6.7 GHz, averaged across 10g of tissue, for a 1W input power through the esophagus. The proposed capsule antenna design allows a maximum allowable net input power of 6.738 mW at 4.2 GHz and 288.99 mW at 6.7 GHz, in compliance with IEEE C95.1-2005. In the unlikely event that the capsule was to rupture unexpectedly, Rogers TMM 13i might not be harmful to the gastrointestinal tract because it is a ceramic thermoset polymer composite [17].

From Table 5, it is observed that the required -3 dB BW of at least 500 MHz for endoscopy application has been achieved at the resonant frequency of 6.7 GHz except for small and large intestines, where it came down to 390 MHz. At 6.7 GHz, the peak gain is about 1.6 dBi, the maximum radiated power is 372 mW, and the radiation efficiency is 96.09%.

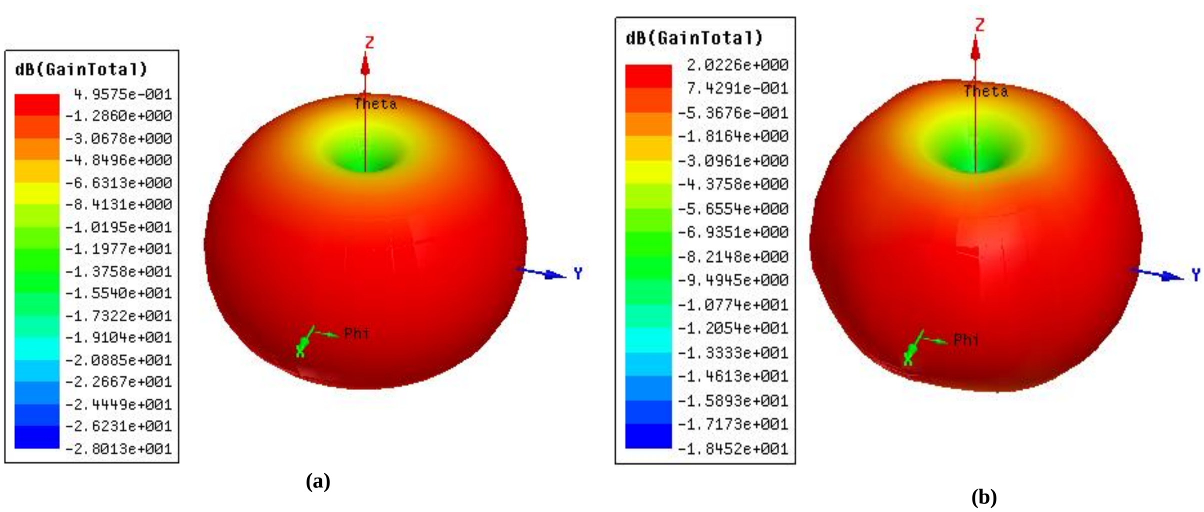
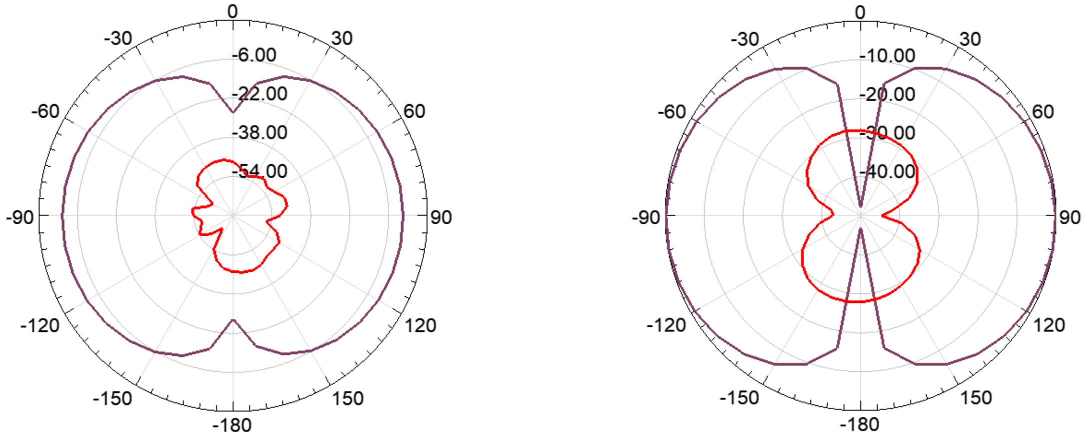
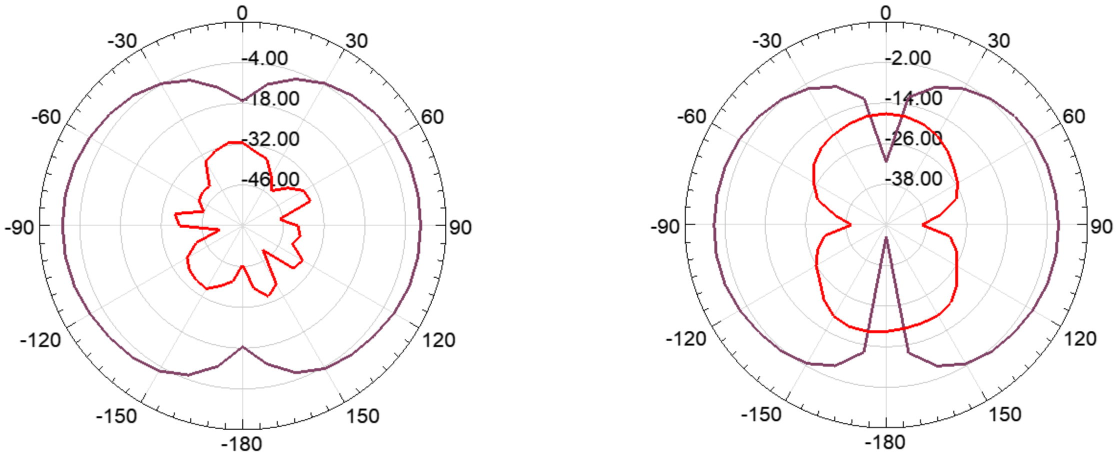


