Propagation Loss and Position Estimation of Capsule Antenna Through Human Body Phantom

Hiroyasu Sato, Yang Li, Qiang Chen
Department of Communications Engineering
Graduate School of Engineering, Tohoku University
Sendai, Japan
sahiro@ecei.tohoku.ac.jp

Abstract— **The propagation loss between a capsule antenna inside a human body phantom and an outside antenna is investigated experimentally. The position estimation of a capsule antenna is also performed by using the received power distribution on a plane located outside phantom. Two frequency band of 320 MHz and 1 GHz are compared. For 320 MHz, a print monopole antenna with a capsule inside a human body phantom is designed and an inductor is used for impedance matching. It is found that there is a relation of tradeoff between the received power and the accuracy of the position estimation a capsule.**

Keywords— capsule antenna, impedance matching, position estimation, received power.

I. INTRODUCTION

Wireless capsule endoscope system has gained popularity in health-care applications [1, 2]. The system uses a wireless transceiver to obtain medical images inside a human body [1]. The efficiency of capsule antenna is extremely low caused by its physical size. The propagation loss through lossy human body is quite large [3-5] and the impedance matching between capsule antenna and its feeding circuit is important to obtain high received power at the outside antenna. Furthermore, the accurate position estimation of capsule is also important in medical diagnosis when the capsule pass through the digestive system of a human body [6].

Various kinds of frequency band were selected for capsule endoscope systems, as examples, ISM band of 315 MHz was used in [7], while 1 GHz was studied in [8]. However, it is not clarified the optimal frequency band to obtain high received power through a human body and the relation between the received power and the accuracy of position estimation of a capsule inside a human body.

In this report, a design of a capsule print monopole antenna at 320 MHz is presented and an experimental study on the received power and the position estimation of a capsule antenna are investigated at 320 MHz and 1 GHz. The relation between the received power and the accuracy of position estimation of a capsule is discussed.

II. GEOMETRY AND EXPERIMENTAL SETUP

Figure 1 shows the geometry of capsule monopole antenna inside a human body. The length of a monopole antenna are 30 mm and the width of 2 mm.

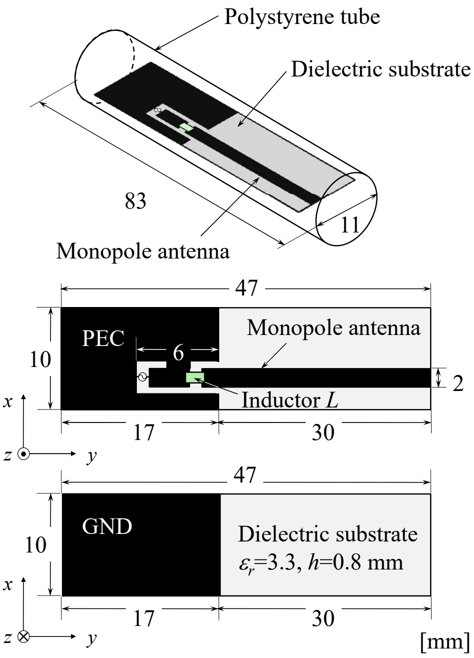


Fig. 1. Geometry of capsule monopole antenna inside human body.

