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Review of the Wireless Capsule Transmitting and Receiving Antennas

Zhao Wang, Eng Gee Lim, Tammam Tillo and Fangzhou Yu
Xi'an Jiaotong - Liverpool University
P.R. China

1. Introduction

The organization of American Cancer Society reported that the total number of cancer related to GI track is about 149,530 in the United State only for 2010 (American Cancer Society, 2010). Timely detection and diagnoses are extremely important since the majority of the GI related cancers at early-stage are curable.

However, the particularity of the alimentary track restricts the utilization of the current available examine techniques. The upper gastrointestinal tract can be examined by Gastroscopy. The bottom 2 meters makes up the colon and rectum, and can be examined by Colonoscopy. In between, lays the rest of the digestive tract, which is the small intestine characterised by being very long (average 7 meters) and very convoluted. However, this part of the digestive tract lies beyond the reach of the two previously indicated techniques. To diagnose the small intestine diseases, the special imaging techniques like CT scan or MRI are less useful in this circumstance.

Therefore, the non-invasive technique Wireless Capsule Endoscopy (WCE) has been proposed to enable the visualisation of the whole GI track cable freely. The WCE is a sensor device that contains a colour video camera and wireless radiofrequency transmitter, and battery to take nearly 55,000 colour images during an 8-hour journey through the digestive tract.

The most popular WCEs, are developed and manufactured by Olympus (Olympus, 2010), IntroMedic (IntroMedic, 2010) and Given Imaging (Given Imaging, 2010). However, there are still several drawbacks limiting the application of WCE. Recently, there are two main directions to develop the WCE. One is for enlarging the advantages of current wireless capsule, for example they are trying to make the capsule smaller and smaller, to enhance the propagation efficiency of the antenna or to reduce the radiated effects on human body. While, others are working on minimizing the disadvantages of capsule endoscope, for instance, they use internal and external magnetic field to control the capsule and use technology to reduce the power consumption.

The role of the WCE embedded antenna is for sending out the detected signals; hence the signal transmission efficiency of the antenna will directly decide the quality of received real-time images and the rate of power consumption (proportional to battery life). The human body as a lossy dielectric material absorbs a number of waves and decreases the power of receiving signals, presenting strong negative effects on the microwave propagation. Therefore, the antenna elements should ideally possess these features: first, the ideal antenna for the wireless capsule endoscope should be less sensitive to human tissue influence; second, the antenna should have enough bandwidth to transmit high resolution images and huge number of data; third, the enhancement of the antenna efficiency would facilitate the battery power saving and high data rate transmission.

In this chapter the WCE system and antenna specifications is first introduced and described. Next, the special consideration of body characteristics for antenna design (in body) is summarized. State-of-the-art WCE transmitting and receiving antennas are also reviewed. Finally, concise statements with a conclusion will summarize the chapter.

2. Wireless Capsule Endoscopy (WCE) system

In May of 2000, a short paper appeared in the journal Nature describing a new form of gastrointestinal endoscopy that was performed with a miniaturized, swallowable camera that was able to transmit color, high-fidelity images of the gastrointestinal tract to a portable recording device (Iddan et al., 2000). The newer technology that expands the diagnostic capabilities in the GI tract is capsule endoscopes also known as wireless capsule endoscopy. One example of the capsule is shown in Figure 1.

Fig. 1. Physical layout of the WCE (Olympus, 2010).

The capsule endoscopy system is composed of several key parts (shown in Figure 2): image sensor and lighting, control unit, wireless communication unit, power source, and mechanical actuator. The imaging capsule is pill-shaped and contains these miniaturized elements: a battery, a lens, LEDs and an antenna/transmitter. The physical layout and conceptual diagram of the WCE are depicted in Figure 1 and Figure 2, respectively. The capsule is activated on removal from a holding assembly, which contains a magnet that keeps the capsule inactive until use. When it is used, capsule record images and transmit them to the belt-pack receiver. The capsule continues to record images at a rate over the course of the 7 to 8 hour image acquisition period, yielding a total of approximately 55,000 images per examination. Receiver/Recorder Unit receives and records the images through an antenna array consisting of several leads that connected by wires to the recording unit, worn in standard locations over the abdomen, as dictated by a template for lead placement. The antenna array and battery pack can be worn under regular clothing. The recording device to which the leads are attached is capable of recording the thousands of images transmitted by the capsule and received by the antenna array. Once the patient has completed the endoscopy examination, the antenna array and image recording device are returned to the health care provider. The recording device is then attached to a specially modified computer workstation (Gavriel, 2000). The software shows the viewer to watch the video at varying rates of speed, to view it in both forward and reverse directions, and to capture and label individual frames as well as brief video clips.

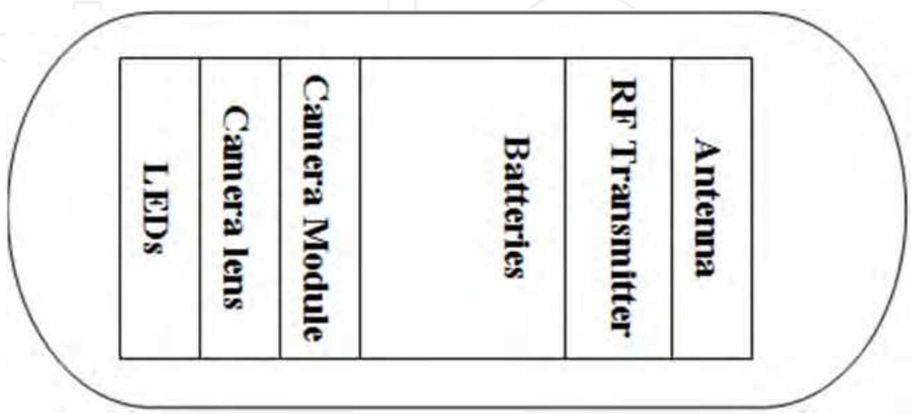


Fig. 2. Conceptual diagram of the WCE.

Since the device received FDA (American Food and Drug Administration) clearance in August 2001, over 1,000,000 examinations have been conducted globally. The 11mm by 26mm M2A capsule is propelled passively, one end of the capsule contains an optical dome with six white Light Emitting Diodes and a CMOS camera that captures 2 images a second (Given Imaging, 2010). These images relayed via a transmitter using a radio frequency signal to an array of aerials from where they are transferred over the wires to a data-recorder. The sensor array allows for continues triangulation of the position of the capsule inside the body of the patient. The accuracy of the capsule location provide by this method was reported to be +/-3 cm (Ravens & Swain, 2002). In December 2004, FDA approved a second type of capsule developed by Given Imaging-the PillCam ESO, which allows the evaluation of esophageal disease. The response to this demand materialized in the development of the pillCam ESO which has the higher frame rate and CMOS cameras positioned at both ends of the capsule. This capsule acquires and transmits seven frames per second from each camera, giving a total of 14 frames per second (Mishkin et al. 2006). Due to the increased frame rate, the capsule battery life is only 20 minutes. In October 2005, Olympus launched a competitor system called EndoCapsule in Europe. The difference lies in the use of a different imaging technology-CCD, which the manufacturers claim is of higher quality (Fuyono, I. 2005). Another feature of EndoCapsule is the Automatic Brightness Control (ABC), which provides an automatic illumination adjustment as the conditions in the GI tract vary. In October 2006, Given Imaging received the CE Mark to market a third capsule-the PillCam COLON though out the European Union. This capsule measures 11mm by 31mm, that is slightly larger than previous products. It captures 4 images a second for up to 10hours. A new feature in Given Imaging capsules is an automatic lighting control (Eliakim et al. 2006; Schoofs et al., 2006). In 2007, PillCam SB2 was cleared for marketing in the US. According to the manufacturers, it offers advanced optics and a wider field of view. PillCam SB2 also captures nearly twice the mucosal area per image. It also provides Automatic Light Control for optimal illumination of each image. In 2009, the second-generation capsule, PillCam COLON2, was cleared by the European Union. The capsule has the ability to adjust the frame rate in real time to maximize colon tissue coverage. To present, Olympus is working on the development of a new generation capsule endoscope, which features magnetic propulsion. Apart from the novel propulsion and guidance system, the capsule designers aim to provide a drug delivery system, a body fluid sampling system and also the ultrasound scan capability. RF System Lab Company announced the design of the new Sayaka capsule (RF System Lab, 2010), which acquires images at a rate of 30 frames per second and generate about 870,000 over an eight hour period of operation. Also, further applications of magnetic fields are presented (Lenaertes & puers, 2006).

