The UHF Band In-body Antennas for Wireless Capsule Endoscopy

Eng Gee Lim, Jing Chen Wang, Zhao Wang, Tammam Tillo and Ka Lok Man

***Abstract*—Wireless Capsule Endoscopy (WCE) has conquered several limitations of traditional diagnostic tools, such as the cable discomfort and the inability to examine the convoluted intestinal regions. However, this technique requires further improvement before it can be implemented. Antenna plays a major role in transmitting and receiving signals in such a system. Transmission efficiency of the antenna determines the quality of images received in real-time. This paper reviews the state-of-the-art WCE transmitting antennas focusing on the design and analysis issues. Extensive investigations are carried out on the development of WCE antennas from the past to the present in two parts. First, the WCE antenna designs including embedded and conformal antennas are introduced and reviewed. Then, two new ideas (case studies) for the design of WCE antenna with about 400MHz bandwidth and omni-directional radiation patterns are introduced，which satisfy the system requirements for WCE. This paper also presents the challenges and prospective of WCE in the future.**

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

I. INTRODUCTION

THE organization American Cancer Society reported that in 2010 the number of cancers related to the gastrointestinal (GI) tract is approximately 149,530 in the United States [1]. In most of these cases timely detection and diagnosis are extremely important since the majority of GI-related cancers caught in the early stages are potentially curable.

Gastroscopy is typically used for the diagnosis of the upper gastrointestinal tract which includes the esophagus, stomach and duodenum. It is a technique in which a long flexible tube equipped with a CCD or fiber-optic camera is inserted into the oral cavity for diagnosis, surveillance, and diagnostic verification of biopsy procedures, as well as therapeutic interventions. For colon and rectal examination, colonoscopy may be employed. The basic working principle of colonoscopy is similar to gastroscopy. However, it is passed through the anus. Gastroscopy and colonoscopy allow the coverage of two important areas of the gastrointestinal track. However, the small intestine, which represents most of the digestive tract, lies beyond the reach of the two aforementioned techniques.

The small intestine in the GI tract is characterized by being very long (average length is 7 meters) and very convoluted. Therefore, the non-invasive Wireless Capsule Endoscopy (WCE) technique was proposed to enable visualization of the entire GI tract.

Development of WCE began in the early 1980s and it is still ongoing, passing through the crucial moment in 2001 when it was approved by the U.S. Food and Drug Administration (FDA). The WCE, as an ingestible capsule, is able to take pictures during its course through the digestive tract including the stomach, large bowel or colon and part of the small bowel after being swallowed. Accordingly, the WCE communication system requires the transmitter to consume minimal power, to be minuscule, and to be optimized for signal transmission through the human body. Fig. 1 shows the typical components within an imaging capsule system with dimensions 11 mm × 26 mm [2].

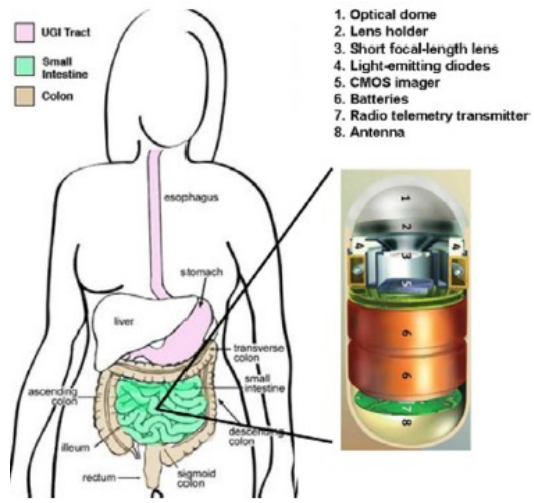


Fig. 1. Biotelemetric imaging capsule components

The capsule endoscopy system is composed of several key parts (shown in Fig. 1): image sensor, lighting, control unit, wireless communication unit, power source, and mechanical actuator. The imaging capsule is pill-shaped and contains several miniaturized elements: a camera lens, a CMOS imager, batteries, LEDs and an antenna/transmitter. When it is used, the capsule records images and transmits them to the belt-pack receiver. The capsule continues to record images at a very high rate over the course of the 7 to 8 hour image acquisition period, yielding a total of approximately 55,000

This work is partially supported by the Natural Science Foundation of Jiangsu province (No. BK2010251 and BK2011352), Suzhou Science and Technology Bureau (No. SYG201011 and SYG201211), and XJTLU Research Development Fund (No. 10-03-16.).

E. G. Lim is with the Xi'an Jiaotong-Liverpool University, China. Email: Enggee.lim@xjtlu.edu.cn

J. C. Wang is with the Xi'an Jiaotong University, China. Email: Elain@stu.xjtu.edu.cn

Z. Wang is with the Xi'an Jiaotong-Liverpool University, China. Email: zhao.wang@xjtlu.edu.cn

T. Tillo is with the Xi'an Jiaotong-Liverpool University, China. Email: tammam.tillo@xjtlu.edu.cn

K.L. Man is with the Xi'an Jiaotong-Liverpool University, China. Email: ka.man@xjtlu.edu.cn

images per examination. Receiver/Recorder Unit receives and records the images through an antenna array consisting of several leads which are connected by wires to the recording unit, worn in standard locations over the abdomen, as dictated by the template for lead placement [3].

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 [4]. Therefore, an efficient communication link between the in-body capsule and the ex-body receiver unit is important for the development and applicability of WCE.

The most popular WCE systems are developed and manufactured by Olympus [5], IntroMedic [6] and Given Imaging [7]. However, there are still several drawbacks limiting the application of WCE. There have been two main goals with regard to WCE development. One is to reinforce the advantages of current wireless capsules, such as creating a smaller capsule, enhancing propagation efficiency of the antenna or reducing radiated effects on the human body. Others are working on minimizing the disadvantages of capsule endoscopy, like using internal and external magnetic field to control the capsule or IC technology to reduce power consumption.

The role of a WCE embedded antenna is to send out the detected signals. Hence the signal transmission efficiency of the antenna will determine the quality of received images in real time as well as the rate of power consumption (proportional to battery life). The human body as a lossy dielectric material absorbs a number of waves and attenuates the power of receiving signals, thus having a strong negative influence on microwave propagation. Therefore, the antenna elements should possess the following features:

- first, the ideal WCE antenna should be less sensitive to human tissue influence;
- second, the antenna should have enough bandwidth to transmit high resolution images and large amount of data;
- third, enhancement of antenna efficiency should facilitate lower power consumption and high data rate transmission [3].

