Miniaturizing RFID for Magnamosis

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***Abstract*— Anastomosis is a common surgical procedure using staples or sutures in an open or laparoscopic surgery. A more effective and much less invasive alternative is to apply the mechanical pressure on the tissue over a few days [1]. Since the pressure is produced by the attractive force between two permanent magnets, the procedure is called magnamosis[1]. To ensure the two magnets are perfectly aligned during the surgery, a miniaturized batteryless Radio Frequency IDentification (RFID) tag is developed to wirelessly telemeter the status of a pressure sensitive mechanical switch. Using the multi-layer circular spiral coil design, the diameter of the RFID tag is shrunk to 10, 15, 19 and 27 mm to support the magnamosis for children as well as adults. With the impedance matching network, the operating distance of these four RFID tags are longer than 10 cm in a 20×22 cm^2 area, even when the tag's normal direction is 45° off the antenna's normal direction. Measurement results also indicate that there is no noticeable degradation on the operating distance when the tag is immersed in saline or placed next to the rare-earth magnet. The miniaturized RFID tag presented in this paper is able to support the magnamosis and other medical applications that require the miniaturized RFID tag.**

I. Introduction

Magnamosis is a minimal invasive surgical method to connect pieces of intestine (*aka* anastomosis) by the attractive force between two permanent magnets without using staples or sutures [2]. Anastomosis is commonly performed for bowel obstruction to treat obesity [1]. Every week, there are thousands anastomosis surgical procedures performed in the United States alone [2]. Presently, this procedure is done using staples or sutures in an open or laparoscopic surgery. In magnamosis, two donut-shaped magnets are delivered in a less invasive way, as illustrated in Fig. 1. The two rare-earth magnets provide a strong attractive force for three to five days to form the anastomosis. The procedure provides a less invasive and more effective alternative to achieve the anastomosis without staples and sutures [1].

One of the critical challenges in the magnamosis procedure is to determine whether the two donut-shaped magnets are perfectly aligned coaxially at the end of the surgery. A pressure activating mechanical switch is placed on one of the donut-shaped magnet's mating surface, as depicted in Fig. 1. The pressure activating mechanical switch has three electrical leads. It provides an electrical short between Lead No. 1 and No. 2 without any pressure. When the pressure reaches a pre-designed value, it provides an electrical short between Lead No. 1 and No. 3, as shown in Fig. 2. When the two magnets are perfectly aligned coaxially, the attractive force between them is large enough to activate the pressure sensitive mechanical switch. A wireless telemetry system is desired to deliver the status of the pressure sensitive mechanical switch to an external reader.

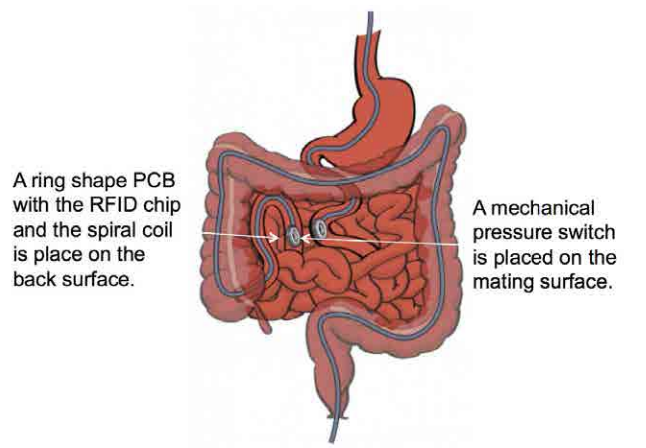

Fig. 1. An illustration of the anastomosis using two donut-shaped rare-earth magnets