3. Antenna specifications for WCE

Wireless capsule transmitting and receiving antennas belong to wireless communication unit. The transceiver in conjugation with an antenna was utilised. A bidirectional communication between the capsule and the external communication unit at recommended frequency for industrial, scientific and medical usage was established. Wireless capsule endoscopy transmitting antenna is for sending out the detected signal and receiving antenna receive the signal outside human body. The signal transmission efficiency of the antenna will directly decide the quality of the received real-images and rate of power consumption. Because a lossy dielectric material absorbs a number of waves and decreases the power of receiving signal, it presents strong negative effects on the microwave propagation (Johnson, & Guy, 1972). Therefore, some features to ideally possess are required. The WCE antenna should be less sensitive to human tissue influence. Enough bandwidth to transmit high resolution images and huge number of data is a requirement for antenna. Also, power saving and high data rate transmission can be obtained with enhancement of antenna efficiency.

In addition to the standard constraints in electronic design, a number of main challenges arise for systems that operate inside the human body. The size of the capsule endoscope system should be small because small-sized capsules are easier to swallow. Therefore, the foremost challenge is miniaturization to obtain an ingestible device (the volume should be smaller than endoscopy). The availability of small-scale devices can place severe constraints on a design, and the interconnection between them must be optimized. The size constraints lead to another challenge, noise. The coexistence of digital integrated circuits, switching converters for the power supply, and communication circuits in close vicinity of the analog signal conditioning could result in a high level of noise affecting the input signal. Therefore, capsule designers must take great care when selecting and placing components, to optimize the isolation of the front end.

The next vital challenge is to reduce power consumption. In particular, the generated wireless signal must not interfere with standard hospital equipment but still be sufficiently robust to overcome external interferences. On the basis of Friis's formula, the total loss between transmitter and receiver increases with the distance between the transmitting and the receiving antennas increasing. As the result of the dispersive properties of human body materials, the transmitting power absorbed by body varies according to the antenna's operating frequency. The radiated field intensity inside and outside the torso or gut area is determined for FCC regulated medical and Industrial Scientific Medical (ISM) bands, including the 402MHz to 405MHz for Medical Implant Communications Service (MICS), 608MHz to 614 MHz for Wireless Medical Telemetry Service (WMTS), and the 902MHz-928MHz ISM frequency band. Moreover FCC has allocated new bands at higher frequencies such as 1395MHz–1400 MHz wireless medical telemetry services (WMTS) band. Carefully selection of target frequency is important during the antenna design.

The effective data rate was estimated to be about 500 Kbps (Rasouli et al. 2010). The transmit power must be low enough to minimize interference with users of the same band while being strong enough to ensure a reliable link with the receiver module. Lower frequencies are used for ultrasound (100 kHz to 5 MHz) and inductive coupling (125 kHz to 20 MHz). The human body is no place for operational obscurity, so the control software must enforce specific rules to ensure that all devices operate as expected. For that reason, key programs must be developed in a low-level (often assembly) language. The last challenge concern encapsulating the circuitry in appropriate biocompatible materials is to protect the patient from potentially harmful substances and to protect the device from the GI's hostile environment. The encapsulation of contactless sensors (image, temperature, and so on) is relatively simple compared to the packaging of chemical sensors that need direct access to the GI fluids. Obtaining FDA (Food and Drug Administration) approval for the US market or CE (European Conformity) marking in Europe involves additional requirements. Capsules must undergo extensive material-toxicity and reliability tests to ensure that ingesting them causes no harm. The maximal data rate of this transmitter is limited by the RC time constant of the Rdata resistor and the capacitance seen at the base. It is clear that formal frequency higher than 1/(Rdata*Cbase), the modulation index decreases, because the injected base current is shorted in the base capacitance. Although the occupied bandwidth decreases, the S/N ratio decreases too, and robust demodulation becomes more difficult at faster modulation rates. From experiments, the limit was found to be at 2Mbps [22]. Considering the sensitivity of small receivers for biotelemetry, the designed antenna should have a gain that exceeds −20 dB (Chi et al. 2007; Zhou et al. 2009).

4. Special consideration of body characteristics for antenna design

The antenna designed for biomedical telemetry is based on the study of the materials and the propagation characteristics in the body. Because of the different environment, the wave radio propagation becomes different in free space. The human body consists of many tissues with different permittivity and conductivity, which leads to different dielectric properties.

The same radio wave propagating through different media may exhibit different features. From an electromagnetic point of view, materials can be classified as conductive, semi conductive or dielectric media. The electromagnetic properties of materials are normally functions of the frequency, so are the propagation characteristic. Loss tangent defined as the ratio of the imaginary to the real parts of the permittivity, which is equation (Kraus & Fleisch, 1999).

$$tan\delta = \frac{\sigma}{\omega\varepsilon} \tag{1}$$

With the specific classification are given in (Kraus & Fleisch, 1999), the body material is dielectric material. The loss tangent is just a term in the bracket. The attenuation constant is actually proportional to the frequency if the loss tangent is fixed; where the attenuation constant is

$$a = \omega\sqrt{\mu\varepsilon}\left[\frac{1}{2}\left(\sqrt{1+\frac{\sigma^2}{\varepsilon^2\omega^2}}-1\right)\right]^{1/2}. \tag{2}$$

The dominant feature of radio wave propagation in media is that the attenuation increases with the frequency. With the formula

$$\gamma = \sqrt{j\omega\mu(\sigma + j\omega\varepsilon)}, \tag{3}$$

$$E = E_0 e^{j\omega t-\gamma z}, \tag{4}$$

$$H = \frac{j}{\omega\mu}\nabla\times \mathrm{E}, \tag{5}$$

It can find out that the power of E plane and H plane reduce with high dielectric constant and conductivity. The total power is consumed easily in human body. The efficiency of antenna becomes lower than free space. With the formula

$$v = \frac{1}{\sqrt{\mu\varepsilon}} \text{ and } \beta = \omega\sqrt{\mu\varepsilon}\left[\frac{1}{2}\left(\sqrt{1+\frac{\sigma^2}{\varepsilon^2\omega^2}}+1\right)\right]^{1/2} = \frac{2\pi}{\lambda}, \tag{6}$$

in a high dielectric material, the electrical length of the antenna is elongated. Compare dipole antenna in the air and in the body material, they have same physical length but electrical lengths are not same. Because of the high permittivity, the antenna in the body material has longer electrical length. The time-averaged power density of an EM wave is

$$S_{av} = \frac{1}{2}\sqrt{\frac{\varepsilon}{\mu}}E_0{}^2, \tag{7}$$

which leads to high power density in human body. The intrinsic impedance of the material and is determined by ratio of the electric field to the magnetic field (Huang & Boyle, 2008).

$$\eta = \sqrt{\frac{j\omega\mu}{\sigma + j\omega\varepsilon}}. \tag{8}$$

Based on wave equation $\nabla^2 E - \gamma^2 E = 0$, A and B in the wave propagating trigonometric form $E = xA\cos(\omega t - \beta z) + yB\sin(\omega t - \beta z)$ can be determined. With the relationship of A and B, it can confirm shape of polarization.