This paper focuses on WCE antenna design and analysis. Extensive investigations are carried out on the development of WCE antennas from the past to the present. First, the WCE antenna designs including embedded and conformal antennas are introduced and described. Then, two new ideas (case studies) for the design of WCE antenna with a 400MHz bandwidth and an omni-directional radiation pattern are introduced, which satisfy the system requirements for WCE. Last but not least, the paper presents the challenges and prospective of WCE in the future.

II. THE EMBEDDED ANTENNA

The WCE communication system requires the transmitter to be compact, to consume less power, and to be optimized for signal transmission through the human body. Designing such an antenna is a challenging task. The design must fulfill several requirements to be an effective capsule antenna including: miniaturization to save precious space in the capsule cavity; omnidirectional radiation pattern in order to provide transmission regardless of the orientation and location of the capsule or receiver; as well as tuning adjustment to compensate for 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 [8], and another is a dual arm spiral antenna [9].

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. 2(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.

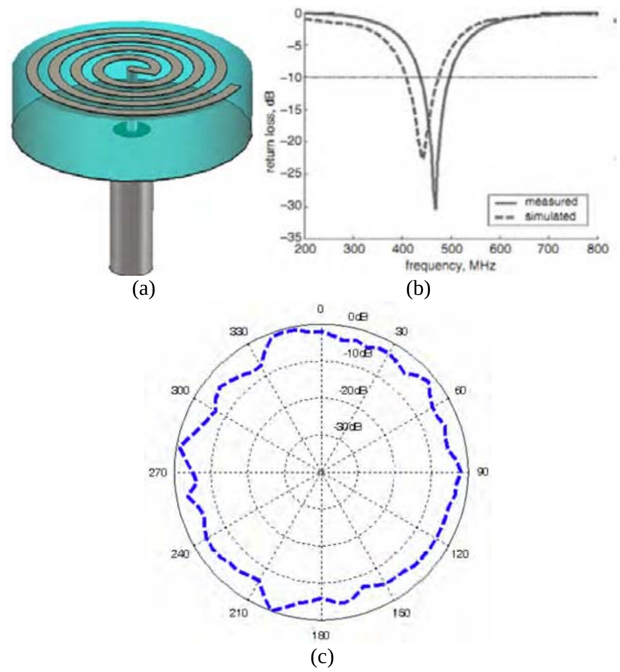


Fig. 2. Single arm spiral antenna: (a) the geometric structure; (b) simulated and measured return losses; and (c) azimuth pattern at 430 MHz

The simulated and measured return losses of the antenna surrounded by human body equivalent material are shown in Fig. 2(b). It can be observed that the bandwidth of the 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. It can be considered as an omni-directional radiation pattern as shown in Fig. 2(c).

The dispersive properties of human body suggest that signals are less vulnerable when they are transmitted at lower frequency range. Therefore, a modified design in [9] is proposed to provide ultra-wide bandwidth at a lower frequency range.

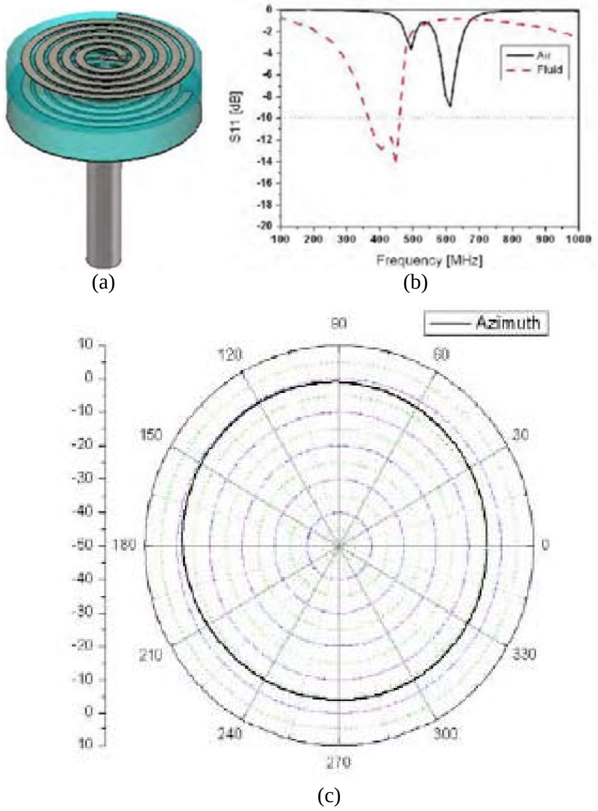


Fig. 3. Dual arm spiral antenna: (a) the geometric structure; (b) measured return losses; (c) azimuth pattern at 400MHz

Fig. 3(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 10.1mm and its height is about 3.5mm. To design a dual spiral antenna, two substrate layers are used. The upper and lower substrate 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. 3(b). Due to the electrical properties of the human body equivalent material, return loss characteristic in the air is poor, though dual resonant characteristic can be observed. However, the proposed antenna has low return loss value at the operating frequency in the fluid with bandwidth of 98 MHz (from 360 MHz to 458 MHz), or fractional bandwidth of about 25%. The simulated radiation pattern as shown in Fig. 3(c) is omni-directional at the azimuth plane with 5dB variation.

B. Conical Helix Antenna

Extensive studies of the helical and spiral antennas were conducted with modified geometric structures. For example, a conical helix antenna [10] fed through a 50 ohm coaxial cable is shown in Fig. 4. A conical helix antenna is bigger than a spiral antenna. However, additional space is not necessary because a conical helix may utilize the tip of the capsule as shown in Fig. 4(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.

