Wireless Capsule Antennas

Eng Gee Lim, Jing Chen Wang, Zhao Wang, Gerry Juans, Tammam Tillo, Ka Lok Man and Meng Zhang

***Abstract*—Wireless capsule endoscopy (WCE) has conquered several limitations of traditional diagnostic tools such as cable discomfort and the inability to examine the more convoluted regions of the intestines. However, this technique requires further improvements before it can be implemented. The antenna plays a major role in transmitting and receiving signals in such a system. Transmission efficiency of the antenna will determine the quality of images received in real-time. This paper reviews the state-of-the-art WCE transmitting antennas. Two types of popular antenna structures will be discussed.**

***Index Terms*—WCE, spiral antenna, embedded antenna, outer wall antenna**

I. Introduction

WITH the invention of WCE, patients no longer have to bear the discomfort of conventional endoscopic methods. In addition, it has opened doors to a new research field whose goal is to develop an ingestible robotic device with full diagnostic and treatment capabilities for gastrointestinal (GI) tract diseases [1]. Existing diagnostic capsules have several limitations. Firstly, most capsules are powered by an internal battery cell that restricts capsule miniaturization. Secondly, current systems are incapable of maintaining a continuous communication link due to random orientations of the capsule [2]. Therefore, an efficient communication link between the in-body capsule and the ex-body receiver unit is important for the development and applicability of WCEs.

The role of a WCE-embedded antenna is to transmit data signals; hence the signal transmission efficiency of the antenna will determine the quality of received real-time images as well as the rate of power consumption, which directly affects battery life. The human body is a lossy dielectric material which absorbs a number of waves and attenuates the power of received signals, thus having a strong negative influence on microwave propagation. Therefore, the antenna elements should possess the following features: First of all, the ideal WCE antenna should be relatively insensitive to human tissue influence. Secondly, the antenna should have enough bandwidth to transmit high resolution images and large amount of data. Lastly, enhancement of antenna efficiency should facilitate lower power consumption and high data rate transmission [3]. Recently, researchers are focused on two types of antenna structures: embedded and conformal antennas.

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II. The Embedded Antenna

The WCE communication system requires the transmitter to be compact, consume low power, and to be optimized for signal transmission through the human body. Designing such an antenna is a daunting task. The design must fulfill several requirements to be an effective capsule antenna such as miniaturization to save precious space in the capsule cavity, omnidirectional radiation pattern in order to maintain data transmission regardless of the orientation and location of the capsule or receiver, as well as tuning adjustment to compensate for in-body effects. In order to meet the above requirements, embedded antennas are used in WCE and they will be described in this section.

A. *Spiral Antenna*

The first design is a miniaturized normal mode helical antenna with the conical structure. A research group from Yonsei University, South Korea, proposed a series of spiral and helical antennas providing ultra-wide bandwidth at hundreds of megahertz. One is a single arm spiral antenna [4], and another is a dual arm spiral antenna [5].

The single spiral-shaped antenna is designed with the spiral arm length of a quarter-wavelength. The configuration of the designed antenna is shown in Fig. 1 (a). It is composed of a radiator and probe-feeding structure. The proposed antenna is fabricated on a substrate with 0.5-oz copper, 3 mm height, and dielectric constant of 2.17. The diameter of the antenna is 10.5 mm with 0.5 mm width conductor.

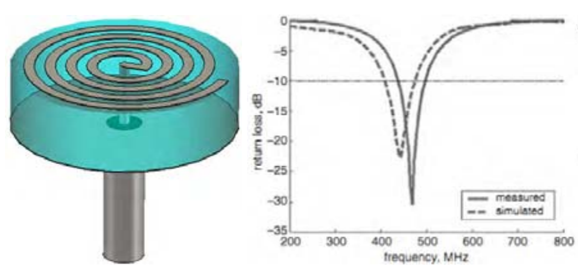

Fig. 1. Single arm spiral antenna: (a) The structural geometry and (b) simulated and measured return losses

The simulated and measured return losses of the antenna surrounded by the human body equivalent material are shown in Fig. 1 (b). It can be observed that the bandwidth of the

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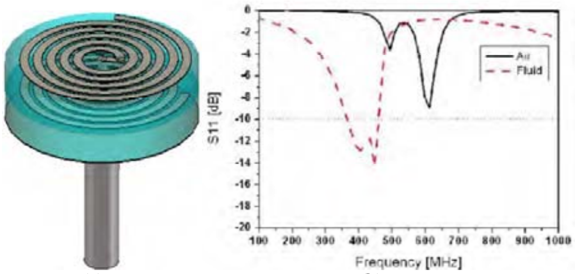
proposed spiral shaped antenna for S11 < -10dB is 110 MHz of 400 - 510 MHz and the fractional bandwidth is 24.1%, which is larger than 20%, the reference for UWB fractional bandwidth.



