Design of an Ultra-Compact UHF Passive RFID Tag Antenna for a Medical Sample Tube

Jung-Nam Lee, Moon-Young Hwang, Sang-Il Lee, Kwang-Chun Lee, and Jong-Kweon Park

In this letter, a small-sized ultra-high frequency (UHF) RFID tag antenna for a medical sample tube is proposed. The RFID tag antenna is designed and fabricated based on the circular loop antenna used in the UHF band (Korea standard, 917 MHz to 923.5 MHz). The tag antenna size is reduced using a circular meander stub. The antenna has a physical size of 8 mm, which is about λ/40 in electrical length. The proposed tag antenna is molded into a medical sample and multitag identification is performed.

Keywords: UHF RFID tag antenna, medical sample tube, loop antenna, multitag.

I. Introduction

Presently, the management of medical samples is conducted by hand. They are antisepticized with formaldehyde, and individual patient samples are then separated and placed into sample cases. In addition, a handwritten patient history is recorded in the sample case. An inappropriate sample may be given to a patient if the information management of the patient is conducted manually. Therefore, medical malpractice, such as surgical mistakes or side effects from medication, may occur, threatening the life of the patient. To solve this problem, an ultra-high frequency (UHF) passive tag antenna can be inserted into the medical sample case.

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RFID systems are classified according to frequency: low frequency (LF) (125 kHz to 134 kHz), high frequency (HF) (13.56 MHz), UHF (860 MHz to 960 MHz), and microwave (2.4 GHz and 5.8 GHz). The LF and the HF RFID systems utilize inductive coupling to carry power transfer and data transmission between the tag and the reader antenna [1]. The UHF and microwave RFID systems use the propagation of electromagnetic waves to transfer information between the tag and reader. LF and HF RFID systems are widely used for the near-field RFID system, due to the advantage of the security. However, because the physical size of the antenna is big, its application to a small item is limited. In addition, because the frequency is low, the data transmission rate is slow and the transmission data volume is restrictive. The UHF near-field RFID system receives a lot of attention, owing to its promising item-level applications to the pharmaceutical and medical systems. The physical antenna size can be suitably reduced to carry out the item-level tagging for small items, which requires the attachment of small antennas.

Various small RFID tag antennas have been developed for UHF RFID systems [1]-[8]. To reduce the size of a tag antenna, a spiral [1], [2] or loop [3]-[6] structure can be used. However, such tag antennas are too large to insert into a medical sample case.

In this letter, we present the design of a small-sized UHF RFID tag antenna for a medical sample tube. The proposed tag antenna modifies the loop structure and reduces the size of the antenna to λ/40 (f_c = 920 MHz). The proposed tag antenna covers a range of 917 MHz to 923.5 MHz (Korea standard). Multitag identification is measured for one hundred medical sample tubes. The multitag identification rate is compared using a far-field reader antenna (Alien reader antenna [ALA-97C]) and a near-field reader antenna (MTG reader antenna [MT-269508]).

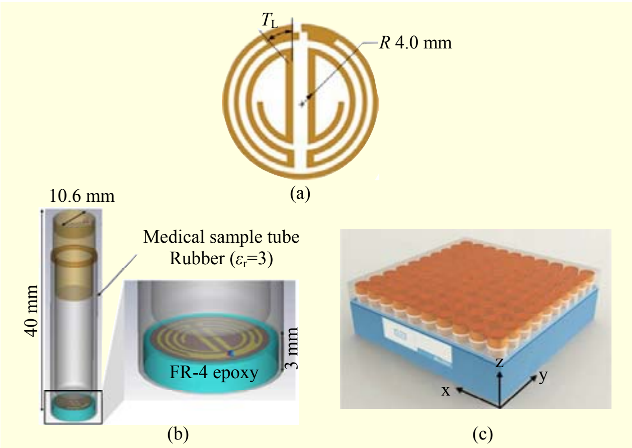

Fig. 1. Geometry of proposed tag antenna: (a) tag antenna without medical sample tube, (b) tag antenna with medical sample tube, and (c) multitag antennas.

II. Tag Antenna Design

Figure 1 shows the geometry of the proposed small-sized UHF RFID tag antenna for medical sample tubes. The tag antenna is supported by a dielectric substrate with a height equal to 0.01 mm and a relative dielectric constant of 3.2 (PI, loss tangent = 0.007).