The multi-layered human body characteristic can be simplified as one equivalent layer with dielectric constant of 56 and the conductivity of 0.8 (Kim & Rahmat-Samii, 2004). So, with the change from free space to body materials, dielectric constant changes from 1 to 56 and conductivity changes from 0 to 0.8. What's more, to detect the transmitted signal independent of transmitter a position, the antenna is required the omni-directional radiation pattern (Kim & Rahmat-Samii, 2004; Chirwa et al., 2003). To investigate the characteristics of antennas for capsule endoscope, the human body is considered as an averaged homogeneous medium as described by the Federal Communications Commission (FCC) and measured using a human phantom (Kwak et al., 2005; Haga et al., 2009).

5. State-of-the-art WCE transmitting and receiving antennas

An antenna plays a very crucial role in WCE systems. Wireless capsule transmitting and receiving antennas belong to wireless communication unit, which provides a bidirectional communication between the capsule and the external communication unit at recommended frequency at which industrial, scientific and medical band was established. Wireless capsule endoscopy transmitting antenna is for sending out the detected signal and receiving antenna receive the signal outside human body. This section is to discuss the current performance of both WCE transmitting and receiving antennas.

5.1 Transmitting antennas

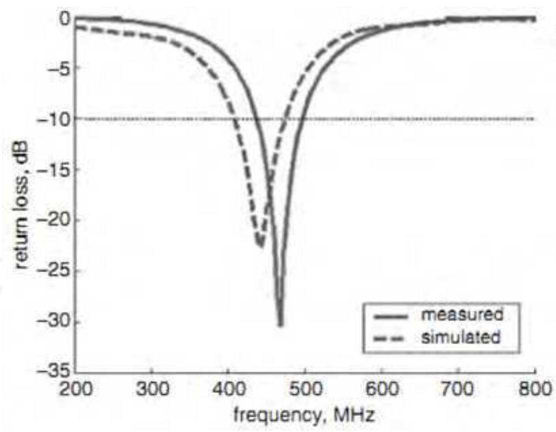
The capsule camera system is shown in Figure 2. One of the key challenges for ingestible devices is to find an efficient way to achieve RF signal transmission with minimum power consumption. This requires the use of an ultra-low power transmitter with a miniaturized antenna that is optimized for signal transmission through the body. The design of an antenna for such a system is a challenging task (Norris et al., 2007). The design must fulfill several requirements to be an effective capsule antenna, including: miniaturization to achieve matching at the desired bio-telemetric frequency; omni-directional pattern very congruent to that of a dipole in order to provide transmission regardless of the location of the capsule or receiver; polarization diversity that enables the capsule to transmit efficiently regardless of its orientation in the body; easy and understandable tuning adjustment to compensate for body effects. Types of transmitting antenna are used such as the spiral antennas, the printed microstrip antennas, and conformal antennas as shown in following subsections.

5.1.1 Spiral antennas

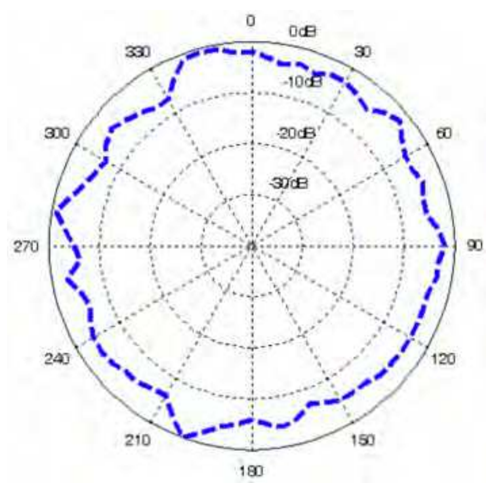
A research group from Yonsei University, South Korea, proposed a series of spiral and helical antennas providing ultra-wide bandwidth at hundreds of megahertz.

Single arm spiral antenna

The first design is a miniaturized normal mode helical antenna with the conical structure (Kwak et al., 2005). To encase in the capsule module, the conical helical antenna is reduced only in height with the maintenance of the ultra-wide band characteristics. Thus, the spiral shaped antenna is designed with the total spiral arm length of a quarter-wavelength. The configuration of the designed antenna is shown in Figure 3(a). It is composed of a radiator and probe feeding structure. The proposed antenna is fabricated on the substrate with 0.5-oz copper, 3 mm substrate height, and dielectric constant of 2.17. The diameter of the antenna is 10.5 mm and 0.5 mm width conductor.



(a) (b)



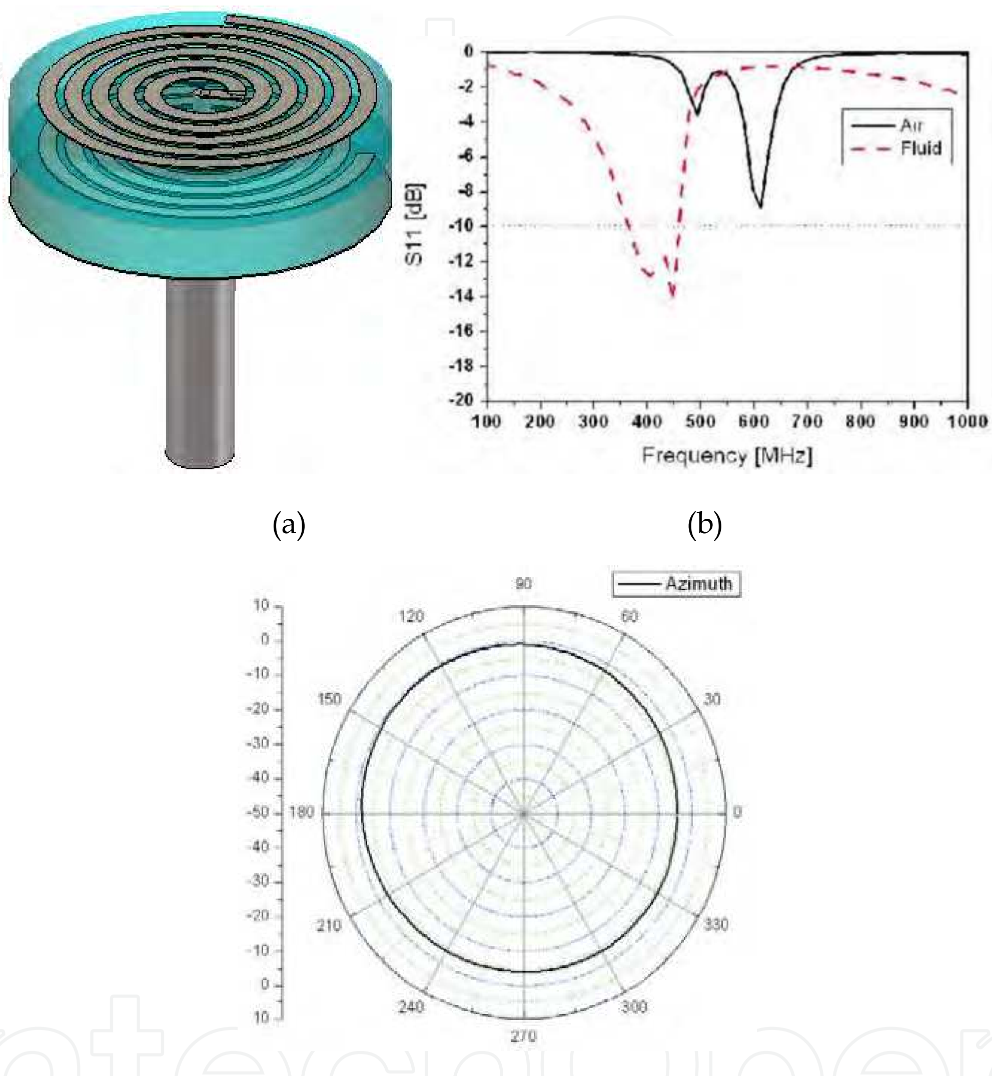
(c)

Fig. 3. Single arm spiral antenna (Kwak et al. 2005): (a) the geometric structure; (b) simulated and measured return losses; (c) azimuth pattern at 430MHz.

