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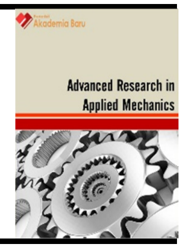

Octafilar Helical Antenna for Wireless In-Body Capsule Endoscopy Applications

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ABSTRACT

This paper introduces the design of circularly polarized octafilar helical antenna dedicated for wireless in-body capsule endoscopy applications at 2.4GHz. The use of the circular polarization antenna permits the freedom in capsule orientation during endoscopy process. A multi-layered cylindrical model for the human body tissues is used. The radiation characteristics of the OFHA encapsulated and placed inside the human model have been investigated. The OFHA in capsule module is resonant at 2.4 GHz with an impedance matching wide bandwidth of 125 MHz. The response of the OFHA with and without capsulation is studied. The electrical length of an implantable antenna increases due to high permittivity of the surrounding body tissues. The resonance frequencies for the OFHA with and without capsule is changed to 4.5 GHz and 5.8 GHz, respectively. The radiation characteristics of the OFHA antenna in different cases are analysed and investigated using the finite integral technique.

1. Introduction

Wireless in-body capsule endoscopy (WCE) is a medical diagnostic technique, which becomes an attractive area of antenna medical application. The WCE offers the advantage of being painless and requires no sedation unlike traditional endoscopies which are painful and time consuming [1]. The WCE is used to record images of the digestive tract for diagnosis and examine convoluted areas of the small intestine that cannot be viewed by other endoscopy techniques [2]. WCE is used to diagnose bleeding, iron deficiency, abdominal pain and tumours in the small intestine [3]. A wireless capsule consists of illuminating light emitting diode (LED), lens, camera, batteries, ASIC (application specific integrated circuit) transmitter and an antenna as shown in Fig. 1 [4].

The WCE procedure includes: 1) swallowing a small size capsule with a tiny camera attached to it. 2) The capsule moves through the digestive tract and takes images. 3) The captured images are transmitted to the on-body wireless receiving unit. 4) Physicians can interpret the images for diagnosis in the real time or offline. The antenna plays an important role in the in-body capsule microscopy. The antenna design has many challenging requirements such as compact size, low

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profile, and wide bandwidth to exhibit robustness against the detuning. The antenna should radiate an omnidirectional pattern to keep the continuous communication with an on-body receiver irrespective of the capsule orientation [5]. Two antenna types have been described in the literature, such as embedded and conformal structures. The embedded antennas are placed inside the capsule module, while conformal antennas are designed on the surface of a capsule module. In the conformal antenna structure, the interior portion of the capsule module is filled with other electronic components [6, 7]. Different antenna shapes are described in literature for WCE such as, magnetic loop antennas, U-shaped patch and helical antennas [8-9]. Resonant quadrifilar helical antenna (QFHA) and octafilar helical antenna (OFHA) are used in a mobile communication, GPS, and radio frequency identification applications [10]. The advantages of the OFHA are its cardioid pattern, circular polarization and relatively small size compared to other antennas.