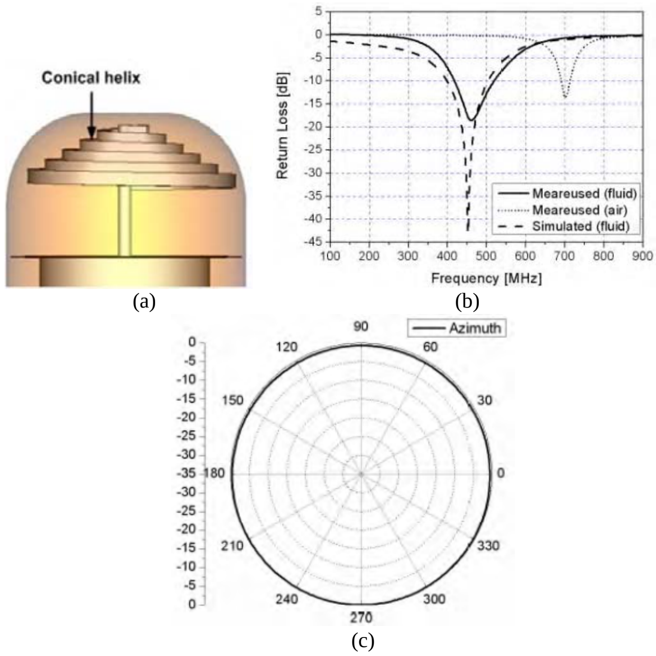


Fig.4. Conical helix antenna: (a) the geometric structure; (b) simulated and measured return losses; (c) azimuth pattern at 450MHz

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. 4(b). Its center frequency is 450 MHz, therefore the fractional bandwidth is about 22%. The proposed antenna has omni-directional radiation pattern with less than 1dB variation, as represented in Fig. 4(c).

C. Fat Arm Spiral Antenna

Another modified design is the fat arm spiral antenna [11] as shown in Fig. 5(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.

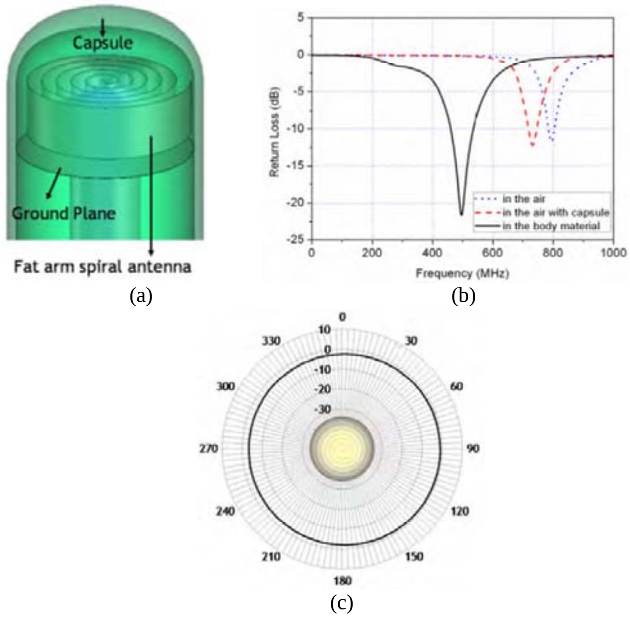


Fig. 5. Fat arm spiral antenna: (a) the geometric structure; (b) return losses; (c) azimuth pattern at 400MHz

The return losses of the antenna in free space, with dielectric capsule shell and in the liquid tissue phantom are plotted in Fig. 5 (b). The resonant frequency is observed to be about 500 MHz in the air, and reduced to 730 MHz due to the capsule effects on the effective dielectric constant and matching characteristic. When the proposed antenna is emerged in the equivalent liquid, 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. The radiation pattern illustrated in Fig. 5(c) presents that this antenna also provides omni-directional feature at azimuth plane.

III. The Conformal Antenna

A conformal geometry exploits the surface of the capsule and leaves the interior open for electrical components including 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 [12] is investigated as a suitable candidate for wireless capsule endoscopy.

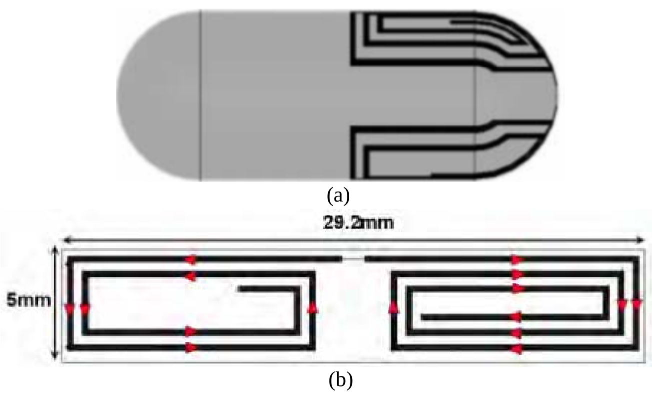


Fig. 6. Conformal chandelier meandered dipole antenna: (a) the geometric structure of the conformal chandelier meandered dipole antenna; (b) Offset Planar Meandered Dipole Antenna with current alignment vectors.

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. 6(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. 6(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 1395 MHz – 1400 MHz wireless medical telemetry services (WMTS) band.

The antenna is placed in the small intestine and it is observed that there is a lot of detuning due to the body conductivity and the dielectric constant (average body composition has a relative permittivity of 58.8 and a conductivity of 0.84S/m). The series resonance shifts closer to 600 MHz. The antenna is then retuned to the operational frequency of 1.4 GHz by reducing the length of the dipole antenna. The return losses of both the detuned and tuned antenna are shown Fig. 7. Fig. 8 shows the radiation pattern of the tuned antenna inside the human body at 1.4 GHz.