The simulated and the measured return losses of the antenna surrounded by human body equivalent material are shown in Figure 3(b). It can be observed that the bandwidth of the proposed spiral shaped antenna for S_{11}<-10dB is 110 MHz of 400-510 MHz and the fractional bandwidth is 24.1 %, which is larger than 20%, the reference of the UWB fractional bandwidth. The measurement result of the azimuth radiation pattern is shown in Figure 3(c). The normalized received power level is varying between 0dB to -7dB, which can be considered as an omni-directional radiation pattern.

Dual arm spiral antenna

The dispersive properties of human body suggested that signals are less vulnerable when they are transmitted at lower frequency range. Therefore, a modified design is proposed to provide ultra-wide bandwidth at lower frequency range (Lee et al. 2007). Figure 4(a) shows the geometry of a dual spiral antenna. The newly proposed antenna is composed of two spirals connected by the single feeding line. The radius of designed 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 of them are both 1.524mm. Two spirals with the same width of 0.5mm and the same gap of 0.25mm have different overall length. The lower spiral antenna is a 5.25 turn structure and the upper spiral is 5 turns.



(a) (b)

(c)

Fig. 4. Dual arm spiral antenna (Lee et al. 2007): (a) the geometric structure; (b) measured return losses; (c) azimuth pattern at 400MHz.

The return loss of the proposed antenna was measured in the air and in the simulating fluid of the human tissue as shown in Figure 4(b). Because of considering electrical properties of equivalent material of human body, return loss characteristic in the air is not good but dual resonant characteristic is shown in the air. However, the proposed antenna has low return loss value at operating frequency in the fluid and its bandwidth is 98MHz (from 360MHz to 458MHz) in the fluid, with the fractional bandwidth of about 25%. The simulated radiation pattern as shown in Figure 4(c) is omni-directional at the azimuth plane with 5dB variation.

Conical helix antenna

Extensive studies of the helical and spiral antennas were conducted with modified geometric structures. For example, a conical helix antenna fed through a 50 ohm coaxial cable is shown in Figure 5. Compared to small spiral antenna, conical spiral takes up much space. However, additional space is not necessary because a conical spiral can use the end space of the capsule as shown in Figure 5(a). The radius of the designed antenna is 10mm and the total height is 5 mm. This size is enough to be encased in small capsule.

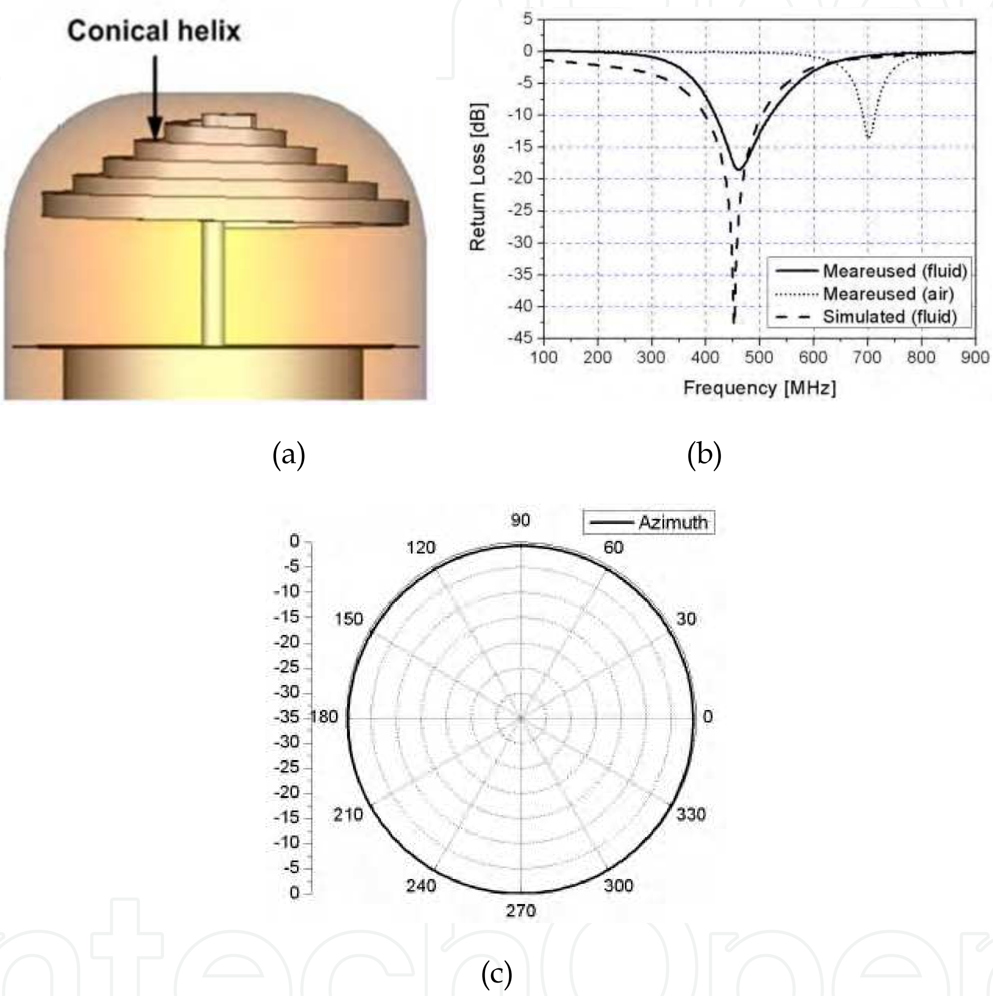


Fig. 5. Conical helix antenna (Lee et al. 2008): (a) the geometric structure; (b) simulated and measured return losses; (c) azimuth pattern at 450MHz.

The proposed antenna provides a bandwidth of 101MHz (from 418MHz to 519MHz) in the human body equivalent material as shown in Figure 5(b). Its center frequency is 450MHz, so the fractional bandwidth is about 22%. The normalized simulated radiation pattern is shown in Figure 5(c). The proposed antenna has omni-directional radiation pattern with less than 1dB variation.

Fat arm spiral antenna

Another modified design is the fat arm spiral antenna as shown in Figure 6(a). The spiral arm is 3mm wide and separated from ground plane with a 1mm air gap. The antenna is simulationally investigated in the air, in the air with capsule shell and in the human body equivalent material.