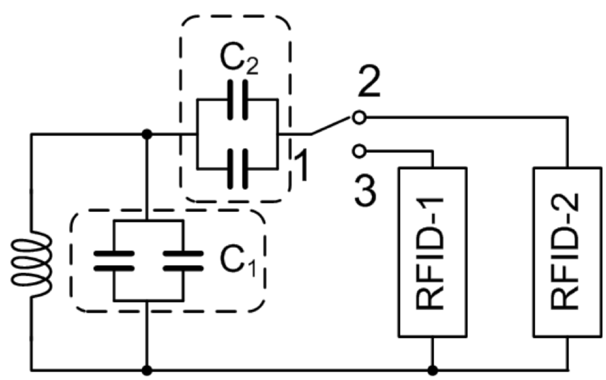

Fig. 2. The circuit diagram of the miniaturized RFID with the multi-layer circular spiral coil antenna

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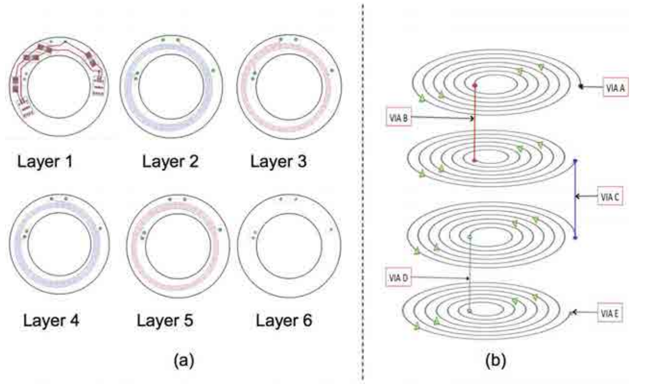

Fig. 3. An illustration of the multi-layer circular spiral coil design (a) The layout of each layer of the RFID tag (b) The coil's current flow direction and its via location

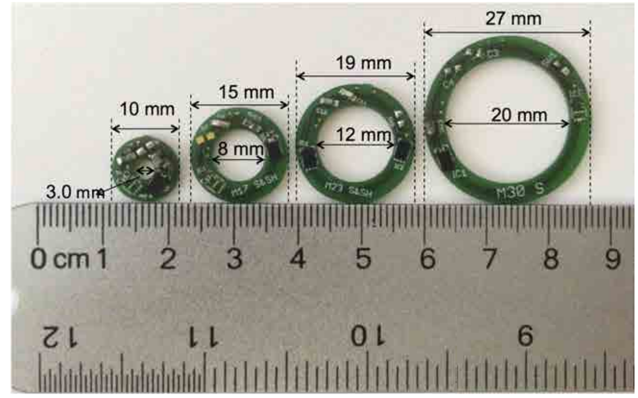

Fig. 4. RFID tags with different sizes

Radio Frequency IDentification (RFID) is an attractive wireless telemetry technology for this application since the RFID tag can operate without battery. However, most RFID tags have their antennas as big as a credit card. It is too large for the magnamosis. In this paper, a RFID with the unique multi-layer spiral coil design is presented to prove the concept for the $in-vivo$ application. The design and implementation of the RFID tag with the miniaturized multi-layer spiral coil is described in Section II. The characterization results are presented in Section III, followed by the Conclusions in Section IV.

II. Design and Implementation

In a batteryless RFID tag, there is a severe trade-off between the antenna size and the operating distance from the external reader to the tag. The batteryless RFID operates using the power harvested by the antenna. The harvested power is proportional to the square of the magnetic flux captured by the coil antenna [3]. The size of the coil antenna directly impacts the amount of the magnetic flux that the coil can capture [3]. Meanwhile, magnetic flux density decreases significantly when the transmitter (RFID reader) moves away from the tag. Thus, preserving the effective magnetic flux capturing area while miniaturizing its overall size leads to a miniaturized RFID for the magnamosis procedure.