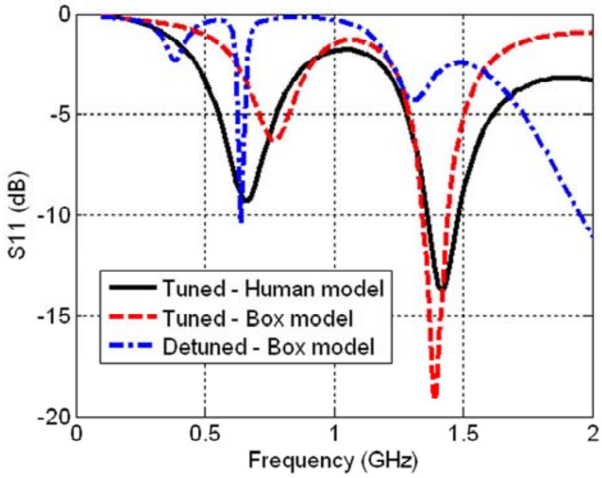


Fig. 7. Simulated return loss of detuned and tuned structure in human model

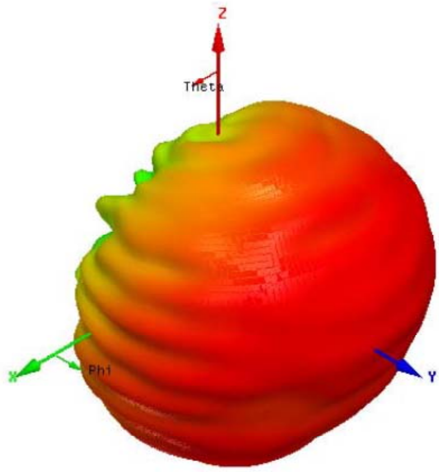


Fig. 8. Simulated radiation pattern at 1.4 GHz

B. Outer-wall loop antenna

The proposed outer-wall loop antenna [13] makes maximal use of the capsule's outer surface, enabling the antenna to be larger than the inner antennas. As shown in Fig. 9(a), the antenna is part of the outer wall of the capsule, thus minimizes volume while improving performance, and uses a meandered line for resonance in an electrically small area. The capsule shell with the relative permittivity of 3.15 has the outer and the inner radius of the capsule as 5.5 mm and 5 mm respectively. Its length is 24 mm. The height of the meander line and gap between meander patterns are set to 7 mm and 2.8 mm respectively. The opposite side of the loop line is meandered in the same way. Although capsule size is reduced, the sphere radius enclosing the entire structure of the antenna is increased.

Fig. 9(b) shows that the proposed antenna has an ultra-wide bandwidth of 260 MHz (from 370 MHz to 630 MHz) for VSWR < 2 and an omnidirectional radiation pattern at azimuth plane (as shown in Fig. 9(c)). Using identical antenna pairs in the equivalent body phantom fluid, antenna efficiency is measured at 43.7% (3.6 dB).

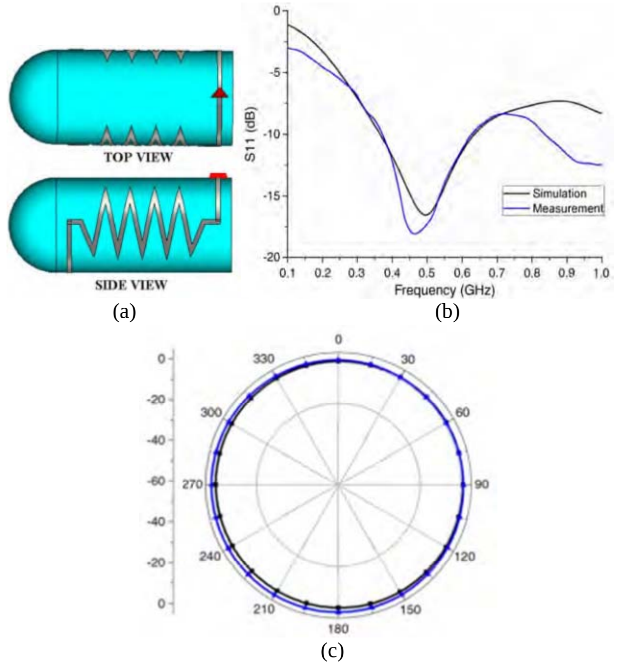


Fig. 9. Outer-wall loop antenna: (a) the geometric structure; (b) simulated and measured return losses; (c) azimuth pattern at 500MHz

C. Conformal Trapezoid Strip Excited Hemispherical Resonator Antenna

A conformal trapezoid strip excited broadband hemispherical dielectric resonator antenna (DRA) [14] is proposed with ultra wide-band (UWB) low band 3.1-4.8 GHz for medical capsule endoscope applications. Fig. 10(a) shows the dimensions of structure of the hemispherical DRA with a radius of 5 mm and a 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.

Fig. 10(b) compares the return loss performance for the taper excitation and the optimized trapezoid excitation. As can be seen, the optimized trapezoid excitation gives better return loss performance with 10-dB bandwidth from 3 to 5 GHz. The radiation pattern in tissue is shown in Fig. 10(c).

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

A patch loaded with a complementary split-ring resonator (CSRR) [15] 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. 11 (a). A 74% size reduction is achieved after CSRR loading.

The different simulation results are plotted in Fig. 11 (b). They show good agreement within approximately 1% tolerance. Fig. 12 shows the measured radiation patterns, where good omni-directionality is observed.

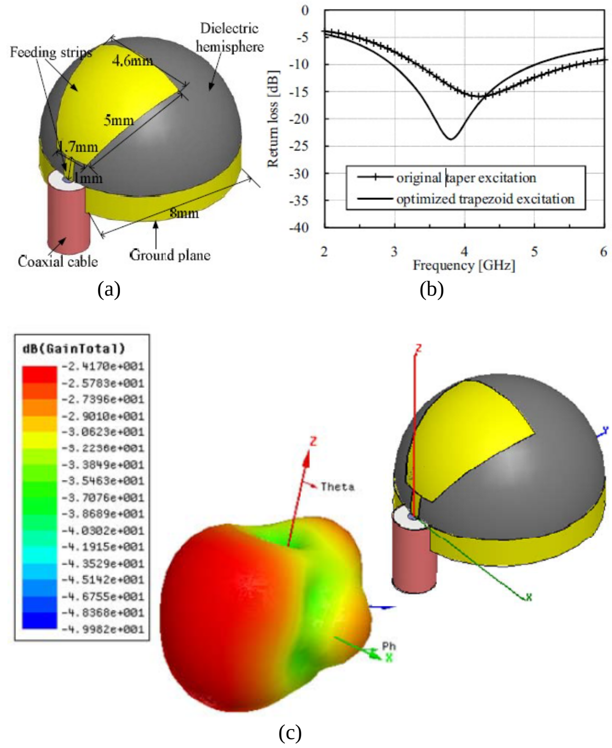


Fig. 10. DRA: (a) the geometric structure; (b) Simulated return losses of original taper excitation and optimized trapezoid excitation in tissue-simulating fluid phantom; (c) azimuth pattern at 4GHz