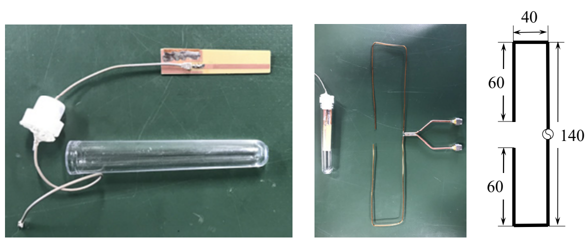
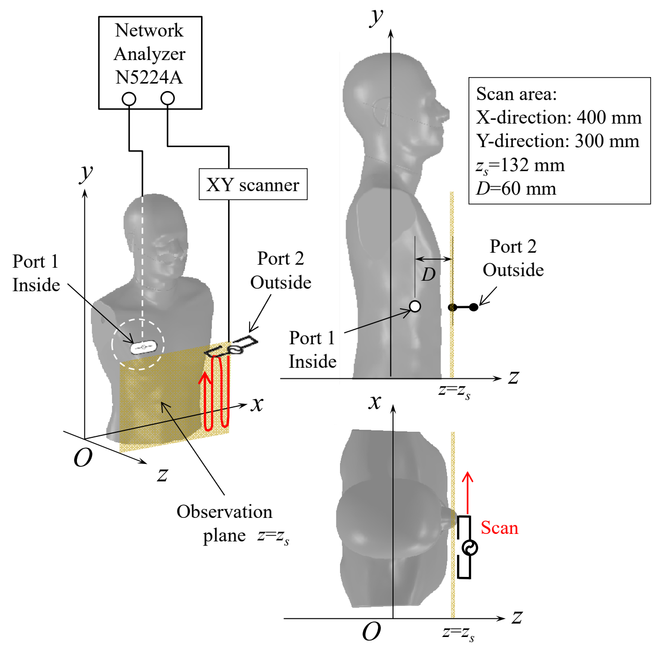
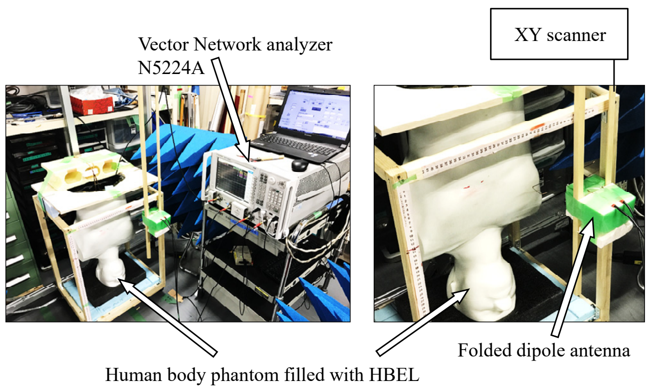


Fig. 2. Photograph of capsule monopole antenna and folded dipole antenna inside and outside of human body, respectively.



(a) Scanning system.



(b) Photograph.

Fig. 3. Experimental setup.

Dielectric substrate are with a length of 47 mm and a width of 10 mm and dielectric constant of ε_r=3.3. An inductor was used for impedance matching between the impedance of printed monopole antenna and the internal impedance of 50 Ω at 320 MHz. A polystyrene tube with length of 83 mm and diameter of 11 mm was used as a capsule. Figure 2 shows photograph of the fabricated capsule monopole antenna and a folded dipole antenna, inside and outside of a human body, respectively. The total length of the folded dipole antenna is 340 mm with resonant frequency of 320 MHz.

Figure 3 shows the experiment setup. A commercial human torso-shaped phantom filled with a human body equivalent liquid (HBEL) developed by SPEAG was used [9].

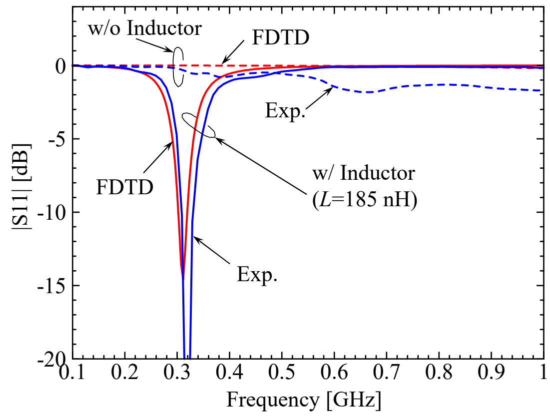


Fig. 4. Reflection coefficient in case with and without inductor..

A capsule antenna was fixed inside the phantom at the position indicated as Port 1 (x, y, 72 mm) and an outside antenna were scanned on an observation plane z=z_s=132 mm by using XY-scanner and its position were indicated as Port 2 (x, y, z_s). The distance between two antenna was set to D=60 mm.

The scan area is 400 mm*300 mm in x and y directions, respectively. S-parameters at each position were obtained by Vector Network Analyzer (Keysight N5224A). Two cases: (a) capsule monopole antenna (inside) and folded dipole antenna (outside) and (b) dipole antenna l_1=20 mm (inside) and dipole antenna l_2= 140 mm (outside) were compared.