A multi-layer circular spiral coil design is presented here to achieve the maximum effective flux capturing area while reducing its overall size, as depicted in Fig. 3. The multi-layer circular spiral coil is implemented in the printed circuit board (PCB) technology, so that it can be easily optimized and reliably manufactured using lithographic tools with the possibility to be fabricated on a flexible substrate. The PCB with the RFID chip will be wrapped with the magnet by the bio-stable plastics. The whole device, the PCB, the RFID chip and the magnet only stay in the body for less than a week [2]. The PCB technology with six metal layers is used here, as depicted in Fig. 3(a). Layer 1 and 6 are used to connect the RFID chip and the pressure sensitive mechanical switch, respectively. Layer 2 to 5 are used to form a 4-layer circular spiral coil. Metal vias are used to connect between layers. As depicted in Fig. 3(b), vias are carefully placed so that planar coils formed by each metal layer are connected in series to form a monolithic multi-layer circular spiral coil antenna. To ensure the reliability of the coil antenna, through-hole vias are used here. The through-hole vias and their connection with two adjacent metal traces are placed in different locations to avoid the conflicts in electrical connections. The multi-layer circular spiral coil design maximizes its effective magnetic flux capturing area while making the overall size of the RFID tag fits the magnamosis application.

Since the magnamosis is targeted at adults as well as children, the outer diameter of the donut-shaped rare-earth magnets ranges from 12 mm to 30 mm in diameter. Four RFID tags with the diameter of 10 mm, 15 mm, 19 mm and 27 mm are fabricated to facilitate the magnamosis with different size, as shown in Fig. 4. The RFID tag is also in in the donut-shape, because its center needs to be accessed by the delivery tools [1]. The inner diameter of each RFID tag is 7 mm less than its outer diameter.

An impedance matching network is added to the tag to ensure that harvested power can be delivered to the RFID circuit efficiently. As depicted in Fig. 2, C_1 and C_2 are placed in parallel and in series with the coil antenna, respectively. Both C_1 and C_2 are formed by two capacitors in parallel, so that their value can be finely tuned. Also, C_1 can be removed by an open, and C_2 can be removed by replacing with an electrical short. The design provides the needed flexibility to tune the impedance matching network for efficient power delivery between the coil antenna and the RFID chip.

The RFID chip used here, M24LR64−R [4], has the form factor of 2×3 mm, which could fit this application, as indicated in Fig. 4. M24LR64−R operates at 13.56 MHz based on ISO 15693 communication standard [4]. Two RFID chips are used in one RFID tag: one to indicate that there is no pressure applied to the pressure sensitive switch; the other to indicate that there is enough pressure, as depicted in Fig. 2. Thus, the status of the pressure sensitive mechanical switch can be thoroughly monitored during the surgery.

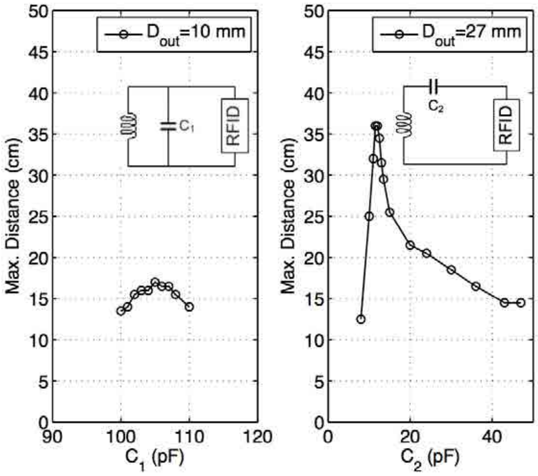

Fig. 5. Maximal operating distance versus the value of the matching capacitor.

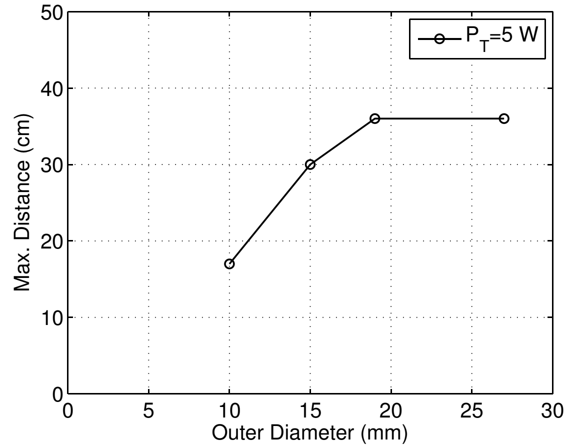

Fig. 6. Maximal operating distance of the RFID tags with different outer diameters.

