International Journal of Technology (2011) 1: 20-27
ISSN 2086-9614

A SMALL 915MHz RECEIVING ANTENNA FOR WIRELESS POWER TRANSMISSION AIMED AT MEDICAL APPLICATIONS

Toshihiro Kumagai[1*], Kazuyuki Saito[2], Masaharu Takahashi[2], Koichi Ito[1]

[1]*Graduate School of Engineering, Chiba University, Japan*
[2]*Research Center for Frontier Medical Engineering, Chiba University, Japan*

(Received: November 2010 / Revised: December 2010 / Accepted: January 2011)

ABSTRACT
Wireless power transmission is being investigated as a means to operate tiny medical devices such as the capsular endoscope, which is able to exist for a long period during diagnostic procedures within the body. In this paper, we examine the wireless power transmission to a capsular endoscope by electromagnetic waves to show its usability for medical applications. A modified helical antenna inside the endoscope is proposed as a power receiving antenna, operating at 915 MHz. By calculating a maximum received power in the stomach using such antenna, the results show that adequate power can be well received.

Keywords: Capsular endoscope; Helical antenna; Medical application; Receiver; Wireless power transmission

1. INTRODUCTION
In recent years, the research of wireless power transmission has been actively investigated in several field studies (Gozalvez, 2007). In general, power transmission uses an electrical cable, while wireless power transmission does not require a cable. Wireless power transmission can be employed by utilizing several methods, yet the most suitable method must be selected in terms of transmission distance and e transmission power level.

We support the use of wireless power transmission in medical field applications for the following reason. The Japanese government issued a new plan to use radio waves in 2010s for home wireless systems and medical micro robots (as a medical system) in order to take measure against the declining birthrate and the aging of society in Japan (MIC, 2009). Currently wireless power transmission in medical field is assumed to be utilized in an artificial heart (Niu et al., 2009) or a capsular endoscope (Murakuni et al., 2009). This technology enables such internal implantation equipments to operate for a long period in the body. In particular, use of the capsular endoscope is noninvasive and less uncomfortable for patients, differing from the existing wired endoscope. Hence, it has become an attractive study in recent years.

Structure of the capsular endoscope and its application in medical systems are depicted in Figure 1. The capsular endoscope is very small, thus it is very difficult to transmit power to equipment outside the human body. In previous studies, the electromagnetic induction method is used for power transmission. Nonetheless, by electromagnetic induction, the power transmitting and receiving coils should be positioned at the same direction; otherwise loss of detection will occur.

*Corresponding author's email: t.kuma@graduate.chiba-u.jp, Tel. +81-43-290-3931, Fax. +81-43-290-3933

This paper investigates wireless power transmission to a capsular endoscope by using the microwave method. Such a method is usually used in the SPS (Space Solar Power Satellite/station) plan (Rodenbeck et al., 2004) and the EV (Electric Vehicle) (Shinohara & Matsumoto, 2004). In the microwave method, the performance of the device called the rectenna (rectifying antenna) that consists of an antenna and rectifying circuit is very important. Summarized in this paper is the design for a power receiving antenna that operates at 915 MHz along the ISM (Industry Science Medical) band. In order to obtain maximum received power through the antenna, we numerically analyzed the antenna characteristics by use of the Finite-Difference Time-Domain (FDTD) method. In fact, in terms of the operating frequency, lower frequency is preferred due to its transmission characteristics and safety to the human body (Murakuni et al., 2009), We, however, selected the operating frequency at 915 MHz based on the ease of antenna design.

