A Deformable Antenna for Stomach Implants

S. Dubey, Y. Tuladhar, A. Murad, and J.-C. Chiao

Electrical Engineering, University of Texas at Arlington
Arlington, TX, 76019, USA

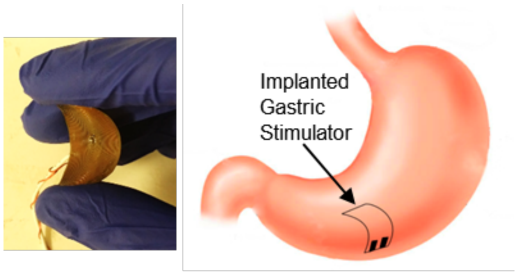
Abstract — **In this paper a flexible spiral loop antenna was proposed, designed and developed for stomach implants. This antenna was designed to harvest wireless power and for communication at 6.78 MHz which is in the industrial, scientific and medical (ISM) band. Characterization of the flexible antennas to wirelessly power a circuitry for electrical stimulation of stomach tissues by near-field inductive coupling was conducted. With a wearable transmitting coil, the system achieved a power transfer efficiency of 14% at an antenna separation distance of 1 cm, and a transferred power of 101mW at 4 cm. The flexible antenna was deformed at various bending curvatures for characterization and a robust power harvesting performance was achieved with bending radii up to 2 cm. The flexible antenna should be capable to harvest energy for gastric stimulation while the stomach moves and digests food.**

I. INTRODUCTION

With demands for advanced healthcare, medical implants with real-time communication and sensing capabilities have gained great attention. However, one of the major issues is the limited battery life. Patients with electronic implants may need to undergo multiple painful surgeries to replace devices after the battery is depleted. Furthermore, in order to be used with natural orifice transluminal endoscopic surgery or minimally invasive surgery implantation procedures which can reduce patients' suffering and care costs, implant sizes need to be as small as possible. This presents a great engineering challenge as the battery volume has to be small yet high energy density battery may not be suitable due to safety concerns.

Wireless power transfer (WPT) technologies for recharging battery or batteryless operation have shown promising results for long-term medical implants. Radio frequency identification (RFID) principle has been utilized to harvest incoming electromagnetic waves for energy to drive an integrated circuit and re-radiate a response signal back to the reader. Sensors can be integrated with the RFID circuitry to embed the physiological parameters in the responding signals. Power consumption is relatively low for such applications as current consumptions in the circuits and sensor are typically low and the electromagnetic losses in tissues for subdermal implants are also low, thus most of the devices utilize antennas with short electric lengths in order to keep the device sizes small.

Integrating therapeutic methods such as electrical stimulation, actuation or drug delivery in implants with sensors to form adaptive closed-loop treatment systems has become attractive to the medical society as they offer better outcomes as personalized medicine. Adding more functionalities in the integrated circuits inevitably require more energy to operate. Furthermore, tissue stimulation and actuation or drug dispensing typically need much more electrical powers in the implant. This is particularly important for stimulation that requires electrical currents. Coil antennas with inductive coupling are usually used to harvest electrical currents for this purpose. Typical coils on rigid substrates, either directly fabricated on the circuit or wrapped around the implant, have been used for wireless power transfer or near field communication [1]-[3].



(a) (b)

Fig. 1. (a) Flexible receiver antenna for wireless power transfer. (b) Implant location inside the stomach.

In this work we designed a coil antenna to power flexible gastric stimulators aiming to be implanted inside the abdominal cavity with electrodes attached to stomach tissues. The implant provides electrical currents to stomach tissues for gastric electrical stimulation as a method to treat gastroparesis. Patients with gastroparesis suffer from delayed emptying of stomach resulting in vomiting, abdominal bloating, nausea and weight loss [4]. Current solution implements a neurostimulator with electrode wires connecting to serosal tissues of stomach for pacing [5]. The large size of neurostimulator requires a major surgery with large incision, which is costly and painful for patients. We have proposed an endoscopically implantable gastrostimulator [1,6] based on a miniature circuit board and inductive coupling without battery to relieve the suffering of implantation surgery. With endoscopic procedures for implantation through mouth and esophagus, which can be done by an out-patient visit, patient's physical and financial budrden can be greatly reduced. In this work, we further developed such a stimulator based on flexible substrate so the device can be easily implemented inside the stomach with existing endoscopes.

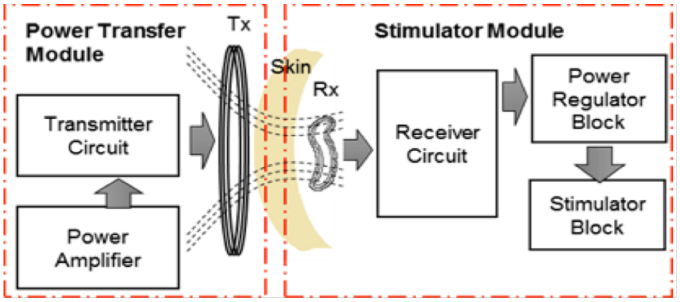


Fig. 2. Block diagram of the stimulator.

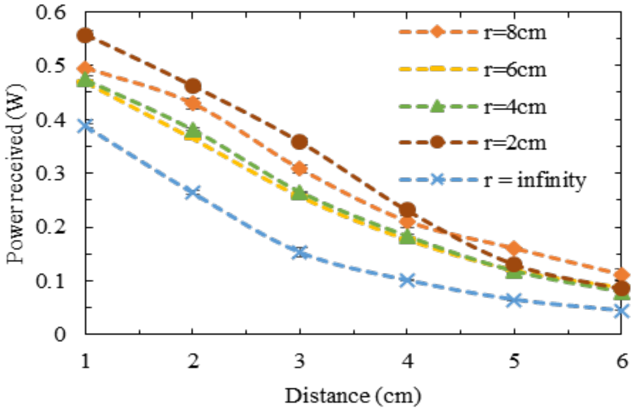


Fig. 3. Power harvested as a function of distance between transmitting and receiving antennas with the receiving antenna at different bending radii.