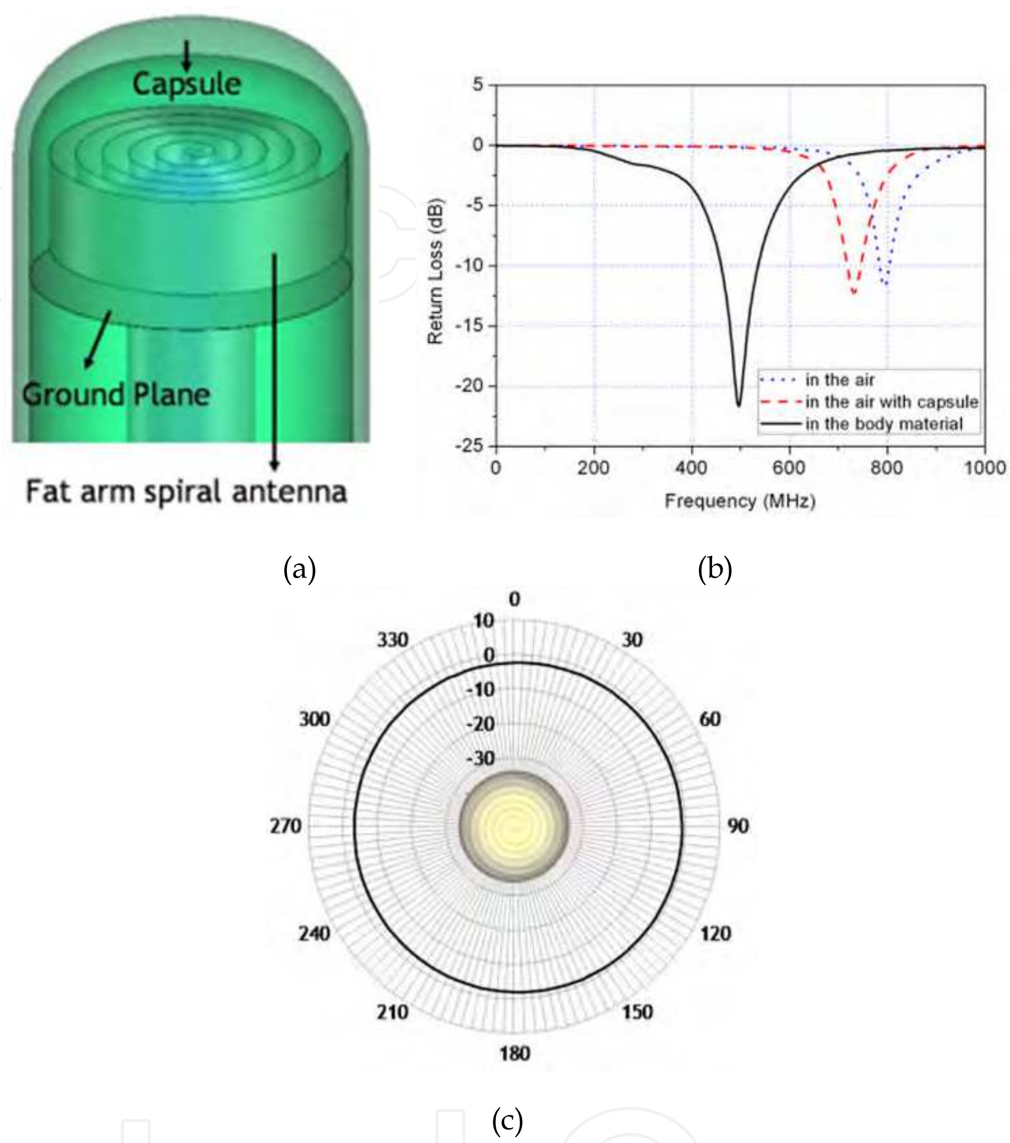
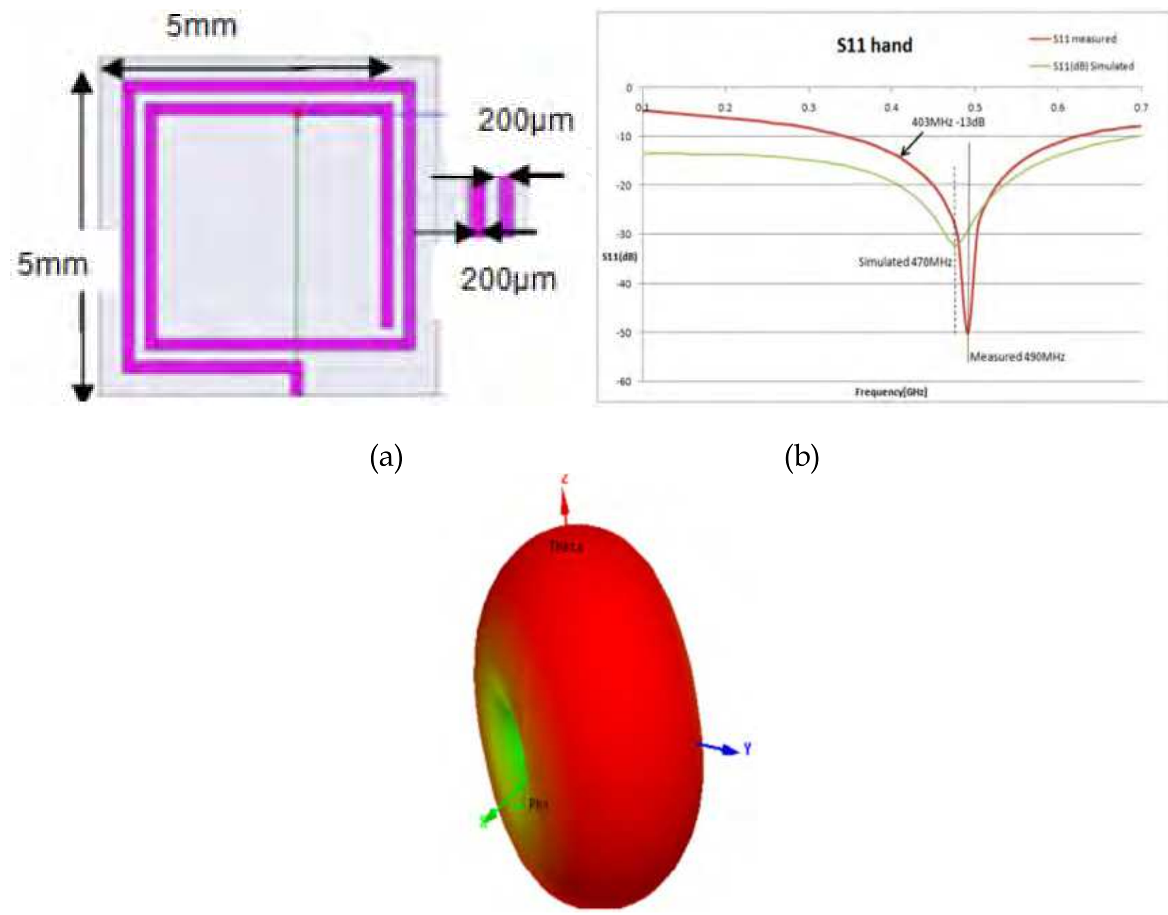


Fig. 6. Fat arm spiral antenna (Lee et al. 2010): (a) the geometric structure; (b) return losses; (c) azimuth pattern at 450MHz.

The return losses of the antenna in free space, with dielectric capsule shell and in the liquid tissue phantom are plotted in Figure 6(b). The resonant frequency is observed about 800 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 a resonant frequency and its bandwidth is 75 MHz (460 ~ 535 MHz) for S_{11} less than -10dB. The radiation pattern illustrated in Figure 6(c) presents that this antenna also provides omni-directional feature at azimuth plane.

Square microstrip loop antenna

A square microstrip loop antenna (Shirvante et al. 2010) is designed to operate on the Medical Implant Communication Service (MICS) band (402MHz -405MHz). The antenna is patterned on a Duroid 5880 substrate with a relative permittivity ε_r of 2.2 and a thickness of 500µm as shown in Figure 7(a). The area of the antenna is approximately 25 mm² which is smaller enough to be encased in a swallowable capsule for children.



(a) (b)

(c)

Fig. 7. square microstrip loop antenna (Shirvante et al. 2010): (a) the geometric structure; (b) simulated and measured return losses; (c) azimuth pattern at 403MHz.