Fig. 9 3-D polar plot of the suggested antenna at (a) 4.3 GHz and (b) 6.7 GHz



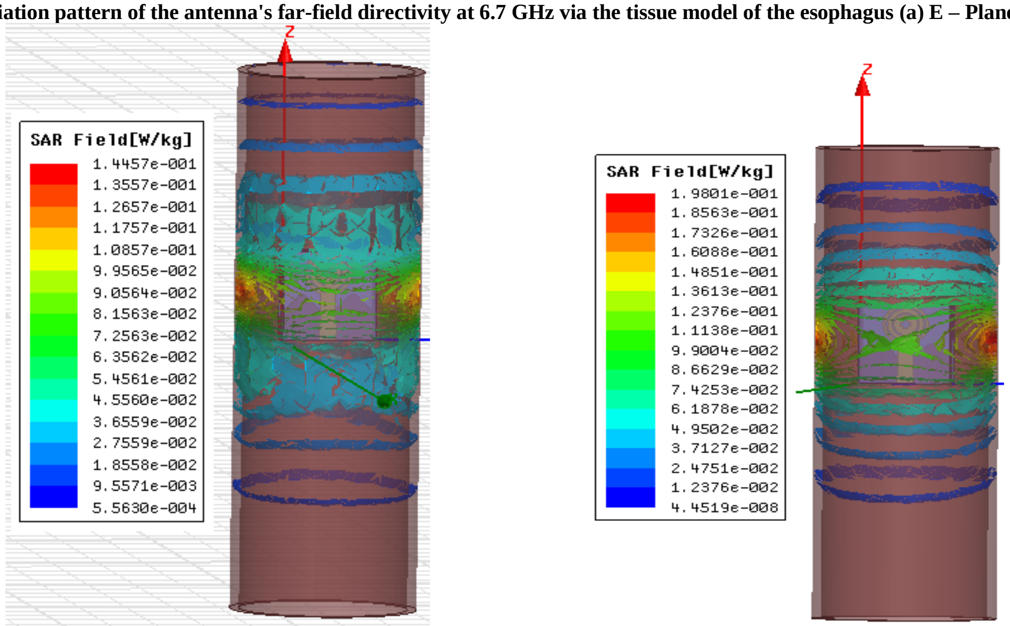
(a) (b)