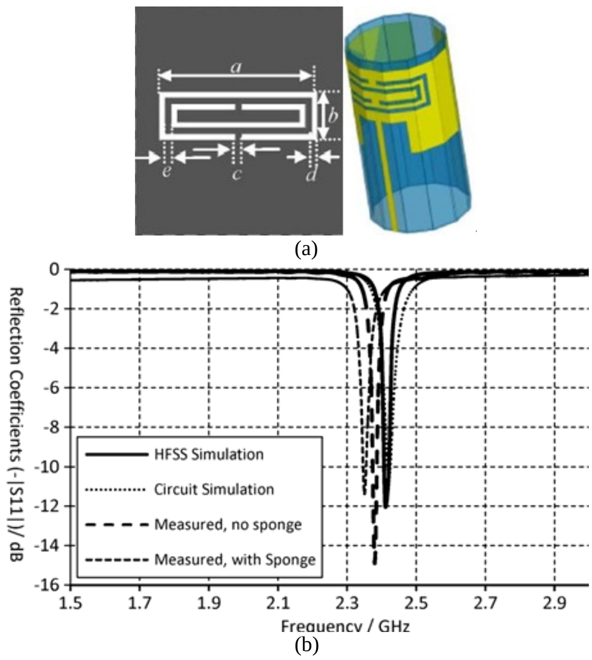


Fig. 11. (a) Planar CSRR; Dimensions: a=13mm b=4mm c=d=e=0.5mm; (b) Simulated and measured antenna return loss

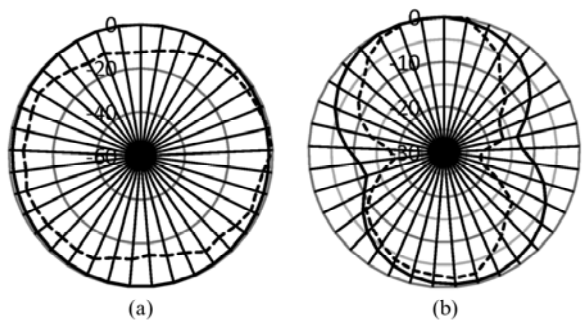
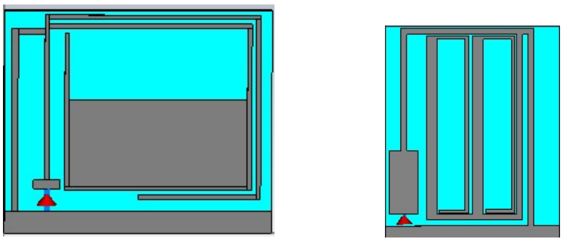


Fig. 12. Normalized radiation pattern on (a) xz-plane and (b) xy-plane

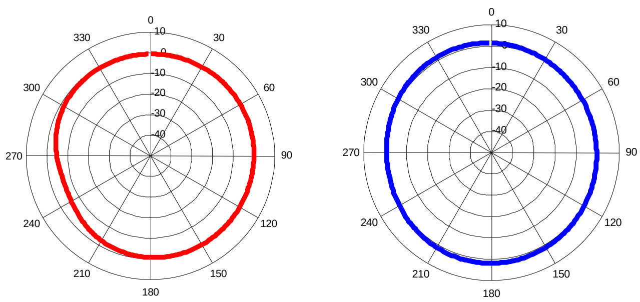
IV. CASE STUDY

To make the capsule easy to swallow and move in human body, the size of the capsule is desired to be as small as possible. However, the size of capsule is limited by the size of the antenna, whose dimension should be proportional to the wavelength at its operating frequency. For the in-body application as WCE, the operating frequency range is selected to be around 400 MHz to 700MHz, within which the traditional antenna size is quite large. Two new WCE antennas operating at 500 MHz with ultra-wide bandwidth were successfully designed and miniaturized [16-18] and the physical layouts of antennas A2 [17] and B2 [18] are shown in Fig. 13. The sizes of the antennas A2 and B2 are 30mm × 25 mm and 18.2 × 15mm, respectively. As the detection of transmitted signal should be independent of the transmitter's position, the two antennas also require the omni-directional radiation patterns. Simulated radiation patterns of antenna A2, and B2 at 500 MHz are shown in Fig. 14 and Fig. 15. The radiation patterns for the two designs are nearly omni-directional.



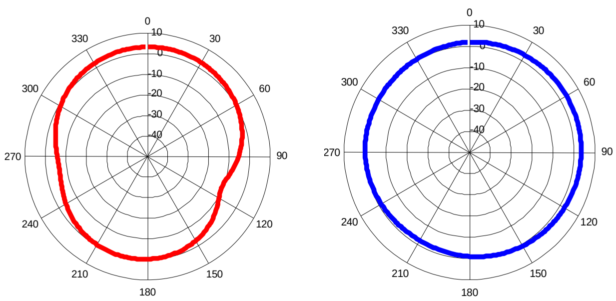
(a) Antenna A2 (b)Antenna B2

Fig. 13. A conformal outer wall antenna: (a)Physical layout of antenna A2; (b) Physical layout of antenna B2



(a) xy-plane (b)xz-plane

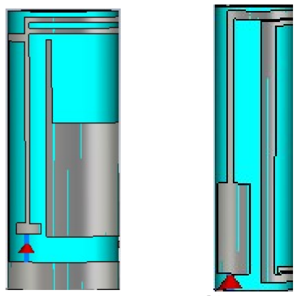
Fig. 14. Radiation pattern of antennas A2



(a) xy-plane (b)xz-plane

Fig. 15. Radiation pattern of antennas B2

To make better use of the capsule's inner space, the antennas A2 and B2 are adhered to the surface of a dielectric layer illustrating the capsule shell, to get the conformal antennas A2-c and B2-c as illustrated in Fig. 16. The dielectric constant of this shell is 3.7.



(a) Antenna A2-c (b)Antenna B2-c

Fig. 16. Physical layout of antenna A2-c and B2-c

In the simulation, 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 A2 can be attached to the surface of a smaller one (radius 5 mm, length 25 mm), and antenna B2 just need a smallest one (radius 4.8mm, length 20.8mm) which can in turn be used for specialized applications such as capsules for children. Fig. 17 (a) shows simulated return losses of the designed antennas A2 and A2-c which have an ultra-wide bandwidth ranging from 325MHz to 835MHz and from 310 MHz to 760 MHz. And antennas B2 and B2-c both have an ultra-wide bandwidth ranging from 330 MHz to 750 MHz and from 310 MHz to 690 MHZ for VSWR < 2, as shown in Fig. 17(b).