(a) (b)

Fig. 2. Dual arm spiral antenna: (a) The structural geometry and (b) measured return losses

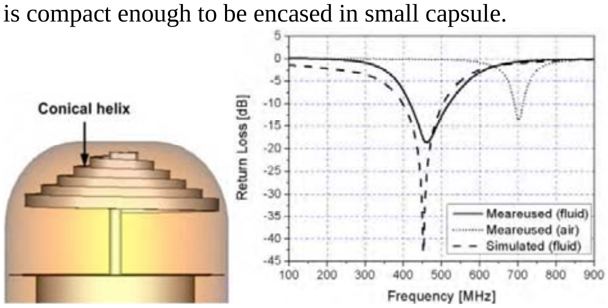
The dispersive properties of the human body suggest that signals are less vulnerable when they are transmitted at lower frequencies. Therefore, a modified design in [5] is proposed to provide ultra-wide bandwidth at a lower frequency range.

Fig. 2 (a) shows the geometry of a dual spiral antenna. The newly proposed antenna is composed of two spirals connected to a single feeding line. The radius of the antenna is 10.1 mm and its height is about 3.5mm. To design a dual spiral antenna, two substrate layers are used. The upper and lower layers have the same dielectric constant of 3.5 and the thicknesses are both 1.524 mm. Two spirals with the same width of 0.5 mm and gap of 0.25 mm have different overall lengths. The lower spiral antenna is a 5.25 turn structure and the upper spiral has 5 turns.

The return loss of the proposed antenna was measured in air and in simulated fluid of human tissue as shown in Fig. 2 (b). Due to the electrical properties of the human body equivalent material, return loss characteristic in the air is poor although dual resonant characteristic can be observed. However, the proposed antenna has low return loss at the operating frequency when submerged in the fluid, with a bandwidth of 98 MHz (from 360 MHz to 458 MHz), or fractional bandwidth of about 25%.

B. Conical Helix Antenna

Extensive studies of helical and spiral antennas were conducted with modified geometric structures. For example, a conical helix antenna [6] fed through a 50 ohm coaxial cable is shown in Fig. 3. A conical helix antenna is bigger than a spiral antenna. However, additional space is not necessary because a conical helix antenna may utilize the tip of the capsule as shown in Fig. 3(a). The radius of the designed antenna is 10 mm and the height is 5 mm. This size is compact enough to be encased in small capsule.



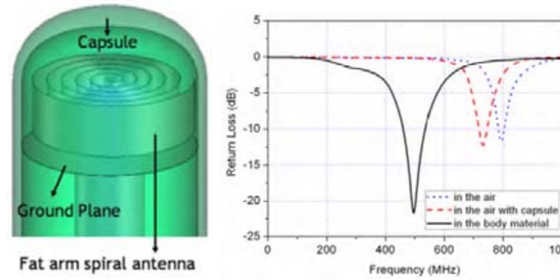
(a) (b)

Fig. 3. Conical helix antenna: (a) The structural geometry and (b) simulated and measured return losses

The proposed antenna provides a bandwidth of 101 MHz (from 418 MHz to 519 MHz) in the human body equivalent material as shown in Fig. 3(b). Its center frequency is 450 MHz, therefore the fractional bandwidth is about 22%.

C. Fat Arm Spiral Antenna

Another modified design is the fat arm spiral antenna [7] as shown in Fig. 4(a). The spiral arm is 3 mm wide and separated from the ground plane with 1 mm of air gap. The antenna is simultaneously investigated in the air, in the air with its capsule shell and in the human body equivalent material.



(a) (b)

Fig. 4. Fat arm spiral antenna: (a) The structural geometry and (b) return losses

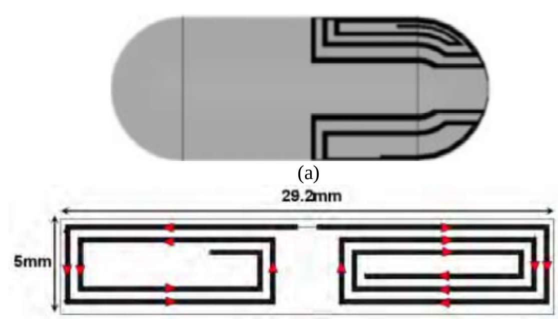
The return losses of the antenna in free space, with the dielectric capsule shell and in the liquid tissue phantom are plotted in Fig. 4 (b). The resonant frequency is observed to be about 500 MHz in the air, and reduced to 730 MHz due to the capsule's effect on the effective dielectric constant and matching characteristic. When the proposed antenna is submerged in the fluid, it shows good matching at the resonant frequency of 800 MHz and its bandwidth is 75 MHz (460 ~ 535 MHz) for S11 less than -10dB.