Fig. 10 The radiation pattern of the antenna's far-field directivity at 4.3 GHz via the tissue model of the esophagus (a) E-plane (b) H-plane.



(a) (b)

Fig. 11 The radiation pattern of the antenna's far-field directivity at 6.7 GHz via the tissue model of the esophagus (a) E – Plane (b) H – Plane



(a) (b)

Fig. 12 Simulated local SAR distributions averaged over 1 g of tissue when the capsule antenna is inserted into the model of the esophagus a) 4.6 GHz b) 6.7 GHz

Table 5. Antenna parameters in different tissues at different frequencies (1 W Input Power)

Parameters	Esophagus		Stomach		Small Intestine		Large Intestine	
f_r (GHz)	4.3	6.7	4.3	6.7	4.3	6.7	4.3	6.7
|S11|dB	-4.27	-15.10	-9.239	-23.55	-6.102	-4.459	-7.17	-5.077
BW_{3dB} (MHz)	80	640	160	930	140	340	150	390
Fractional BW (%)	1.16	9.55	3.71	14.13	3.24	5.11	3.48	5.90
Radiation Efficiency (%)	86.38	95.65	85.40	96.09	81.27	85.18	75.10	71.43
Maximum Gain (dB)	-13.75	-18	-12.25	-22.15	16.60	-22.25	-11.70	-11.25
Max. SAR [W/kg]	0.145	0.198	0.0045	7.54	1.368	1050	234	208
Radiated power (mW)	0.430	276.4	0.372	372.1	9.48×10^{-5}	234.1	0.388	79.75
Accepted Power (mW)	6.738	288.9	6.884	387.3	7.41	665.2	7.60	129.81
Peak Gain (dBi)	0.108	1.603	0.0688	1.679	0.0309	0.613	0.1389	1.1951
Front to back ratio	2.385	1.068	1.2529	1.100	1.4126	1.768	2.3193	1.4425
Peak Directivity	1.702	1.676	1.274	0.0309	0.613	1.742	2.7225	1.9452

Table 6. Maximum power requirement of the proposed antenna to satisfy 1g SAR values (<1.6 W/Kg) for the esophagus, stomach, small intestine and large intestine

Parameters	Esophagus		Stomach		Small Intestine		Large Intestine	
f_r (GHz)	4.3	6.7	4.3	6.7	4.3	6.7	4.3	6.7
Max. Input Power(mW)	90	26	700	100	5	1.5	10	2.9
Radiated Power(mW)	38.887	22.683	248.5	96.762	0.4870	0.351	3.307	1.346
Accepted power(mW)	56.157	22.967	370.58	98.992	2.3426	0.998	6.7723	1.9893
Peak gain (dBi)	1.1209	1.5932	1.0854	1.6366	0.3693	0.6131	0.9264	1.2
Peak Directivity	1.6187	1.6131	1.6183	1.6743	1.7766	1.7425	1.8968	1.7724
Efficiency (%)	69.24	98.76	67.07	97.74	20.79	35.18	48.84	67.70