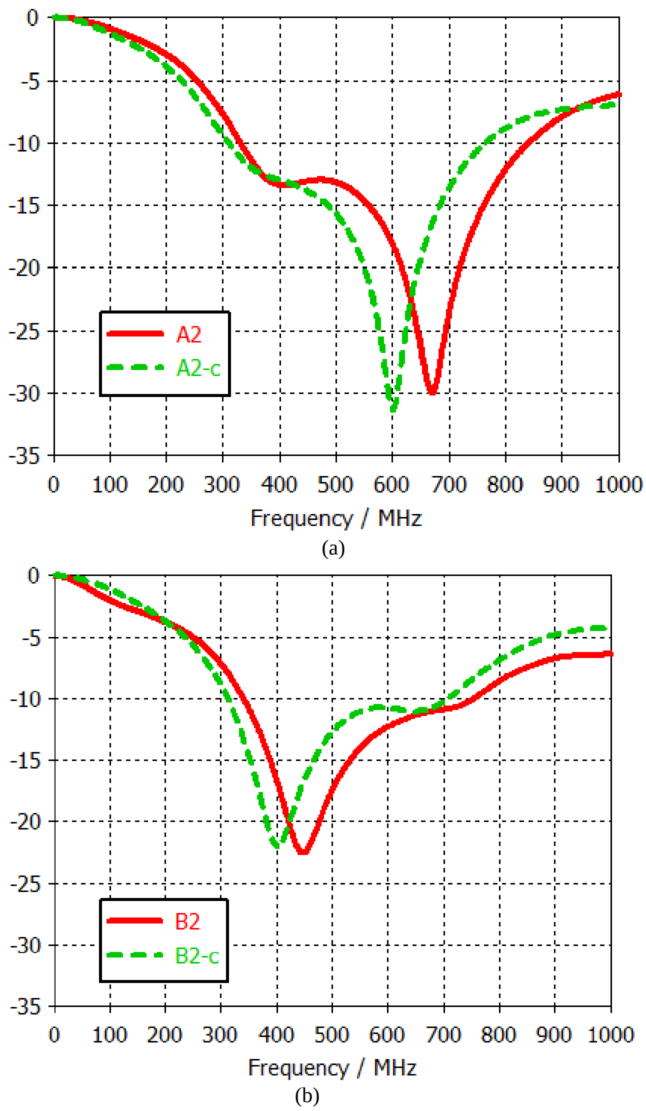
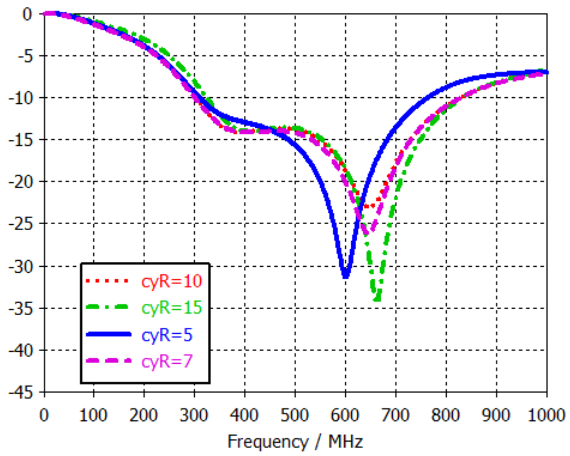


Fig. 17. (a) The return loss of conformal antennas A2 and A2-c; (b) The return loss of conformal antennas B2 and B2-c.

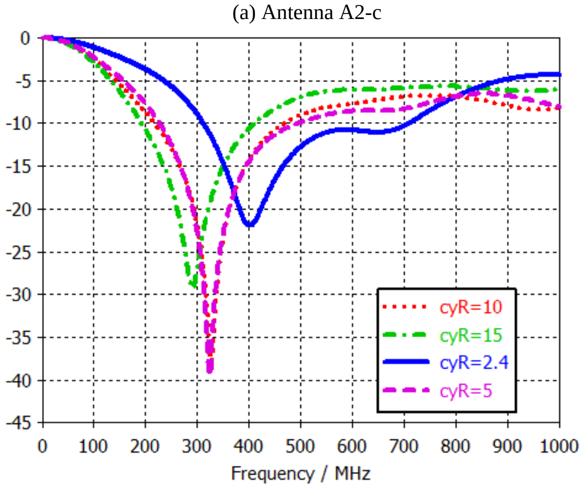
Furthermore, the antenna is insensitive to the radius of the capsule and hence the tolerance of the fabrication can be greatly relaxed. The planar antenna A2 is bent and attached to the surface of a cylinder, whose radius is varied as 5 mm, 7 mm, 10 mm and 15 mm, respectively. And the cylinder radius of antenna B2 changed as 2.4mm, 5mm, 7mm, 10mm and 15mm, respectively. The return losses of antennas are illustrated in Fig. 18. It is interesting to see that the radius of A2 and B2 do not influence the resonances significantly, which brings convenience and saves the cost of accurate fabrication of antenna.

The two antennas are bent and attached on the surface of a dielectric layer illustrating the capsule shell. The dielectric constant of this shell is 3.7, and the thickness of the shell is varied accordingly, varying as 0.5 mm, 1.6 mm and solid. Fig. 19 illustrates that the four antennas are not very sensitive to the thickness of capsule shells.

To validate the operation of the designed antennas, they were fabricated and measured by using Agilent N5230C Network Analyzer. The designed antennas were engraved on FR-4 substrate (as shown in Fig. 20).