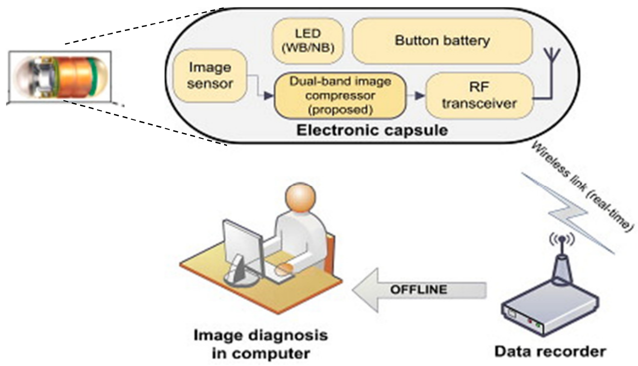
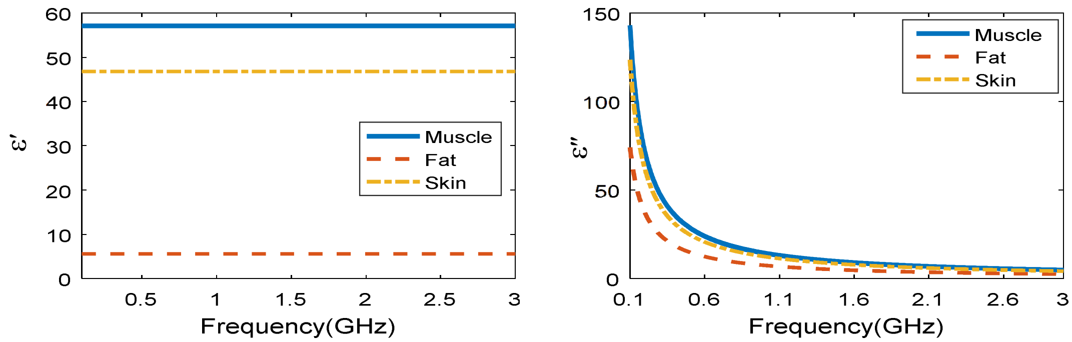


Fig. 1. Schematic diagram of wireless capsule endoscopy system [4]

In this paper, the radiation characteristics conformal OFHA WCE at 2.4 GHz are investigated. The OFHA is designed taking into account the effect of the encapsulation material and the human body characteristics. A cylindrical multilayer module is used to implement the dispersive properties of the human body. The finite integration technique (FIT) [11] is employed to analyse the antenna structure and the results are compared with that calculated using finite element method (FEM) [12]. A comparison between the performance of the conformal OFHA in capsule module embedded in the human body and OFHA in free-space is investigated.

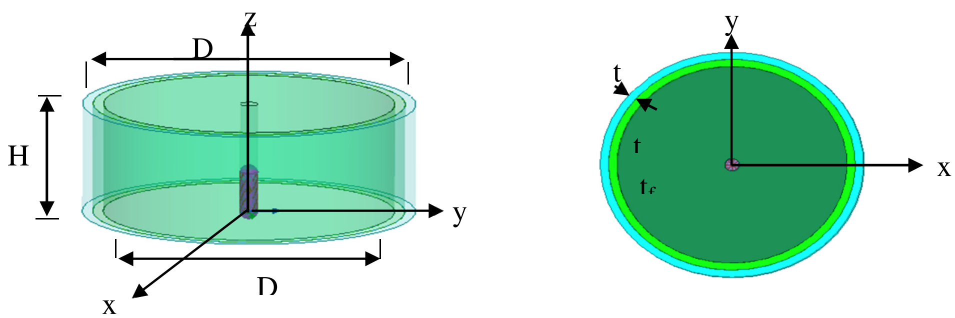
2. Electrical Properties of the Body Tissues

The human body is considered as an inhomogeneous multilayer medium of frequency dependant dispersive materials. The tissue layers have different composition and electrical properties, such as permittivity, conductivity and loss tangent [5]. The frequency response of permittivity and conductivity of different human tissue is shown in Fig. 2. The real part of the permittivity, ε′ remains constant, where the fat tissue has a low dielectric constant of ε'_r=5.6. The imaginary part of permittivity, ε″, decreases with frequency.



(a) ε′ (b) ε″

Fig. 2. The electrical properties of the skin, fat, and muscle tissues of the human body