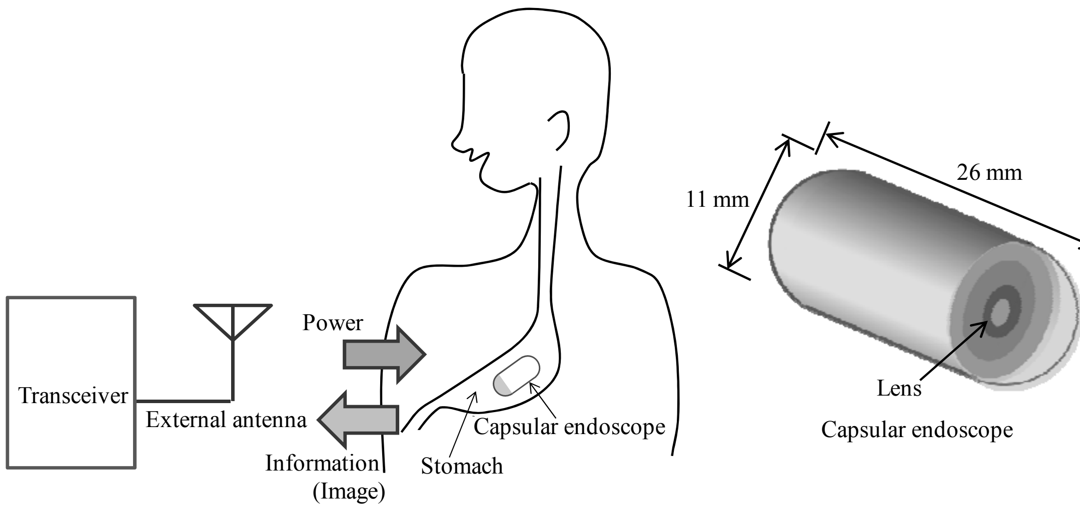

Figure 1 Wireless power transmission system for capsular endoscope

2. DESIGN OF ANTENNAS

2.1. Receiving Antenna for 915 MHz in Air Space

The structure of the designed antenna (Figure 2) is shown; the antenna is assumed to be inserted into a capsular endoscope, hence, we designed it as a folded-helical sheet antenna with a diameter of 10 mm and height of 27 mm. The entire length of the antenna conductor sheet is 343 mm (1.05 λ). We selected a folded-type antenna because the input impedance of the normal helical antenna is low, which creates difficulty in impedance matching. By our design, the left end of the antenna was shortened, while the right one was opened. This structure makes it easy to adjust the resonant frequency when the antenna is fabricated. The size of the antenna is linked for the capsular endoscope, which is currently produced by several manufacturers (Given Imaging, 2001; Olympus Medical Systems Corp., 2005; RF SYSTEM Lab., 2005). The size of the endoscope antenna is 26 mm in length and 11mm in diameter (Figure 1). The width of the sheet is 1.8 mm, and a feeding point is set at the center of the antenna.

We analyzed the input characteristics in terms of the reflection coefficient (S_{11}) and the input impedance. As shown in Figures 3 and 4, at 915 MHz of the desired operating frequency, the reflection coefficient was -14.9 dB and the input impedance was 40.5 Ω and 13.5 Ω for resistance and reactance, respectively. The radiation pattern is omnidirectional in *x-y* plane (Figure 5) with peak gain of 0.43 dBi. With this omnidirectional pattern, it is expected that the endoscope can send information while it is inside the body.