III. Measurements

A. Setup

The RFID reader, LRM1002−E, is from OBID [5]. Its maximal transmitting power is able to reach 5 W. Its antenna has the size of 31×33 cm. Rulers are setup for measuring the perpendicular distance from the RFID tag to the antenna. The characterization is focused on the maximal operating distance at various circumstances.

B. Matching

Impedance matching plays a critical role in efficiently delivering the harvested power to the RFID. When the antenna coil is dramatically miniaturized comparing to M24LR64's original reference design, its matching network needs to be re-configured. The RFID tag design includes both the parallel matching capacitor C_1 and the series matching capacitor C_2. When the antenna coil is small, $e.g.$ the outer diameter of the tag is 10 mm, the parallel matching capacitor is preferred to achieve longer operating distance. When the 10 mm tag is placed in the center of the reader's antenna, its maximal operating distance is measured versus different values of C_1, and plotted in Fig. 5. The maximal operating distance of the 10 mm tag is able to reach 17 cm. When the antenna coil is big, $e.g.$ the outer diameter of the tag is 27 mm, the series matching network works better. The maximal operating distance of the 27 mm tag is measured with different matching capacitance in series, and plotted in Fig. 5. Since the overall quality factor of the larger tag is higher, the operating distance is more sensitive to the matching capacitor value.

C. Size

The maximal operating distance of the RFID tag needs to exceed 10 cm to facilitate the magnamosis. After the matching network is optimized, the RFID tag's maximal operating distance is measured and plotted in Fig. 6. The tag is placed in the center of the reader's antenna. Its normal direction is perpendicular to the reader's antenna. The transmitting power of the reader is 5W. Fig. 6 shows that the tags have the operating distance ranging from 17 cm to 36 cm, which is enough to support the magnamosis operation.

D. Location and Orientation

When the RFID tag is used in magnamosis, one of the challenges is that the exact location and the orientation of the RFID tag are unknown. Thus, it is impossible to ensure the tag is placed in the center of the reader's antenna, and its normal direction is perpendicular to the reader's antenna. To ensure the RFID tag can operate with various locations and orientations, its maximal operating distance is measured when it is placed in different location with different orientations. The 10 mm tag is characterized because it has the shortest operating distance, as depicted in Fig. 6. First, the tag's maximal operating distance at various location is measured and plotted in Fig. 7, when the tag's normal direction is perpendicular to the reader's antenna. Fig. 7 indicates that, when the tag is less than 6 cm away from the center, its maximal operating distance exceeds 15 cm, which is only 2 cm less than the peak. Second, when the tag's normal direction is 45° to the normal direction of the reader's antenna, the maximal operating distance in the center is reduced to 16 cm, as indicated in Fig. 8. Within a 20×24 cm^2 area, the operating distance is still longer than 10 cm. If two reader's antennas that are orthogonal to each other are used in the application, the miniaturized RFID tags with any orientation will be detected.

E. Environment

The maximal operating distance of the miniaturized RFID tags are also measured when the tag is: (1) immersed in the saline to emulate the absorptive bio-tissues; (2) placed next to a rare-earth magnet. No noticeable degradation in the operating distance is observed.