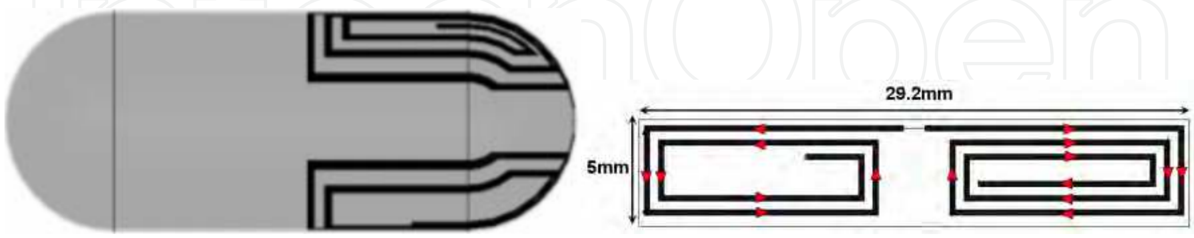
The simulated and measured return losses as shown in Figure 7(b) presents that the antenna provides enough bandwidth to cover the 402MHz to 405MHz band. At the FSK operating frequency 403MHz, the measured return loss is -13dB. Moreover, the designed antenna shows a large tolerance to impedance variation at the MICS band, in correspondance to ε_r variation. The designed antenna also has an omni-directional radiation pattern at azimuth plane.

5.1.2 Conformal antennas

A conformal geometry exploits the surface of the capsule and leaves the interior open for electrical components including the camera system. Several designs made efficient usage of the capsule shell area are selected as examples and introduced in this subsection.

Conformal chandelier meandered dipole antenna

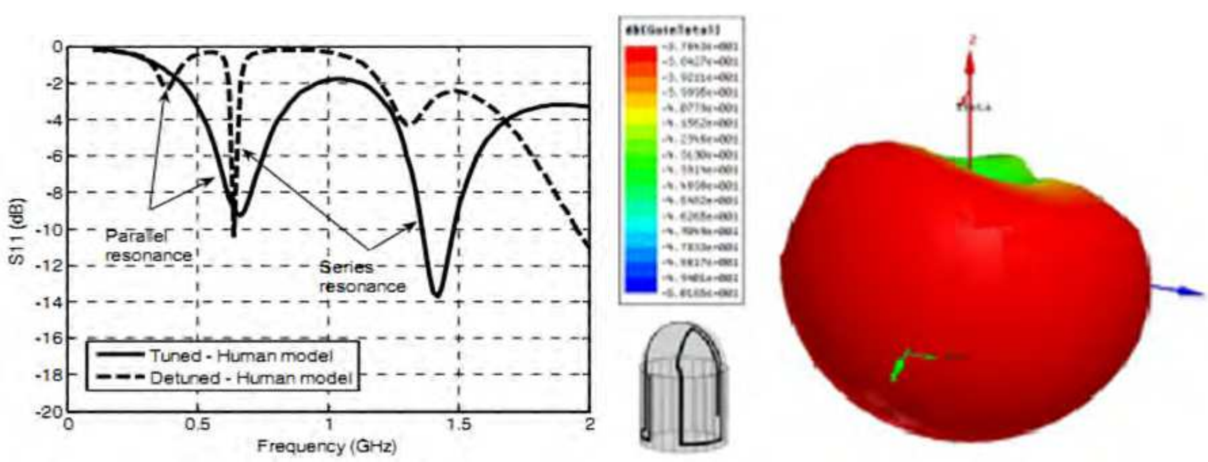
The conformal chandelier meandered dipole antenna is investigated as a suitable candidate for wireless capsule endoscopy (Izdebski et al., 2009). The uniqueness of the design is its miniaturization process, conformal structure, polarization diversity, dipole-like omni-directional pattern and simple tunable parameters (as shown in Figure 8(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 Figure 8(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 around 1395MHz – 1400 MHz wireless medical telemetry services (WMTS) band.



(a) (b)

Fig. 8. Conformal chandelier meandered dipole antenna (Izdebski et al., 2009): (a) the geometric structure of the conformal chandelier meandered dipole antenna; (b) Offset Planar Meandered Dipole Antenna with current alignment vectors.

The offset planar meandered dipole antenna is simulated on a 0.127 mm thick substrate with a dielectric constant of 2.2. 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 Figure 9(a). Figure 9(b) shows the radiation pattern of the tuned antenna inside the human body at 1.4 GHz.



(a) (b)

Fig. 9. Conformal chandelier meandered dipole antenna (Izdebski et al., 2009): (a) the return losses of detuned and tuned structure in human model; (b) azimuth pattern at 1.4GHz.

The radiation pattern is dipole-like but tilted due to the conformity of the structure. The axial ratio (dB) for the conformal chandelier meandered dipole antenna is about 7dB (elliptical polarization). It possesses all the characteristics of planar structure along with polarization diversity.

Outer-wall loop antenna

The proposed outer-wall loop antenna (Yun et al., 2010.) makes maximal use of the capsule's outer surface, enabling the antenna to be larger than inner antennas. As shown in Figure 10(a), the antenna is part of the outer wall of the capsule, thus decreasing volume and increasing 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 5.5mm and 5mm, respectively. Its length is 24 mm. The height of the meander line and gap between meander patterns are set to 7mm and 2.8mm, respectively. The opposite side of the loop line is meandered in the same way. Although capsule size is reduced, the radius of sphere enclosing the entire structure of the antenna is increased.

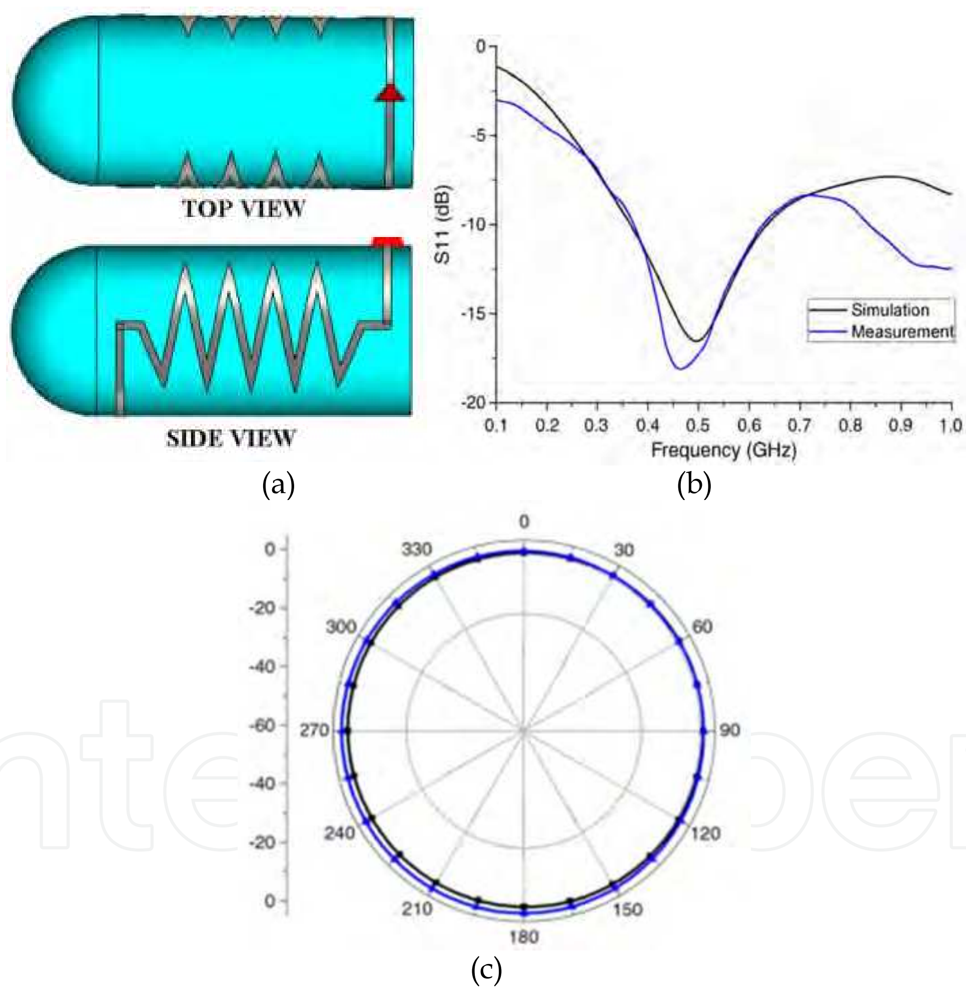


Fig. 10. Outer-wall loop antenna (Yun et al., 2010.): (a) the geometric structure; (b) simulated and measured return losses; (c) azimuth pattern at 500MHz.