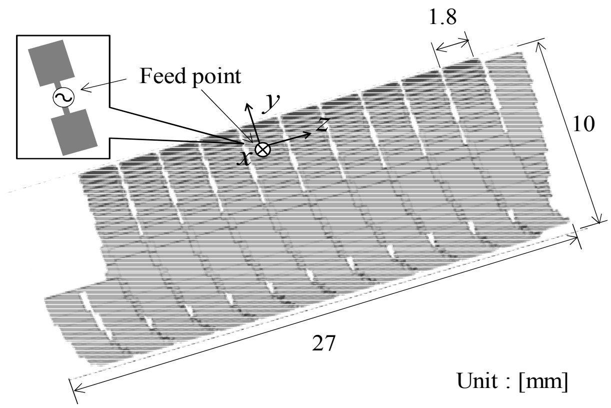

Figure 2 Structure of receiving antenna

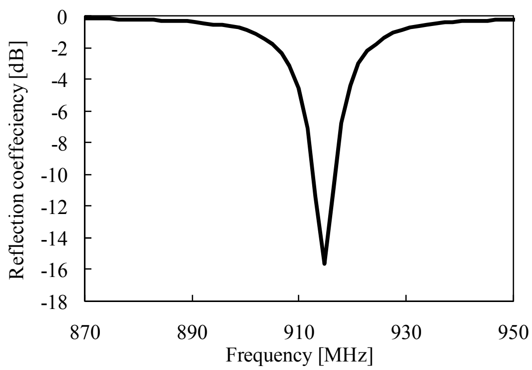

Figure 3 Reflection coefficient

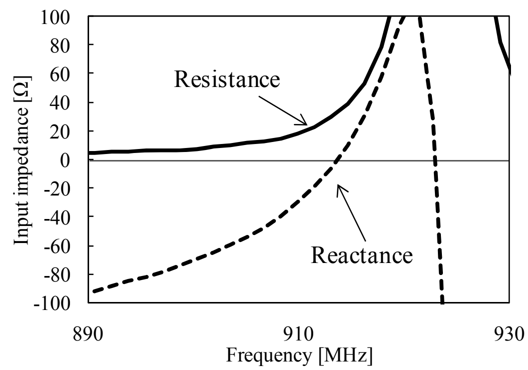

Figure 4 Input Impedance

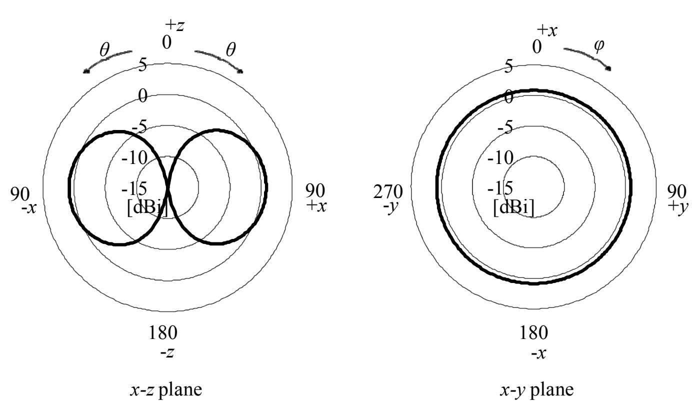

Figure 5 Radiation pattern in free space

2.2. Receiving Antenna for 915 MHz near the Human Body

In Section 2.1, it was noted that the antenna inside the endoscope was designed in free space with good results. However, the capsular endoscope will touch the human tissue when reaching into the stomach, thus requiring us to analyze input characteristics under such conditions. In general, the resonant frequency of the antenna shifts to the lower frequency when the antenna is situated near the human body, allowing us to redesign the structure of the antenna to adjust the resonant frequency. The reflection coefficient when the antenna is placed at 2 mm from the human body is shown in Figure 6 (normal). From this figure, we can see the resonant frequency considerably shifts to the lower frequency range.

We adjusted the resonant frequency to become 915 MHz (as shown in Figure 6) by shortening the entire length of the antenna conductor sheet to 308 mm (0.94 λ). The diameter and height are 10 mm and 27 mm, respectively.

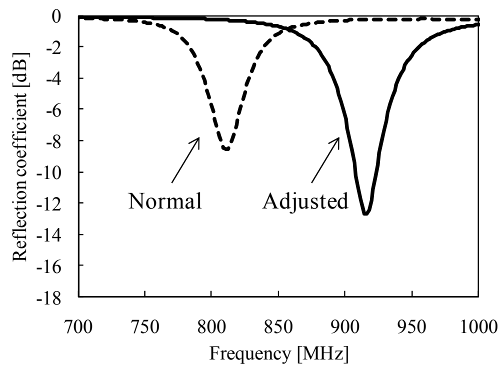

Figure 6 Reflection coefficient of adjusted antenna

2.3. Transmitting Antenna

In this section, the investigation of the transmitting antenna that radiates power to the receiving antenna is observed. When electromagnetic waves are radiated to the human body, radiation exposure to the human body must be considered. An evaluation standard for electromagnetic wave exposure called Specific Absorption Rate [W/kg] (SAR) is defined by the following formula:

$$\mathrm{SAR} = \frac{\sigma}{\rho} E^2 \tag{1}$$

where, σ is the conductivity of human tissue [S/m], ρ is density of human tissue [kg/m^3], and E is the electrical field intensity (effective value) [V/m]. The standard limitations for average SAR per arbitrary 10g of tissues and whole-body are defined by the International Commission on Non-Ionizing Radiation Protection (ICNIRP). In the frequency range from 10 MHz to 10 GHz, under an environment where the exposure to electromagnetic waves can be managed, the limit value is 10 W/kg; while in a general public environment, the limit value is 2 W/kg. In this paper, we apply the managed environment for SAR evaluation.

The radiated power from transmitting antenna could be higher by reducing SAR value. In the present investigation, we examine the transmission power of half-wave length dipole antennas as transmitting antenna. The calculation model is shown in Figure 7. Two rectangular parallelepipeds are modeled as a human body. The size of the human body is infinite in y-axis and z-axis direction. There is an air space 30 mm from the body's surface and the receiving antenna is placed in the center of the space. A simple dipole antenna is used as the receiving antenna to shorten the calculation time.

In addition, the electric constant used for the human body model is the value (relative permittivity ε_r: 36.7 and conductivity σ: 0.63 [S/m]) multiplied with the muscle's electric constant at 915 MHz by a factor of 2/3. It is common for evaluation purposes that the averaged electric constant of the human body is 2/3 of the muscles and body density is 1000 kg/m^3. The transmission efficiency and the maximum local 10 g-averaged SAR are calculated when multiple transmitting dipole antennas are set within 100 mm distance in the y-direction and located 20 mm from the human body surface. The maximum received power is calculated as well.

From calculation results for transmission efficiency and maximum local 10 g-averaged SAR normalized by 1 W (shown in Figure 8), it is noted that there is no significant change in transmission efficiency except for the case that two antennas are used as a transmitting antenna. It can also be seen that the 10g-averaged SAR does not largely change, except for the case that the one antenna is used. The highest SAR value is observed at the body surface. SAR distributions are depicted in Figure 9, and the figures show the possibility to avoid higher SAR at local concentrations by using multiple transmitting antennas. The radiation power is calculated when the maximum local 10g-averaged SAR becomes 10 W/kg, where it is a limitation value by the ICNIRP. Calculation results indicate that when three dipole antennas are used as a transmitting antenna, the highest power is possibly obtained (Figure 10).