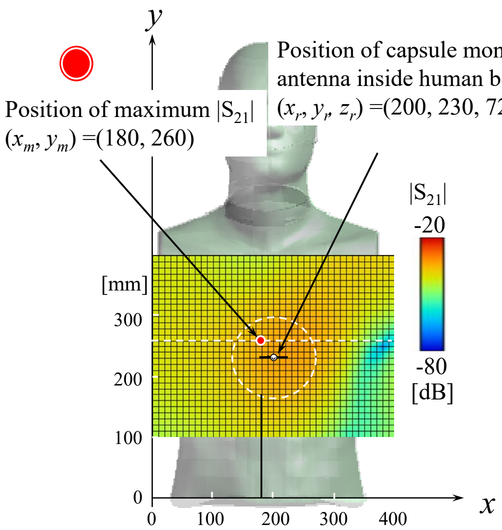
III. Impedance Matching

Impedance of capsule monopole antenna Z_a placed in torso-shaped phantom was simulated using FDTD analysis with considering dispersive effect of complex permittivity and was obtained as Z_a=R_a+$j$$X_a$=1.5+$j$(-425) Ω at 320 MHz. A series inductor was used for matching the impedance Z_a to 50 Ω. TRL calibration technique was used for measurement and impedance of Z_L=R_L+$j\omega L$=33+j369 Ω at 320 MHz was obtained. Figure 4 shows the reflection coefficient with and without an inductor obtained by the experiment and the numerical analysis. In the FDTD simulation, the copper loss of conductor has been neglected and the measured value of Z_L at 320 MHz was used. In the case with inductor, $|S_{11}|$ of less than -14 dB has been obtained by the presence of inductor. It is considered that the impedance matching is realized by the presence of resistive component of inductor R_L=33 Ω, which is quite larger than that of antenna R_a=1.5 Ω.

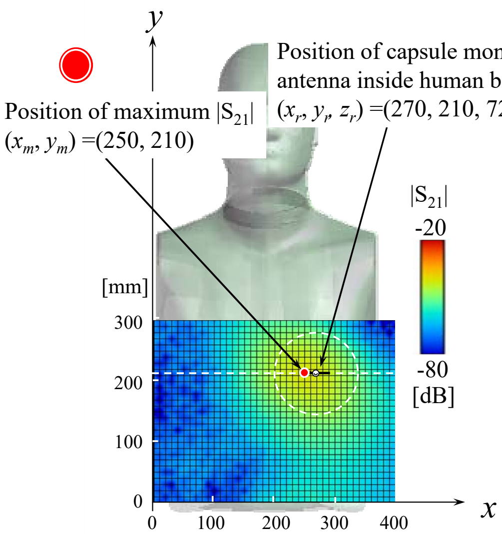
IV. Position Estimation of Capsule Antenna

To evaluate the propagation loss and the accuracy of position estimation of a capsule antenna through a human body phantom, two frequency band of 320 MHz (Case 1) and 1 GHz (Case 2) were compared. In the case of 320 MHz band, a capsule monopole antenna with an inductor (inside) and a folded dipole antenna (outside) were used. In the case of 1 GHz band, a dipole antennas with length of l_1= 20 mm (inside) and l_2= 140 mm (outside) were used [3, 5]. The impedance matching for each inside and outside antennas were realized in both cases of 320 MHz band and 1 GHz band.

Figure 5 shows the distributions of transmission coefficient $|S_{21}|$ on an observation plane $z=z_s=132$ mm. In the case of 318 MHz, large $|S_{21}|$ in a whole area of the observation plane was observed. Maximum value of $|S_{21}|=-33.3$ dB is observed at $(x_m, y_m)=(180, 260)$ which is different from the real position of $(x_r, y_r)=(200, 230)$ with the distance $\Delta R=[(x_r-x_m)^2+(y_r-y_m)^2]^{1/2}=36$ mm. In the case of 1 GHz, it is observed that the region with large $|S_{21}|$ is limited around the real position of $(x_r, y_r)=(270, 210)$. Maximum value of $|S_{21}|=-39.3$ dB is observed at $(x_m, y_m)=(250, 210)$ with the distance $\Delta R=20$ mm. From above results, it is found that accuracy for the position estimation of a capsule antenna is high in case of 1 GHz, while the received power is small compared with the case of 318 MHz. It is considered that there is a relation of tradeoff between the accuracy of the position estimation and the received power.



(a) Case 1 (318 MHz)



(b) Case 2 (1 GHz)

Fig. 5. Distribution of transmission coefficient |S21| on observation plane $z=z_s=132$ mm.

V. Conclusion

In this research, the received power through a human body phantom and the position estimation of capsule antenna were investigated with comparing two frequency band of 320 MHz and 1 GHz. It is found that there is a relation of tradeoff between the accuracy on the position estimation and the received power. Considering battery-less wireless capsule endoscope systems, the lower frequency will be preferred for the power transfer while the higher frequency should be used not only for the position estimation of a capsule antenna but also for data transfer with high data rate.

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