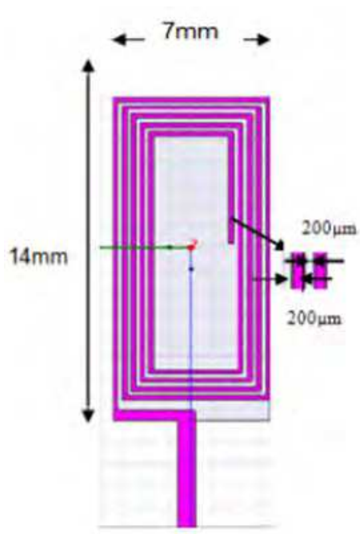
Figure 10(b) shows that the proposed antenna has an ultra wide bandwidth of 260 MHz (from 370MHz to 630 MHz) for VSWR<2 and an omnidirectional radiation pattern at azimuth plane (as shown in Figure 10(c)). Using identical antenna pairs in the equivalent body phantom fluid, antenna efficiency is measured to 43.7% (3.6 dB).

5.2 Receiving antennas

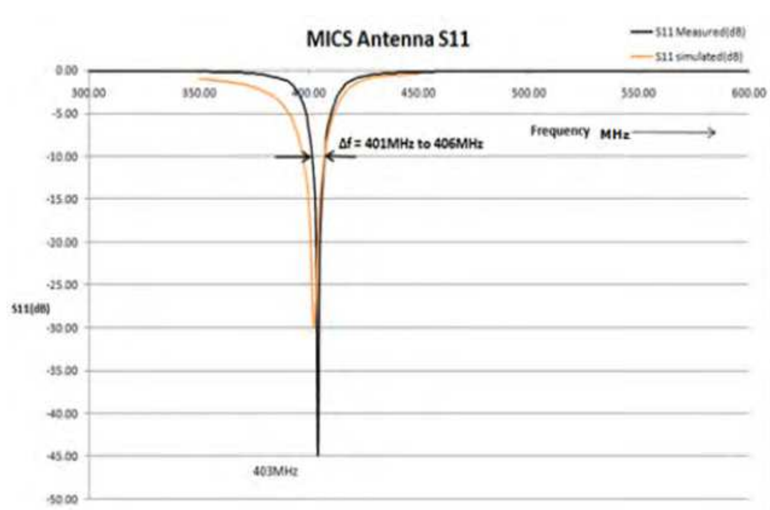
The receiving antennas are operating outside of human body, which is no longer limited by its size. Therefore, the design of receiving antennas is less challenge than the design of transmitting antennas. In this subsection, several types of receiving antenna are selected as examples.

Narrow bandwidth antenna for receiver

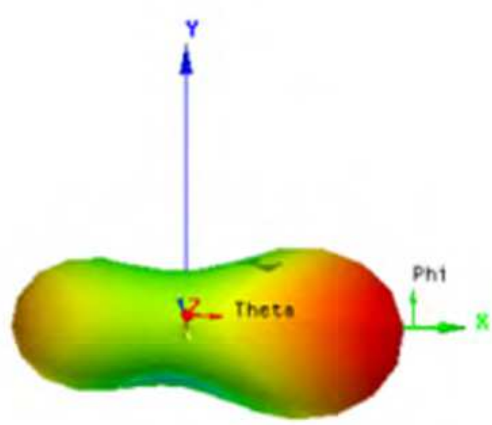
A narrow bandwidth receiving antenna is designed using microstrip loop structure (Shirvante et al. 2010). The antenna is patterned using a milling machine on a Duroid 5880 substrate with a relative permittivity ε_r of 2.2 and a thickness of 500μm as shown in Figure 11(a). The overall length of the wire is approximately a quarter wavelengths: λair /4 = 187mm at 402MHz for air medium.



(a)



(b)



(c)

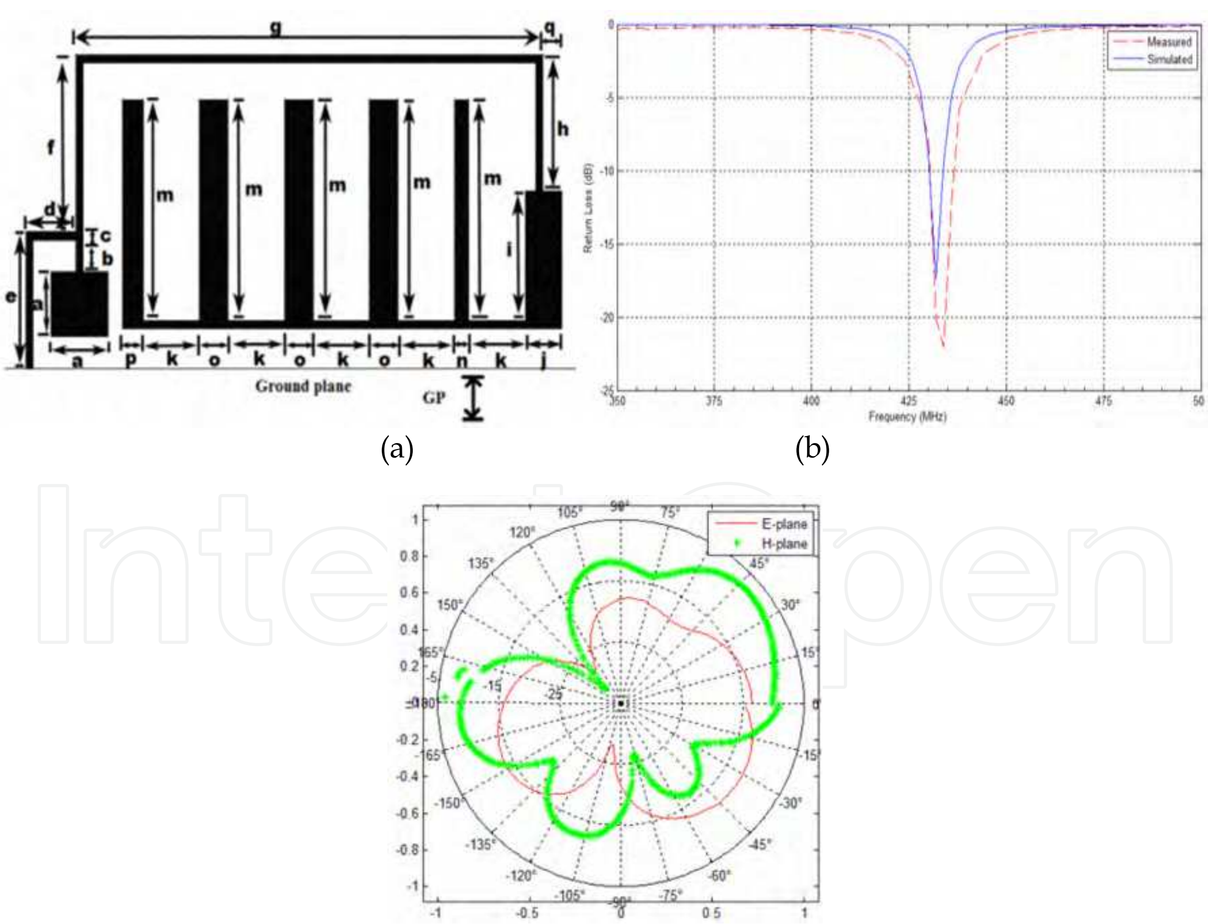
Fig. 11. Rectangular microstrip loop antenna (Shirvante et al. 2010): (a) the geometric structure; (b) simulated and measured return losses; (c) azimuth pattern at 403MHz.