Table 7. Comparison of the proposed antenna with previously reported work

Reference	Antenna	Resonant frequency	Antenna Size	SAR Reduction technique	Increment in SAR (%)
[19] 2019	T-shaped planner antenna design	Multiple resonant (2.23, 2.4, 5, 5.8, 3, 3.5, 11.8 and 13.1)	(0.26×0.253×0.0059) λ for frequency 2.23 GHz (55×54×2.8) mm^3	Slotted circular shape and a complementary SRR	13.3
[20] 2021	Mobile phone model that exists on CST software	(1.602, 2.712, and 3.88) GHz	NA	(2×3) hybrid SRR array	Upto 36.64
[21] 2021	monopole antenna (2×2) rectangular EBG array with slots	Narrow bandwidth around (2.4, 3.5, and 5.8) GHz	(45.3×34.1×1) mm^3	(2×2) rectangular EBG array with slots	More than 25

[22] 2021	Microstrip antenna	Narrow bandwidth around 26 GHz	$(42.1\times32\times1.35)$ mm^3	(4×3) EBG array	More than 20
[23] 2021	Rectangular patch antenna, with two SRR	2.5 GHz and 5.5 GHz,	$(30\times18\times1.6)$ mm^3	Metamaterial slab consists of a (5×3) array of pentagon split ring resonator	14.5

Similarly, at 4.3 GHz, the peak gain is 0.13 dBi, maximum radiated power is 0.430 mW and Radiation efficiency is 6.38%. For better transmission, radiation efficiency needs to be improved while the antenna travels through the small and large intestines. SAR need to be reduced.

5.2. Characterization from Input Power Point of View

Table 6 displays the maximum power required by the proposed antenna to meet the 1g SAR values (<1.6 W/Kg) for the stomach, small and large intestines, and the esophagus. This table shows that the input power for 4.3 GHz will be 8 mW, and the input power for 6.7 GHz will be 3 mW, which satisfies IEEE and ICNIRP regulations.

6. Comparison of the Proposed Antenna with Existing Research Work

When constructing antennas for portable communication systems, one of the most crucial aspects to take into account is the Specific Absorption Rate (SAR) because the human body can suffer significant harm from the absorption of dangerous electromagnetic waves. Particularly when creating wearable or mobile phone antennas that are in direct contact with the human body, numerous characteristics, including antenna position, size, and thickness, can be controlled to lower the SAR value. From Table 7, it is observed that the proposed antenna gives the best miniaturization result, wide bandwidth, and omnidirectionality with allowable SAR value except for the small intestine. For better transmission, radiation efficiency needs to be improved while the antenna travels through the small and large intestines.

7. Conclusion

Size reduction, non-toxic substrate selection, omnidirectional radiation pattern, acceptable SAR preservation, and broad bandwidth maintenance are the fundamental issues facing WCE transmitting antennas. An antenna must be characterised in order to meet each of these requirements. This paper addressed the design, simulation, and analysis of a miniature UWB ingestible capsule antenna for wireless capsule endoscopy.

In HFSS, the antenna and its four operational zones, including the gastrointestinal tract, are modelled. According to the modelling results, the antenna has an operating frequency of around 4.3 GHz and 6.7 GHz with a -3 dB fractional bandwidth of about 1.16% and 9.55%, respectively. The antenna provides circular polarization with an omnidirectional emission pattern. From the comparative analysis, it is observed that the required -3 dB BW of at least 500 MHz for endoscopy application can be achieved at the resonant frequency of 6.7 GHz. At 6.7 GHz, the peak gain is about 1.6 dBi, and the maximum radiated power is 372 mW with a radiation efficiency of 96.09%. Similarly, at 4.3 GHz, the peak gain is 0.13 dBi, maximum radiated power is 0.430 mW and Radiation efficiency is 6.38%.

For better transmission, radiation efficiency needs to be improved while the antenna travels through the small and large intestines. The proposed single antenna can be used for all the GI tracts, although the dielectric constant varies across the entire GI tract. However, the existing literature needs different antennas for different GI tracts.

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