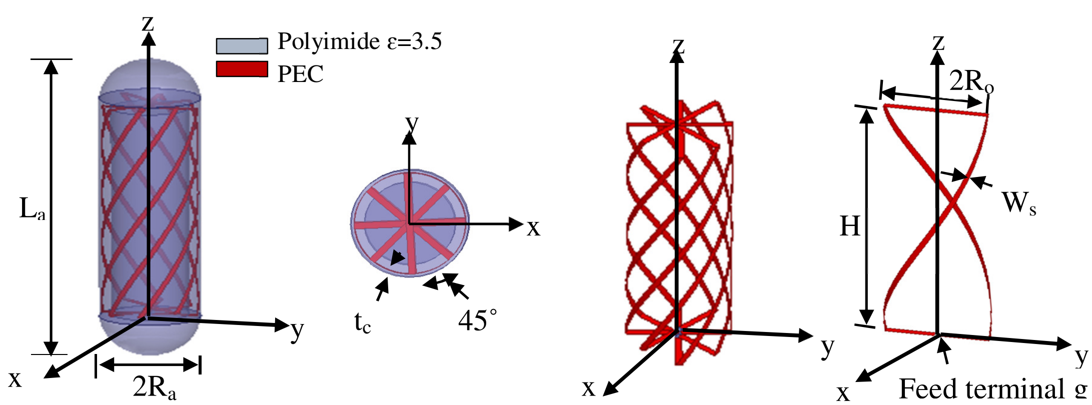
(a) 3-D view (b) Top- view

Fig. 3. The structure of multi-layered cylindrical body module with embedded capsule

Table I

The dispersive properties of the human body tissues at 2.4 GHz

Tissue	Relative permittivity	Loss tangent
Muscle	57.129	0.10433
Fat	5.5798	0.5526
Skin	46.787	0.11007
Encapsulation material(Polyimide)	3.5	0.0025



(a) 3-D view of capsule module (b) 3-D View of the conformal OFHA

Fig. 4. The detailed construction of the capsule model with OFHA on its surface

2.1 OFHA Embedded in Body Model Design

Multi-layered cylindrical model is used to simulate the human body tissues [5] with the capsule model embedded in its centre. The model provides an accurate estimation of reflections and absorptions in different body tissues. Figure 3 shows an implantable capsule module inside a three layered cylindrical model which consists of skin, fat, and muscle. The dimensions of the cylindrical model are: skin tissue is 6.4×6.4×5 cm^3 with thickness 4 mm, fat tissue is 6×6×5 cm^3 with thickness 4 mm, and muscle tissue is 5.6×5.6×5 cm^3 with thickness 52 mm. The dispersive properties of different tissues at 2.4 GHz are listed in Table I. A capsule module with conformal OFHA on its surface, is embedded in the centre of the human body model. The capsule diameter is 3.53 mm, length is 25 mm, and its shell thickness is 0.82 mm of flexible Polyimide substrate (ε_{rc} = 3.5 and tan δ = 0.0003) as shown in Fig. 4a. The OFHA antenna consists of four identical bifilar helices arranged coaxially with 45^o degree separation to each other in space as shown in Fig. 4b. The rectangular coordinates of any arbitrary point on the bifilar element are given by [10]

$$\begin{aligned} x &= R_o \cos(u + \pi p / 2) \\ y &= R_o \sin(u + \pi p / 2) \\ z &= R_o\, u \tan \alpha \end{aligned} \tag{1}$$

where p=0 and p=2 for helix arms. u is the angle measured from the x-axis, started from **u=0** and ended at **u=2πN**, R_o is the helix radius, and α is the pitch angle. The four identical helices compromising the OFHA are fed from a phasing network producing a phase progression of 45^o degrees. The OFHA dimensions are optimized to operate at 2.4 GH, R_o= 3.3 mm, H= 8.85 mm, and N=0.5. The antenna strip has width W_s = 0.4 mm. The antenna is fed via coaxial cable at the bottom end of the antenna with feeding gab g = 0.4 mm. The antenna has no ground plane.