The tag antenna size is reduced using a circular meander stub. The antenna has a physical size of 8 mm, which is about $\lambda/40$ in electrical length. The microchip used is an Alien Higgs-3, and the impedance of the microchip is $Z_c = 12 - j132\ \Omega$ at 920 MHz. The tag antenna is located at the bottom of the medical sample tube. The tag is fixed using FR-4 epoxy, which has a dielectric constant of 4.5. The medical sample tube has a 40 mm × 10.6 mm dimension, and dielectric rubber (ε_r = 3) is used. As shown in Fig. 1(c), medical sample tubes (100 EA) are composed into a plastic matrix-type case. The reader antenna is positioned under the sample tubes box at the separation distance, and tag identification is performed.

III. Simulated and Measured Results

Figure 2 shows the simulated and measured results of the proposed tag antenna. The simulation results are obtained using the simulation tool Ansoft HFSS, and the reliability of the obtained results is confirmed.

Figure 2(a) shows the results of a tag antenna (with circular meander), the operating frequency of which is 1.1 GHz. However, when a medical sample tube is used, the simulated half-power bandwidth for RL < 3 dB is 50 MHz (895 MHz to 945 MHz), which covers the 6.5 MHz bandwidth requirements of the Korea standard for UHF RFID (917 MHz to 923.5 MHz).

It is impossible to measure the return loss of the proposed tag

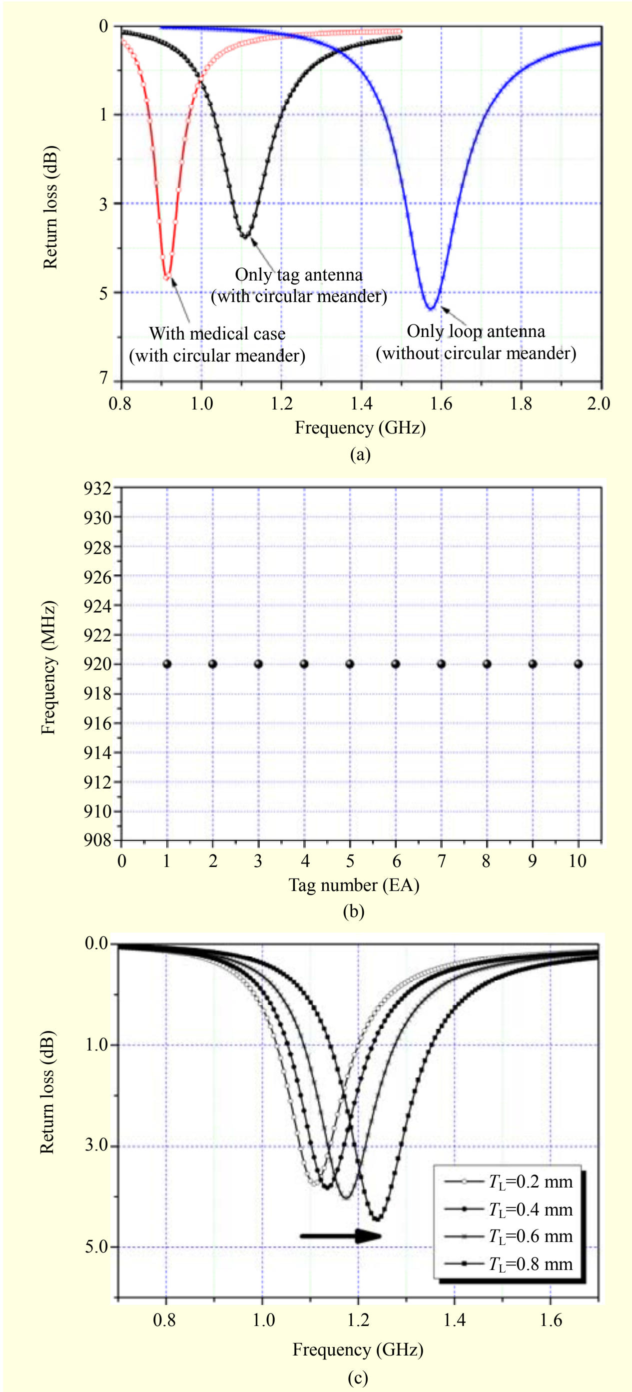

Fig. 2. (a) Simulated, (b) measured results of tag antenna, and (c) effects of different tag antenna values.

antenna because the size of the tag antenna is very small. For the tag antenna measurement, two handheld readers, AT-870 and TC-2600A, are used to improve the reliability. Ten prototypes of the medical sample tube are then chosen, and the identification rate of each is measured at a separation distance of 5 cm. As shown in Fig. 2(b), all ten medical sample tubes are identified at 920 MHz.