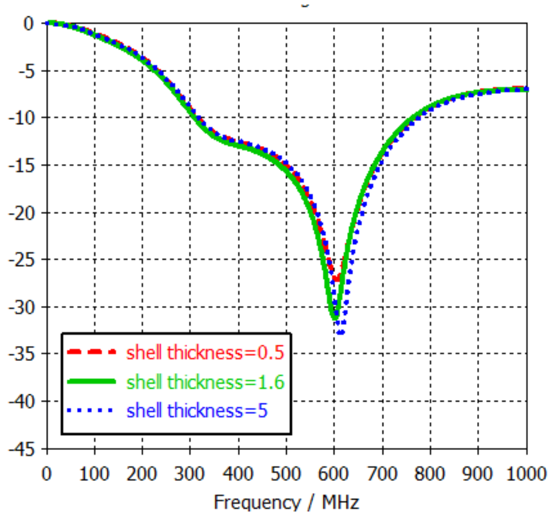


(a) Antenna A2-c

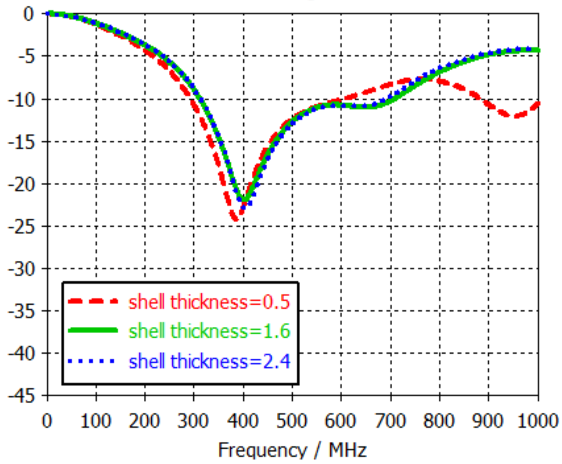


(b) Antenna B2-c

Fig. 18. The return losses of different cylinder radius



(a) Antenna A2-c



(b) Antenna B2-c

Fig. 19. Different thickness shell of capsule

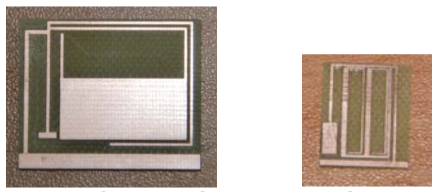


Fig. 20. The engraved antennas A2 and B2

A "Tissue-simulating liquid" is needed for simulating the human body dielectric environment when measuring the antennas. The Tissue-simulating liquid is a mixture of sugar, Sodium Chloride、De-ionized water、Hydroxyethyl Cellulose、Bactericide、Diethylene Glycol Butyl Ether、Triton X-100、Diacetin、1,2-Propanediol and so on chemical material [19]. While using an open-ended coaxial probe to measure the liquid, the complex permittivity of the tissue-simulating liquid can be calculated by using the following equations (1-4) [20-21]. Therefore, the dielectric constant and the conductivity of the Tissue- simulating liquid can be obtained by measuring the reflection coefficient of the liquid.

$$\varepsilon = \varepsilon' - j\varepsilon'' \quad (1)$$

$$\varepsilon' = \frac{1}{2\pi f Z_0 C_0} \times \frac{-2|\Gamma|\sin(\varphi)}{1+2|\Gamma|\cos(\varphi)+|\Gamma|^2} - \frac{C_f}{C_0} \quad (2)$$

$$\varepsilon'' = \frac{1}{2\pi f Z_0 C_0} \times \frac{1-|\Gamma|^2}{1+2|\Gamma|\cos(\varphi)+|\Gamma|^2} \quad (3)$$

$$\sigma = 2\pi f \varepsilon_0 \varepsilon'' \quad (4)$$

ε – complex permittivity;

ε' – real part of the complex permittivity

ε'' – imaginary part of the complex permittivity

f – the operation frequency

C_0 – the capacitance of the air-filled parallel plate capacitor

C_f – the electric field concentration inside the teflon-filled part of the coaxial line

Γ – the reflection coefficient of the end of probe

The designed antennas to be measured are placed at the center of a plastic container filled with the Tissue-simulating liquid, as shown in Fig. 21.

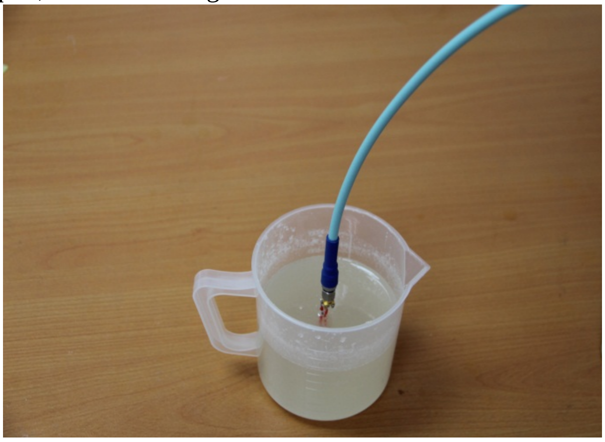


Fig. 21. The antenna placed in the liquid

The simulated and measured return losses of the designed antennas B2 in the Tissue-simulating liquid are presented in Fig. 22. It can be observed that the resonances of the simulation and measurement results agree each other.

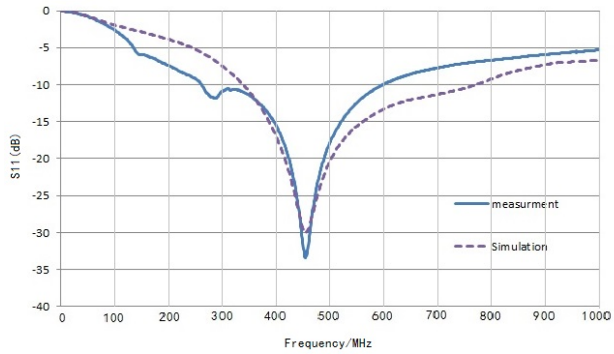


Fig. 22 Comparison between simulated return loss and measured return loss

V. The WCE challenges

This section outlines the major challenges limiting the use of WCE. These limitations include the long examination times which vary from 45 to 180 minutes per patient, which means there may be delays which limit the number of patients who may benefit from the service. Another limitation is short of battery life, which may necessitate the capture of small image resolution with low frame rates. Most of WCE deficiencies are related to the fact that it is a wireless procedure. Consequently, unlike endoscopy, it cannot be used to obtain biopsies or perform therapy, and once swallowed, it cannot be controlled remotely. Images may be limited by transit and position as it moves through the GI tract.

Although WCE has a lot of advantages, there are a number of risks which cannot be simply ignored. WCE is not for everyone and is contraindicated in patients with known or suspected gastrointestinal obstructions, strictures or fistulas, cardiac pacemakers or other implantable electromedical devices and swallowing disorders. In fact, a few cases of capsule retention have been reported in the past, in which the capsule remains in the digestive tract for more than two weeks. There is also a low risk of skin irritation from the sensor array sleeve adhesive or silicone exposure. These risks may pose problems and medical or surgical intervention may be necessary to address any of these complications.

VI. The future of WCE

The current WCE system design is satisfactory but there is room for improvement. A number of issues such as hardware limitation, capsule positioning and locomotion control still need to be resolved. Current WCE system design issues and research in resolving these issues will be investigated.

Future research trends can be divided into three main categories, namely, positioning, application and hardware improvement. In current WCE systems, the capsule location within the GI tract cannot be ascertained as real-time tracking proves to be challenging. Researchers are trying to find ways to locate the capsule or alternatively, to employ methods of propelling the capsule out of the GI tract.