III. The conformal antenna

A conformal geometry utilizes only the surface of the capsule and leaves the interior open for electrical components such as the camera system. The antennas tend to be part of the capsule outer wall to minimize space. Several designs which make efficient use of the capsule shell area are selected as examples and introduced in this subsection.

A. Conformal Chandelier Meandered Dipole Antenna

The conformal chandelier meandered dipole antenna [8] is investigated as a suitable candidate for wireless capsule endoscopy.



(b)

Fig. 5. Conformal chandelier meandered dipole antenna: (a) The structural geometry of the conformal chandelier meandered dipole antenna; (b) Offset Planar Meandered Dipole Antenna with current alignment vectors.

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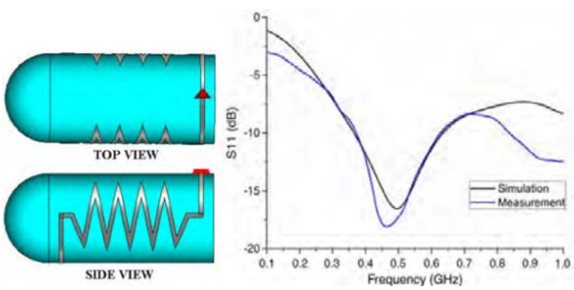
The uniqueness of the design is its miniaturization process, conformal structure, polarization diversity, dipole-like omnidirectional pattern and simple tunable parameters (as shown in Fig. 5 (a)). The antenna is offset-fed in such a way that there is an additional series resonance excited in addition to the parallel resonance (as shown in Fig. 5 (b)). The two arms with different lengths generate the dual resonances. This additional series resonance provides better matching at the frequency of interest. This antenna is designed to operate at around the 1395 MHz – 1400 MHz wireless medical telemetry services (WMTS) spectrum.

B. Outer-wall loop antenna

The proposed outer-wall loop antenna [9] makes optimal use of the capsule's outer surface, enabling the antenna to be larger than the inner antennas. As shown in Fig. 6 (a), the antenna is part of the capsule outer wall, thus volume is minimized while improving performance. It uses a meandered line for resonance in an electrically small area. The capsule shell with relative permittivity of 3.15 has the capsule's inner and outer radius of 5 mm and 5.5 mm respectively. Its length is 24 mm. The height of the meander line and gap between the meander patterns are set to 7 mm and 2.8 mm respectively. The opposite side of the loop line is meandered similarly. Although capsule size is reduced, the sphere radius enclosing the entire structure of the antenna is increased.



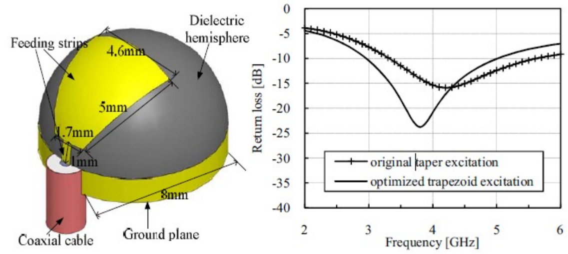
(a) (b)

Fig. 6. Outer-wall loop antenna: (a) The structural geometry; (b) simulated and measured return losses

Fig. 6 (b) shows that the proposed antenna has an ultra-wide bandwidth of 260 MHz (from 370 MHz to 630 MHz) for VSWR < 2. Using identical antenna pairs in the equivalent body phantom fluid, antenna efficiency is measured at 43.7% (3.6 dB).

C. Conformal Trapezoid Strip Excited Hemispherical Resonator Antenna

A conformal trapezoid strip excited broadband hemispherical dielectric resonator antenna (DRA) [10] is proposed with ultra wide-band (UWB) low band of 3.1 - 4.8 GHz for medical capsule endoscopy applications. Fig. 7 (a) shows the structural dimensions of the hemispherical DRA with radius of 5 mm and dielectric constant of 3. Hemispherical DRAs can make use of the capsule dome volume allocated for the antenna. The surrounding medium of the capsule antenna can be approximately determined as one homogeneous layer with average dielectric constant of 51.5 and average conductivity of 3.2 S/m.