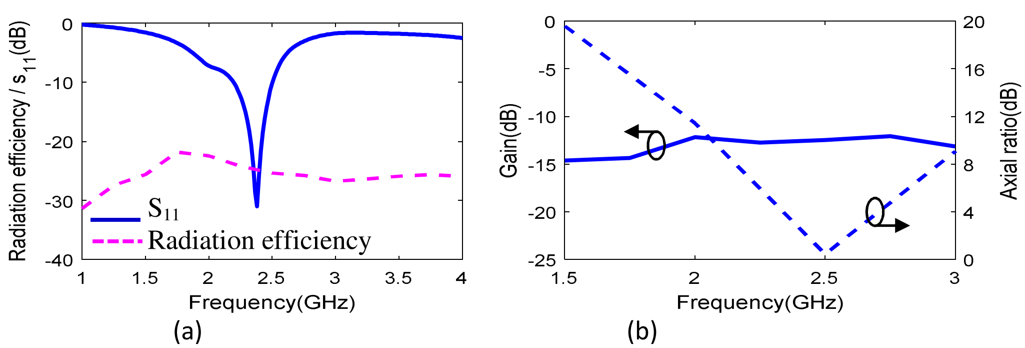
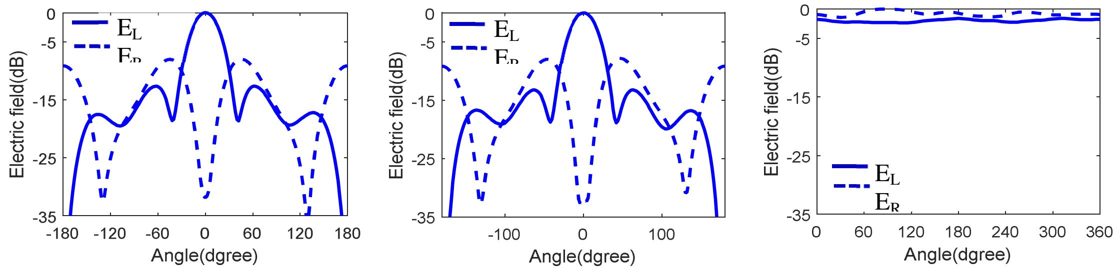


Fig. 5. (a) The reflection coefficient and radiation efficiency responses, (b) The gain and axial ratio responses of the capsule module embedded in the human body model

The reflection coefficient and radiation efficiency responses of the capsule module embedded in the human body model is shown in Fig. 5a. The capsule module is resonant at 2.4 GHz with impedance matching wide bandwidth of 125 MHz to overcome the detuning effect of body materials. The capsule module introduces radiation efficiency of -24.8 dB at 2.4 GHz with a variation of 9 dB over the operating frequency band. The gain and axial ratio variations versus frequency are shown in Fig. 5b. The gain is changed within 2.5 dB, while the 3-dB axial ratio bandwidth is 270 MHz. The capsule module introduces a gain of -12.58 dB and the axial ratio of 1.4 dB at 2.4 GHz. The normalized left hand, E_L, and right hand, E_R, circular polarization field components of capsule module in the body model at f=2. 4 GHz are shown in Fig. 6. The omnidirectional CP pattern is obtained in x-y plane with high front to back ratio for E_L of 32 dB is obtained in x-z and y-z planes. The half-power beamwidth (HPBW) is 64 degrees.

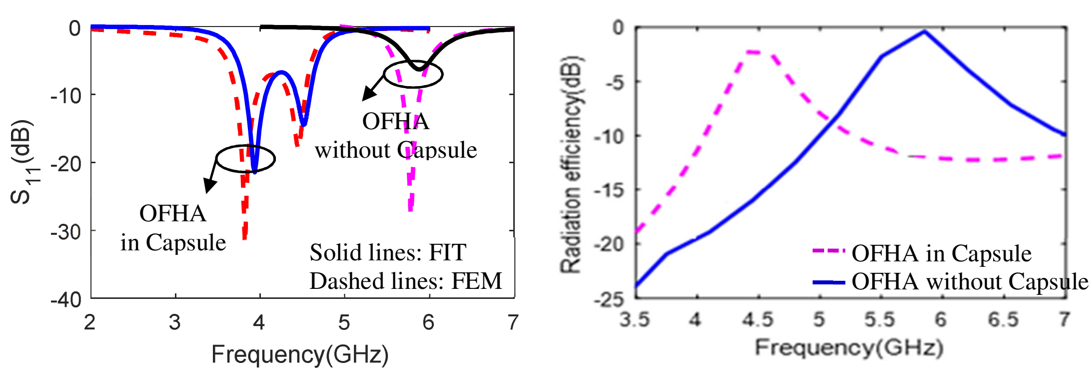


(a) x-z plane (b) y-z plane (c) x-y plane

Fig.6. The circular polarization radiation patterns of the capsule module embedded in the human body model at 2.4 GHz in different planes