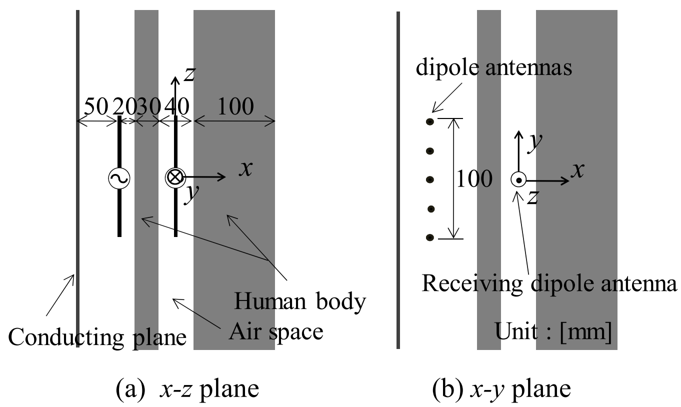

Figure 7 Calculation model with dipole antennas

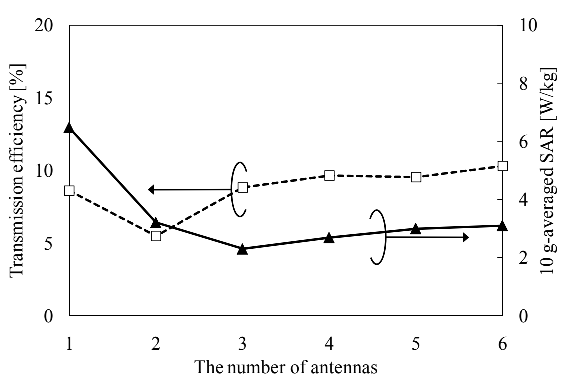

Figure 8 10g-averaged SAR and transmission efficiency

2.4. Optimization for Calculation Model

The maximum received power, which is obtained from the designed receiving antenna, is numerically calculated. In the calculation model (Figure 11) and in accordance with the results in Section 2.3, three dipole antennas are used as transmitting antennas and placed at 20 mm from the human body surface. The infinite conductor plate is set at 50 mm behind the transmitting antenna. The two receiving antennas described in Sections 2.1 and 2.2 (folded-helical antenna) are located at 15 mm and 2 mm, respectively, from the left side of the 30 mm-thickness human body.

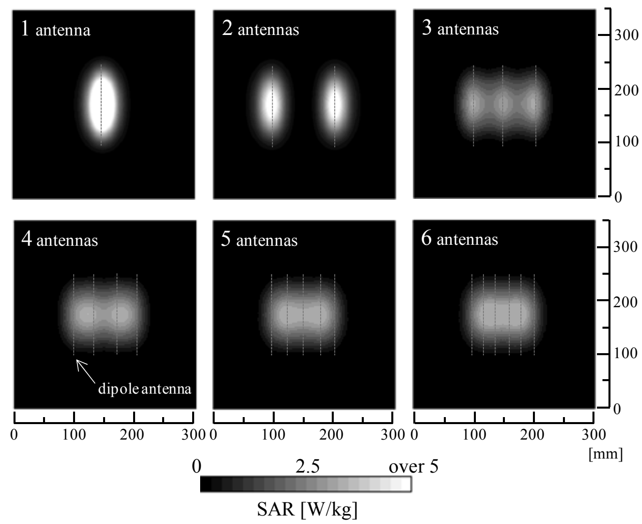

Figure 9 SAR distributions in the human body surface depend on the number of antennas

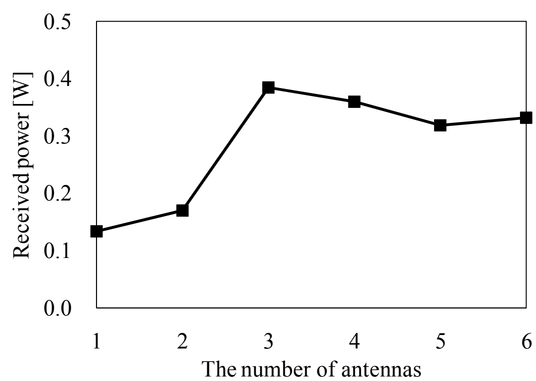

Figure 10 Received power depends on the number of antennas

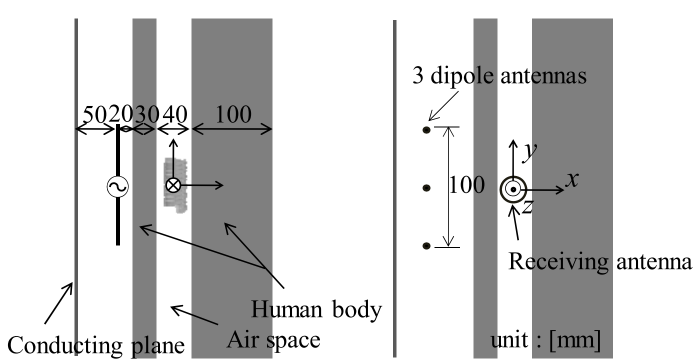

Figure 11 Calculation model using 3 dipole antennas and designed receiving antenna