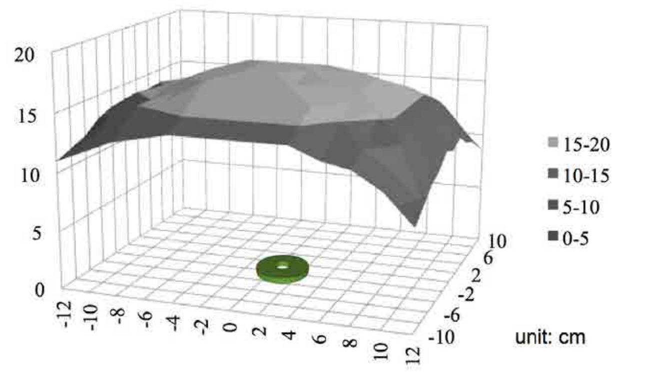

Fig. 7. Maximal operating distance at different location of the reader's antenna. The origin is located at the center of the antenna. The outer diameter of the RFID tap is 10 mm. The reader's transmitting power is 5 W. The tag is parallel with the antenna.

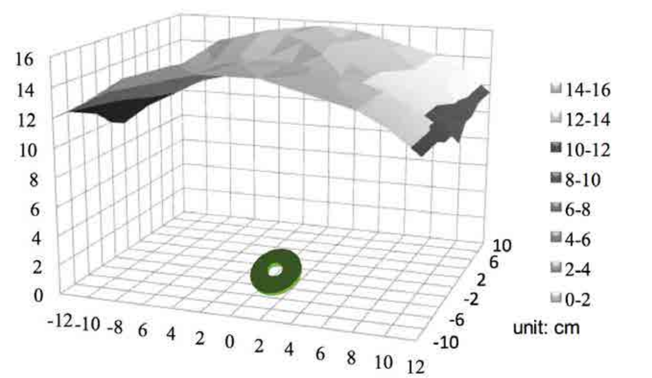

Fig. 8. Maximal operating distance at different location of the reader's antenna. The origin is located at the center of the antenna. The outer diameter of the RFID tap is 10 mm. The reader's transmitting power is 5 W. The tag's normal direction is 45° to the normal direction of the reader's antenna.

F. Transmitting Power

The RFID tag's maximal operating distance can also be extended by simply increasing the reader's transmitting power. The maximal operating distances of the tags with diameter of 15 mm and 27 mm are measured and plotted in Fig. 9, when the external RFID reader's transmitting power increases from 1 W to 5 W. The maximal operating distance of the 15 mm tag and the 27 mm tag are increased from 22 cm to 30 cm, and from 26 cm to 36 cm, respectively. The measurement results suggest that the operating distance of the RFID tag could be extended by increasing the reader's transmitting power. Comparing to Fig. 5, increasing the reader's transmitting power is not as effective as the impedance matching in extending the RFID tag's operating distance.

IV. Conclusions

Using the multi-layer circular spiral coil design, the RFID tags, often in the size of a credit card, are miniaturized to a donut-shaped ring with the outer diameter ranging from

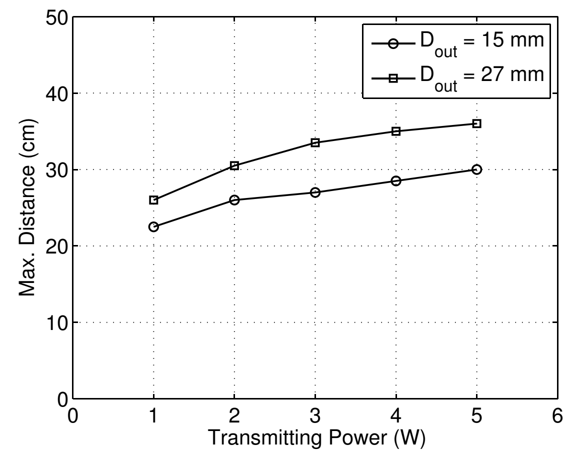

Fig. 9. The maximal operating distances of the tags with diameter of 15 mm and 27 mm are measured when the external RFID reader's transmitting power increases from 1 W to 5 W.

10 mm to 27 mm. With the impedance matching network, the operating distance of these RFID tags are longer than 10 cm in a 20×22 cm^2 area, even when the tag's normal direction is 45° off the antenna's normal direction. Without any noticeable degradation on the operating distance when the tag is immersed in saline or placed next to the rare-earth magnet, the miniaturized RFID is ready for $in-vivo$ animal trial.

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