Figure 11(b) shows the simulated and measured return losses of the proposed antenna. The return loss shows a deep null of -30dB at 403MHz. The directional rational pattern as shown in Figure 11(c) provides the possibility to aim the receiver to human body area, where the transmitter sends signals from. Therefore, for narrow bandwidth applications, such as the ASK or FSK modulation, the line loop antenna is a good choice.

Miniaturized microstrip planar antenna

To accommodate the antenna in a small communication unit, a meander line style structure is used (Babar et el., 2009). The antenna's radiating part is shorted with the ground plane, to further decrease the size of the antenna structure. The reduction of the size of the antenna by shortening also reduces the gain of the antenna, as decreasing the size of the antenna more than its wavelength affects the efficiency of the antenna.

The antenna was fabricated on a double sided copper FR4 – printed circuit board, with 1.6mm thickness as shown in Figure 12(a). The excitation is given through an SMA connector from the opposite direction of the PCB to the antenna structure. The total size of the antenna structure is 20mm x 37mm. There is no ground plane present on the opposite side of the PCB, where the antenna structure is present, which helps in getting an omni-directional radiation pattern.



(a) (b)

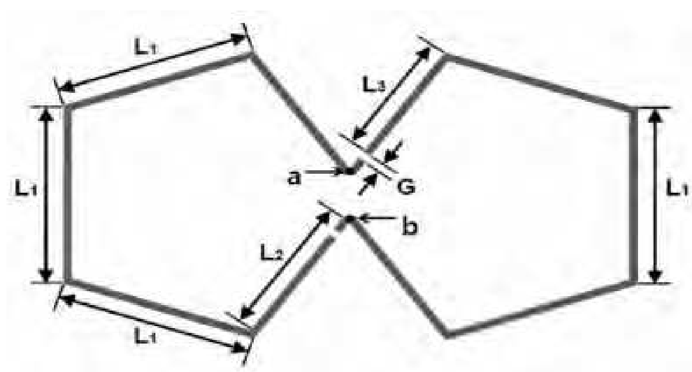
(c)

Fig. 12. Microstrip planar antenna (Babar et al. 2009): (a) the geometric structure; (b) simulated and measured return losses; (c) radiation patterns at 433MHz.

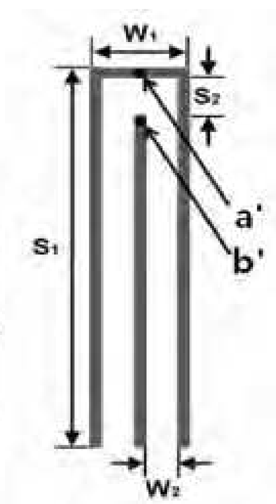
Figure 12(b) presents that the operating frequency of the antenna is 433 MHz with the bandwidth of 4MHz. Figure 12(c) shows the radiation pattern of the antenna's E and H-plane. The achieved max gain from the antenna was around -6.1 dBi.

Receiver antenna with buffer layer

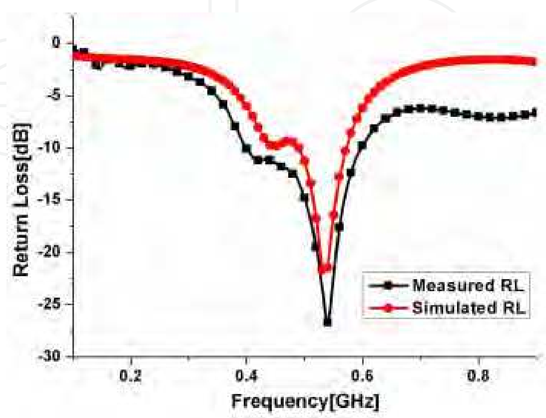
The dual pentagon loop antenna having circularly polarization is proposed (Park, S. et al., 2008). The configuration of the proposed dual pentagon loop antenna is shown in Figure 13(a). The proposed antenna and the feeding structure were etched on the front and the back of a substrate (Figure 13(b)). And a-a' are b-b' are shorted as follows. The proposed antenna was designed a dual loop type to enhanced H-field since the current direction of each of loops is different. And there is a gap on each of loops to make a CP wave (Morishita & Hirasawa 1994; Sumi et al., 2004 as cited in Park, S. et al., 2008). The strip widths of the primary loop and of the CPW are 0.80 mm; the used substrate is R/flex 3850; L1 = 12.93 mm, L2 = 10.97 mm, L3 = 10.21 mm, G = 0.49 mm, S1 = 26.01 mm, S2 = 1.65 mm, W1 = 5.80 mm, W2 = 1.70 mm. The CPW feeding line on the back of substrate is used to efficiently excite balanced signal power which makes to have a broadband.



(a)



(b)



(c)

Fig. 13. Receiver antenna with buffer layer (Park, S. et al., 2008): (a) the pentagon dual loop antenna; (b) feeding structure; (c) simulated and measured return losses.

Figure 13(c) presents that the bandwidth of the receiver antenna is from 400 MHz to 600 MHz for VSWR≤2. As a wave in air meets a medium of which relative permittivity is very high over air, much reflection is inevitably generated. So we designed the buffer layer having ε_r between air and human body for reducing the reflection, artificially. The buffer layer which is added a little bit loss is attached on the back of the proposed antenna for reducing a size of antenna and back lobe power.

6. Conclusions

Because of the requirement of medical test for GI tract, WCE came to the world. It solves many restrictions on exploring GI tract. With the development from 2001, WCE has become a promising device with suitable requirement. It has image sensor and lighting, control unit, wireless communication unit, power source, and mechanical actuator. The system can be operated outside the human body, the size of the capsule endoscope system is smaller, and the interconnection between devices was optimized, power consumption also reduced with technology optimized. Some companies and individual are still studying on new functions and optimization.

For wireless capsule endoscopy antenna, several basic standards and situation of operation in human body were discussed. The signal transmission efficiency of the antenna will directly decide the quality of the received real-images and rate of power consumption. Because of the lossy material absorbs a number of waves and decreasing the power of receiving signal, human body presenting strong negative effects on the microwave propagation. Wireless capsule endoscopy transmitting antenna is for sending out the detected signal inside human body and receiving antenna receive the signal outside human body. Several transmitting antennas are introduced in this article. The two fundamental types of transmitting antenna are the spiral antennas and conformal antennas both feature as the small physical size, relatively large bandwidth, omni-directional pattern and polarization diversity. The receiving antennas operating outside of human body are also discussed, such as the narrow bandwidth antenna for receiver, microstrip meandered planar antenna and the receiver antenna with buffer layer. All of them operate well outside the human body.

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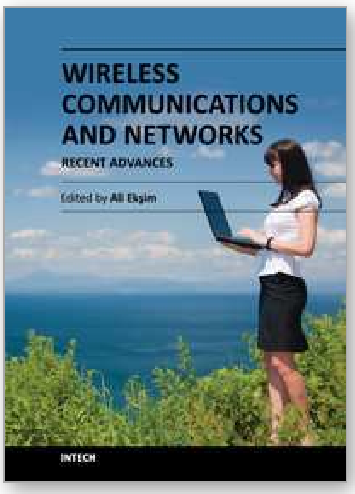

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InTech Europe
University Campus STeP Ri
Slavka Krautzeka 83/A
51000 Rijeka, Croatia
Phone: +385 (51) 770 447
Fax: +385 (51) 686 166
www.intechopen.com

InTech China
Unit 405, Office Block, Hotel Equatorial Shanghai
No.65, Yan An Road (West), Shanghai, 200040, China
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
Fax: +86-21-62489821