Providing new applications like therapy or drug delivery through WCE is also a fascinating research trend. Future WCE devices may hold up to one milliliter of liquid or powder, which may be released at a targeted site within the body. It may contains a small amount of gamma-emitting tracer, allowing precise tracking in real time using an external gamma camera. In this scenario, when the capsule reaches the target area, an external electromagnetic field actuates the capsule's piston, ejecting the payload. The shell then passes harmlessly out of the body.

Researchers are always trying to make the WCE smaller, lighter and more functional but hardware limitation is a bottleneck to the WCE system. There are numerous proposals to improve current WCE designs, such as replacing the CCD sensor with CMOS, improving light sensitivity, controlling frame rate, as well as managing power consumption.

VII. Conclusion

WCE was invented due to demand for detailed investigation of the GI tract. It solves many a number of issues posed by preceding technologies. Since its inception in 2001, WCE has become a promising technology with great potentials. The WCE device has an array of sensors working together as a cohesive unit and system that can be operated outside the human body. Improvement in the technology is still ongoing with the size of the capsule getting smaller and the components becoming more efficient. Companies and individuals are still aiding its development, performing optimizations and adding new features.

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 the images received in real-time as well as the rate of power consumption. This paper reviewed some state-of-the-art WCE transmitting antennas. Two types of popular antenna structures were discussed in this paper, 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. However, the bandwidth of the antennas should be as wide as possible in order to transmit high resolution images and large amount of data. Moreover, two new designed WCE antennas are proposed and measured in this paper.

Also this paper has delved into the historical development of WCE and reviewed state-of-the-art WCE designs. In addition, features of existing devices were examined in terms of their diagnostic capabilities and limitations. Finally, research trends were briefly discussed along with possible improvements which may find their way in future WCE devices.

References

[1] American Cancer Society, "Key statistics about cancers", Oct. 1st, 2010, http://www.cancer.org/Cancer/index

[2] P. Izdebski, H. Rajagopalan, and Y. Rahmat-Samii, "Conformal ingestible capsule antenna: A novel Chandelier meandered Design," *IEEE Trans. Antennas and Propag.* Feb. 2009, pp.900-909

[3] Z. Wang, E. G. Lim, T. Tillo and F. Z. Yu, "Review of the Wireless capsule transmitting and receiving antennas", Book title: *Wireless Communications and Networks - Recent Advances.* Intech Open. ISBN 978-953-51-0189-5. Chapter 2, pp.27-46. March 2012

[4] Z. Fireman, and Y. Kopelman, "New frontiers in capsule endoscopy," J Gastroenterol Hepato. 2007, pp. 1174–1177.

[5] EndoCapsule – Taking capsule endoscopy to next level, Official website of Olympus, access at Sep. 30th, 2011, http://www.olympus-europa.com/endoscopy/2001_5491.htm

[6] MicroCam Info, Official website of IntroMedic, access at Sep. 30th, 2011. http://www.intromedic.com/en/product/productInfo.asp

[7] Overview of product, Official website of Given Imaging, access at Sep. 30th, 2011. http://www.givenimaging.com/en-int /HealthCareProfessionals/Pages/pageHCP.aspx

[8] S.I. Kwak, K. Chang and Y.J. Yoon, "Small spiral antenna for wideband capsule endoscope system", *Electronics Letters*, Vol. 42, Issue 23, November 2006, pp. 1328 -1329.

[9] S. H. Lee, K. Chang and Y. J. Yoon, "A dual spiral antenna for wideband capsule endoscope system," in Microwave Conference, 2007. pp. 1–4.

[10] S. H. Lee, Ki. Chang, Ki. J. Kim and Y. J. Yoon. "A Conical Spiral Antenna for Wideband Capsule Endoscope System" Antennas and Propagation Society International Symposium, IEEE. 2008, pp.1-4.

[11] S. H. Lee and Y. J. Yoon, "Fat arm spiral antenna for wideband capsule endoscope systems," in Proc. Radio and Wireless Symposium. 2010, pp. 579–582.

[12] P. Izdebski, H. Rajagopalan, and Y. Rahmat-Samii, "Conformal ingestible capsule antenna: A novel Chandelier meandered Design," in special issue IEEE Trans. Antennas and Propagation. Feb. 2009, pp.900-909.

[13] S. Yun, K. Kim, and S. Nam, "Outer wall loop antenna for ultra wideband capsule endoscope system," *IEEE Antennas Wireless Propagation Letters*. vol. 9, Dec. 2010, pp. 1135–1138.

[14] Q. Wang, K. Wolf and D. Plettemeier. "An UWB capsule endoscope antenna design for biomedical communications" Applied Sciences in Biomedical and Communication Technologies (ISABEL), 2010 3rd International Symposium on. pp. 1-6.

[15] X.Y. Cheng, D. E. Senior, C. Kim and Y. K. Yoon. "A Compact Omnidirectional Self-Packaged Patch Antenna with Complementary Split-Ring Resonator Loading for Wireless Endoscope Applications" *IEEE Antennas and Wireless Propagation Letters.* 2011, pp.1532-1535.

[16] E. G. Lim, J. C. Wang, Z. Wang, T. Tillo, K. L. Man and N. Zhang, Wireless Capsule Endoscopy, Lecture Notes in Engineering and Computer Science: Proceedings of The International MultiConference of Engineers and Computer Scientists 2013, 13-15 March, 2013, Hong Kong, pp700-701.

[17] E. G. Lim, Z. Wang, F. Z. Yu, T. Tillo and K. L. Man et al. "Transmitter Antennas for Wireless Capsule Endoscopy", SoC Design Conference (ISOCC). 2012, pp. 269-272.

[18] J. C. Wang, E. G. Lim, Z. Wang, Y. Hang, T. Tillo, M. Zhang et al. "UWB Planar Antennas for Wireless Capsule Endoscopy" IEEE International Workshop on Antenna Technology, Mar, 2013.

[19] MORLAB Offer "Tissue-simulating liquid" Products for OTA and SAR Test. 2009. http://www.morlab.cn/en/2009/0123/article_27.html

[20] H. L. Gong, S. D. Chen, D. J. Q. "Rebuilt and Modified Model for Complex Permittivity Measurement Using the Coaxial Line" *Information and Electronic Engineering*. Dec. 2008. pp. 448-451

[21] Y. Gao, G. S. Yang, H. Wang, J. Q. Wang, S. P. Chen. "Measurement and Amendment of Complex-permitivities of Distilled Water and Nacl Solution". *J Biomed Eng*. 2005, 22(3), pp. 548-549.