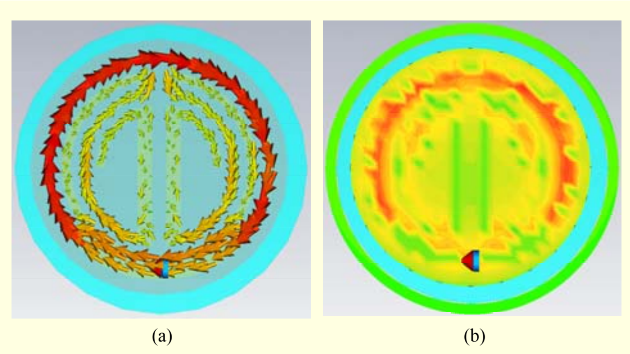

Fig. 3. (a) Simulated surface current and (b) magnetic field.

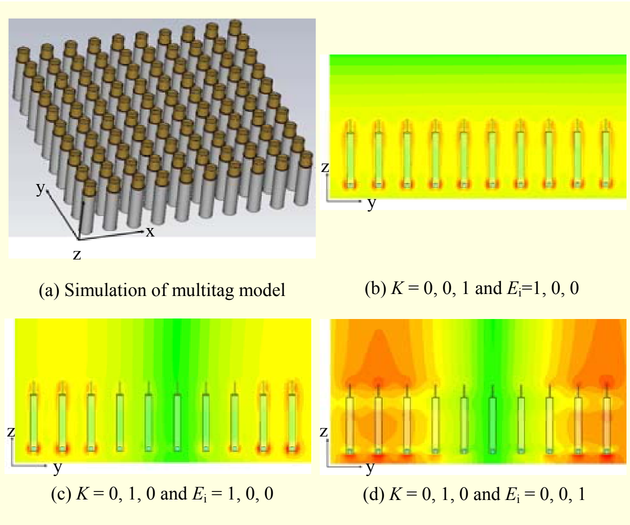

Fig. 4. Electric field distributions for three types of uniform wave.

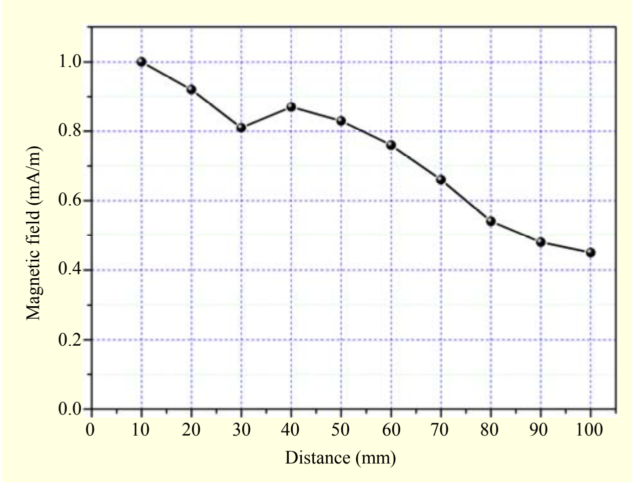

Fig. 5. Simulation of magnetic field intensity with change in distance.

Figure 2(c) shows the simulated return losses of only the tag antenna (without medical sample tube) for different sizes of T_L. From this figure, we can see that, as T_L is increased, the resonance frequency moves to a high frequency. From the results in Fig. 2(c), by selecting the geometry (T_L) of the tag antenna, the antenna can be tuned to the operating frequency.

Figure 3 shows the simulated surface current and magnetic field distribution of the proposed tag antenna (with a medical sample tube) at 920 MHz. When the operating frequency increases to the UHF band, the UHF RFID loop antenna cannot produce a uniform magnetic field, and, thus, the antenna generates a weak magnetic field in certain regions of the antenna. As the figure shows, although the proposed tag antenna is very small and uses the UHF band, the same surface current flow and a uniform magnetic field distribution are observed.

In this letter, we simulate the tag antenna characteristics according to the incident wave of three cases. First, propagating direction K is perpendicular to the tag antennas, and electric field E_i is tangential to the 100 medical sample tubes: $K = 0, 0, 1$ and $E_i = 1, 0, 0$. Second, both the propagating direction and the electric field are tangential to the 100 medical sample tubes: $K = 0, 1, 0$ and $E_i = 1, 0, 0$. Third, the propagating direction is tangential to the 100 medical sample tubes, and the electric field is perpendicular to the 100 medical sample tubes: $K = 0, 1, 0$ and $E_i = 0, 0, 1$. The total electric field distribution in the yz-plane at 920 MHz is shown in Fig. 4.