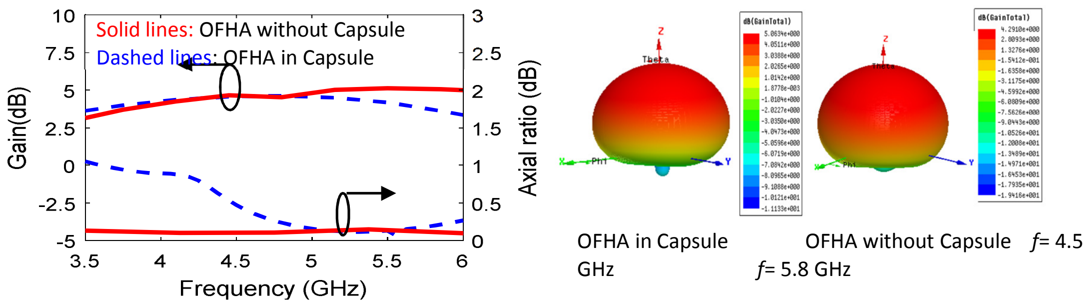
2.2 Design Conformal OFHA in Capsule Model in Free Space

The electrical properties of body tissues affect the characteristics of an antenna, such as electrical length, radiation efficiency and gain. The electrical length of an implantable antenna increases due to high permittivity of the surrounding body tissues. However, in capsule/without capsule in free-space, the antenna size becomes large at 2.4 GHz and miniaturization techniques are required for its dimensions. Therefore, a higher resonant frequency is obtained as compared to the embedded case in-human body scenario for the given fixed dimensions of the OFHA antenna. This phenomenon is called as dielectric loading effect. The reflection coefficient responses of the antenna inside the capsule module and in free-space are shown in Fig. 7a. The capsule module introduces a resonance frequency of 4.5 GHz, while 5.8 GHz for antenna in free-space without encapsulation. The encapsulation material introduces wider impedance matching bandwidth of 228 MHz compared to the free-space case. Both structures are simulated using the FEM and compared to the FIT. Good agreements between results are obtained. The variation of radiation efficiency versus frequency is shown in Fig. 7b.



(a) (b)

Fig. 7. (a) The reflection coefficient, (b) The radiation efficiency responses of the OFHA in capsule module and without capsule.



(a) (b)

Fig. 8(a). The gain and axial ratio versus frequency (b) 3-D gain patterns at the resonance frequencies of the OFHA in capsule module and without capsule

The OFHA in free space introduces high efficiency of -0.4 dB. A lower efficiency for the OFHA in the capsule module compared to free-space scenario due to the losses in the encapsulation material. The gain and axial ratio variations for the OFHA in capsule module and in free-space are shown in Fig. 8a. A nearly constant gain of about 5 dB is obtained with broadband circular polarization covering the entire frequency band. The 3-D gain patterns for the OFHA in capsule module at f=4.5GHz, and in free-space at f=5.8GHz are shown in Fig. 8b. A directive broad beam radiation with broad beam with HPBW of 123 degrees is introduced.

3. Conclusion

In this paper, a circularly polarized octafilar helical antenna is designed and analysed for 2.4 GHz wireless in-body capsule endoscopy applications. The WCE system records images of the digestive tract and transmit it wireless to receiving unit. The human body tissues are simulated using a multi-layered cylindrical model with the capsule placed in its centre. The capsule module introduces radiation efficiency of -24.8 dB with a variation of 9 dB over the operating frequency band. The 3-dB axial ratio bandwidth is 270 MHz. Omnidirectional CP pattern is obtained in x-y plane. The front to back ratio of E_L is obtained in x-z and y-z planes and equal to 13 dB. An investigation of the OFHA performance with and without capsule module is presented. The OFHA in free space introduces high efficiency of -0.4 dB. A nearly constant gain of about 5 dB is obtained with broadband circular polarization covering the entire frequency band.

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