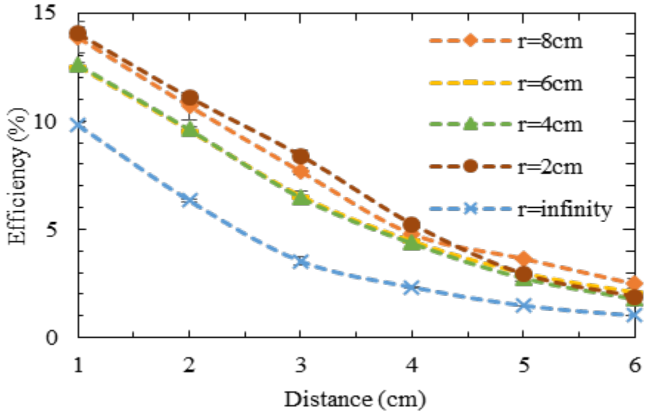


Fig. 4. Power harvesting efficiency as a function of distance between transmitting and receiving antennas with the receiving antenna at different bending radii.

II. SYSTEM DESIGN

Owing to the flexible nature of the substrate, the antenna can be made conformal onto the stomach tissue and bent along with the motions of the stomach. The flexibility makes it feasible to deliver the device through mouth and esophagus by endoscopic process. The entire device can be rolled into a cylinder-shape capsule to fit into a plastic tube in front of an endoscope probe. Once the endoscope carries the device into the stomach, it will be unfolded and placed inside the stomach wall through a small incision on the mucosal layer by a gripper passing through the working channel of endoscope. The primary objective of this work was to design a robust yet flexible antenna which could harvest sufficient wireless power during stomach movement. Figure 1(a) shows the fabricated flexible antenna and (b) shows the implant location inside the stomach.

The system diagram for power harvesting using the deformable antenna is shown in Fig. 2. A class-E power amplifier (IRF 510, Vishay Semiconductors) driving a planar spiral antenna with an outer diameter of 10 cm and 7 turns made of 35 µm thick copper was used for inductive coupling. A 25-turn spiral coil was fabricated using photolithography and etching on a copper-coated polyimide substrate with a size of 36 mm × 20 mm for the receiver coil. The measured inductance of the coil was 7.5 µH. The power transfer efficiency was obtained at the resonant frequency of 6.78 MHz. The output power was obtained for a load of 100 Ω. Power harvesting performance of the deformable receiver antenna was extensively investigated at different bending curvatures that would occur during stomach contraction.

III. RESULTS

WPT experiments were conducted using a benchtop setup where receiver antenna was bent with a certain bending radius by conforming it onto plastic models, made by 3-D printing, with curved surfaces. Output voltage was measured across the load resistor R_L to calculate harvested power P_r and power harvesting efficiency η_{eff} by

$$\mathrm{P_r} = \frac{V_{Lrms}^2}{R_L} \tag{1}$$

$$\eta_{eff} = \frac{P_{out}}{P_{in}} = \frac{P_r}{V_{dd} \times I_{dd}} \tag{2}$$

where V_{Lrms} is the output rms voltage, V_{dd} and I_{dd} are the DC input voltage and current. Figure 3 shows power harvested by the receiver coil at various distances with different bending conditions in which r denotes the bending radius of the receiving antenna substrate.

Maximum power was obtained when the receiving antenna was bent outwards to the transmitter antenna with a bending radius of 2 cm. Shown in Figure 4, a power transfer efficiency of the system was obtained as 14% at a 1-cm separation distance and decayed with distance as expected. For gastric stimulation, the average distance between transmitter and receiver antennas is 4 cm [6]. 101 mW power was maintained as the stimulator bent at the 4-cm distance.

IV. CONCLUSION

In this study, we implemented a deformable coil that can be implanted inside stomach wall to harvest energy for batteryless gastric stimulation. Performance was evaluated at 6.78 MHz as the stomach curvature changed. Both harvested energy and wireless power transfer efficiency vary with the bending curvature. 101 mW power was maintained for a power transfer distance of 4 cm as the coil bent.

REFERENCES

[1] S. Deb, *et. al.*, “An Endoscopic Wireless Gastrostimulator (with video),” *Gastrointestinal Endoscopy*, vol. 75, no. 2, pp 411- 415, 2012.

[2] F. Zhang, *et. al.*, "In Vitro and In Vivo Studies on Wireless Powering of Medical Sensors and Implantable Devices," *Life Science Systems and Applications Workshop,* pp.84-87, April 2009.

[3] H. Cao, *et. al.*, “An Implantable, Batteryless and Wireless Capsule with Integrated Impedance and pH Sensors for Gastroesophageal Reflux Monitoring,” *IEEE Transactions on Biomedical Engineering*, Vol. 59, No. 11, pp. 3131-3139, Nov. 2012.

[4] W. L. Hasler, “Gastroparesis,” *Curr. Opin. Gastroenterol. 28(6),* pp. 621-628. 2012.

[5] J. J. Haans, *et al*, “Review Article: The Diagnosis and Management of Gastroparesis,” *Aliment. Pharmacol. Ther. 26 Suppl 2,* pp. 37-46. 2007.

[6] S. Rao, *et. al.,* "Wireless Gastric Stimulators," *2014 Texas Symposium on Wireless and Microwave Circuits and Systems*, pp. 1-4, April 2014.