Figure 4 shows the simulated surface current and magnetic field distribution of 100 medical sample tubes. As shown in Figs. 4(c) and 4(d), in which the propagation vector of the uniform wave is tangential to the sample tubes, the wave distribution is zero at the center of the sample tubes. The propagation vector of the uniform wave is perpendicular to the sample tubes, as shown in Fig. 4(b), and the wave can go through all sample tubes.

The distance of the reader antenna positioned in the bottom of the sample tube for multitag identification is important. A medical sample tube uses the near field rather than the far field. Therefore, the incidence distance of the uniform plane wave is changed at the sample tube bottom from 10 mm to 100 mm, and the magnetic field intensity in the sample tube is simulated.

Figure 5 shows the simulated results of the magnetic field intensity according to the distance variation of the uniform plane wave. As shown in the figure, when the uniform plane wave is incident at 10 mm, a maximum magnetic field intensity of 1 mA/m is obtained, and the intensity of the magnetic field intensity becomes weak as the distance increases. The multitag identification rate is expected to be reduced as the distance between the reader antenna and the sample tubes increases, based on the simulation results.

Figure 6 shows the reading range and multitag identification rate of the measured tag antennas. The proposed tag antenna is

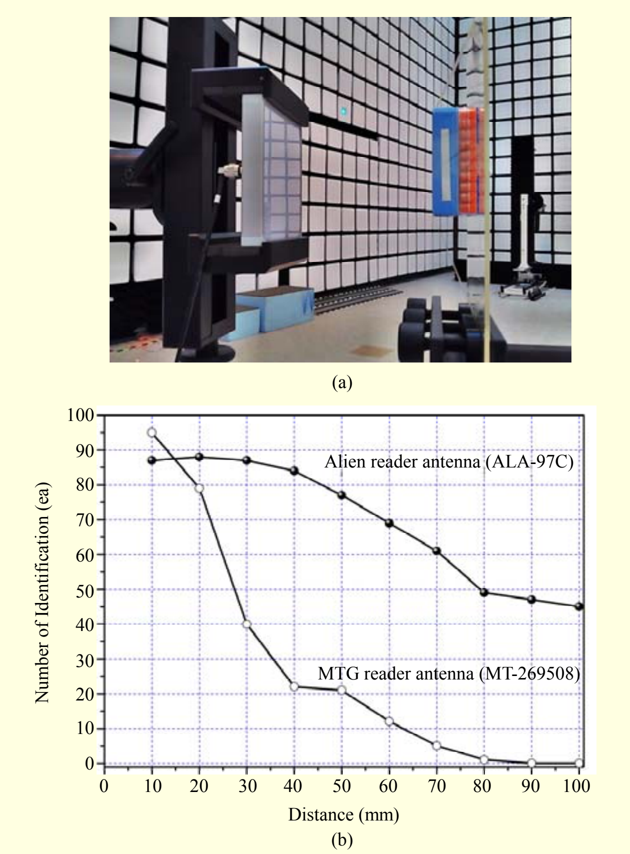

Fig. 6. (a) Setup environment of tag identification and (b) number of tag identification.

carried out in an anechoic chamber at the Korea RFID/USN Center, Seoul, Republic of Korea. The proposed tag antennas are measured using two types of reader antenna: near-field (MT-269508) and far-field (ALA-97C). The input power of the reader antennas is 1 W (30 dBm). The tag antennas are measured at an interval of four seconds, and the reader antenna automatically moves from 10 mm to 100 mm. From this figure, the near-field reader antenna is identified to have a maximum of 95 tags at 10 mm, and the far-field reader antenna is identified to have a maximum of 88 tags at 20 mm. For the near-field antenna, the multitag identification rate is drastically decreased at 30 mm. It is confirmed that Figs. 5 and 6 coincide because the magnetic field intensity received by the tag antennas becomes weak as the distance between the reader antenna and sample tubes increases. We need low read distances for medical application as it will prevent reading unnecessary tags in the vicinity, and, hence, the MTG reader antenna is better than a regular high-gain antenna.

IV. Conclusion

It is a challenge to design an electric UHF small loop antenna with a generated uniform magnetic field distribution for a medical sample tube. The proposed tag antenna was designed, fabricated, and characterized for UHF RFID communication applications. The multitag identification rate was compared using two types of reader antenna: a far-field reader antenna and a near-field reader antenna. The multitag identification rate of the near-field reader antenna was much better than that of the far-field reader antenna.

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