3. RESULTS

Calculation results of the optimized model, summarized in Table 1, validate that when the receiving antenna described in Section 2.1 is used, the transmission efficiency is 1.7%. The efficiency comes from the radiated power of the transmitting antenna and the received power obtained by receiving antenna. When the antenna designed in Section 2.2 which can operate near human body is used, the transmission efficiency improves to 1.9%. The maximum local 10g-averaged SAR is similar with the results in Section 2.3 that a dipole antenna is used as a receiving antenna.

From the calculation results, When 10g-averaged maximum SAR which is defined by ICNIRP becomes 10 W/kg that is the limitation value, the radiation power is 4.4 W. Then, the received power is 85 mW when the receiving antenna is located near human body, while the received power is 74 mW when the receiving antenna and human body are separated. It seems reasonable that these results are adequate values for received power even though the rectification efficiency is another issue that should be considered. In fact, the antenna described in Section 2.2 should be adopted for most cases since in real applications, the antenna touches the human body.

Table 1 Calculation result of optimized model

Distance from the body surface	Radiated power from transmitting antenna	Received power	Transmission efficiency
15 mm	4.4 W	75 mW	1.7 %
2 mm		85 mW	1.9 %

4. CONCLUSION

The receiving antennae that can be inserted on a capsular endoscope have been designed, and the method for transmitting power by using dipole antennas has been numerically examined. The results show us that the power of 85 mW can generally be well received, thus the wireless power transmission by the microwave method is a viable application. In the future, fabrication of the designed antenna and experimental testing will be conducted to prove the validity of the calculation results. Moreover, we intend to perform examination of the receiving antenna when it is placed inside the intestines as well.

5. REFERENCES

Given Imaging Homepage, 2001. *PillCam SB.* Available at: <http://www.givenimaging.com/en-us/HealthCareProfessionals/Pages/PillCamSB.aspx> [Accessed Jan. 5, 2011].

Gozalvez, J., 2007. WiTricity-The Wireless Power Transfer, *IEEE Vehicular Technology Magazine*, Volume 2, pp. 38-44.

Japanese Ministry of Internal Affairs and Communications–MIC, 2009. Available at: <http://www.soumu.go.jp/main_content/000030534.pdf>

Murakuni, E., Higaki, N., Shiba, K., 2009. Analysis of Human Body Electric Field Distribution Using the Transmitting Antenna in an Implantable Device, *ITE Technical Report*, Volume 33, Number 15, pp.13–18.

Niu, Q., Wang, L., Dong, T.,Yang, H., 2009. Application of a MEMS-based Energy Harvester for Artificial Heart Wireless Energy Transmission, *Proceedings of 2009, ISECS International Colloquium on CCCM*, Volume 1, pp.38–41.

Olympus Medical Systems Corp., 2005. *Endo Capsule.* Available at: <http://www.onaka-kenko.com/endoscope-closeup/endoscope-technology/et_06.html> [Accessed Jan. 5, 2011].

RF SYSTEM lab., 2005. *Sayaka.* Available at: <http://www.rfsystemlab.com/sayaka/index.html> [Accessed Jan. 5, 2011].

Rodenbeck, C.T., Li, M.Y., Chang, K., 2004. A Phased-Array Architecture for Retrodirective Microwave Power Transmission from the Space Solar Power Satellite, *Microwave Symposium*, Volume 3, pp.1679–1682.

Shinohara, N., & Matsumoto, H., 2004. Wireless Charging System by Microwave Power Transmission for Electric Motor Vehicles, the Institute of Electronics, *Information and Communication Engineers (IEICE) Transaction on Electronics*, Volume J87-C, Number 5, pp.433–44.