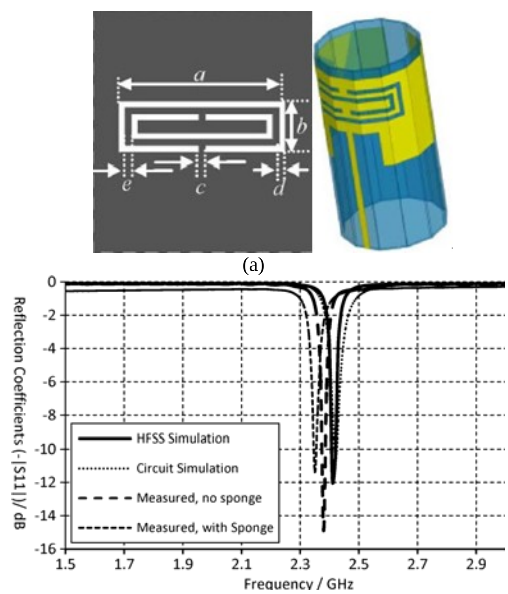
(a) (b)

Fig. 7. DRA: (a) The structural geometry; (b) Simulated return losses of original taper excitation and optimized trapezoid excitation in tissue-simulating fluid phantom

Fig. 7 (b) compares the return loss performance for the tapered excitation and the optimized trapezoid excitation. As can be seen, the optimized trapezoid excitation gives better return loss performance with 10dB bandwidth from 3 to 5 GHz.

D. A Self-packaged Patch Antenna with Complementary Split-ring Resonator

A patch loaded with a complementary split-ring resonator (CSRR) [11] is fabricated on a flexible substrate with a dielectric constant of 2.2 and folded in a cylindrical shape, forming a self-packaged folded patch antenna with a quasi-omnidirectional radiation pattern. A schematic diagram is shown in Fig. 8 (a). A 74% size reduction is achieved after CSRR loading.



(b)

Fig.8. (a) Planar CSRR; Dimensions: a = 13 mm, b = 4 mm, c = d = e = 0.5 mm; (b) Simulated and measured antenna return loss

The measurement and simulation results are plotted in Fig. 8 (b). They show good agreement within approximately 1% tolerance.

E. A Conformal Outer Wall Antenna

The capsule size is limited by the size of the antenna, but the resonant frequency of the designed antenna is around 500 MHz, which has a free-space wavelength that is much larger than the capsule length. The miniature sizes of antennas A3 [12] and B2 [13] have been successfully designed and the physical layouts of antennas A3 and B2 are shown as in Fig. 9.

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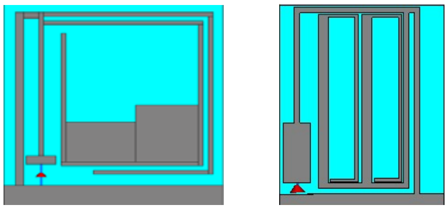
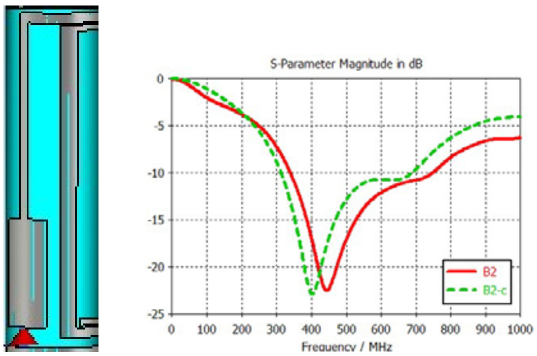


(a) Antenna A3 (b)Antenna B2

Fig. 9. Physical layout of antennas A3 and B2

The size of the antenna A3 is 23 mm × 24 mm, and it has a large bandwidth from 360 MHz to 580 MHz



(a) (b)

Fig. 10. A conformal outer wall antenna: (a) Physical layout of conformal antenna B2-c; (b) Return loss of conformal antennas B2 and B2-c.

To minimize capsule space, the conformal antenna B2 is adhered to the surface of a dielectric layer forming the capsule shell. The dielectric constant of this shell is 4.4, as illustrated in Fig. 10 (a). The antenna is placed at the center of a body-equivalent material with dielectric constant of 56 and conductivity of 0.8 S/m. Compared to the currently used capsule (radius 11 mm, length 26 mm), antenna B2 can be attached to the surface of a smaller one (radius 4.8 mm, length 20.6 mm). The smaller capsule may be used for children or adults with swallowing difficulties. Fig. 10 (b) shows antennas B2 and B2-c which have a wide bandwidth ranging from 330 MHz to 750 MHz and from 310 MHz to 690 MHZ for VSWR < 2. Furthermore, the antenna is insensitive to the radius of the capsule and hence fabrication tolerance is higher.

IV. Conclusion

Because lossy material absorbs a number of waves and attenuates the power of received signal, the human body has a strong negative influence on microwave propagation. The signal transmission efficiency of the antenna will determine the quality of images received in real-time as well as the rate of power consumption. This paper reviewed a number of state-of-the-art WCE transmitting antennas. Two types of antenna structures were discussed; one is the embedded antennas and the other is the conformal antenna. All of them have omnidirectional radiation patterns. In order to make the WCE smaller, the size of the transmitting antenna should be as small as possible. The bandwidth of the antennas however, should be as wide as possible in order to transmit high resolution images and large amount of data.

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