Power Transfer for a Flexible Gastric Stimulator

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***Abstract* — Gastroparesis is a disorder reported to be prevalent among 30−50% of diabetics. Gastric electrical stimulation (GES) to the stomach has been used to treat the symptoms of gastroparesis. It usually consists of a large stimulator implanted inside the abdominal cavity with electrodes attached to the stomach tissues. In this work, we have designed, developed and tested a wirelessly powered gastric stimulator based on a flexible substrate that can be rolled into a capsule for endoscopic delivery and implantation. The stimulator can be conformed to the stomach curvature and attached onto the tissues. Characterization of transmitter and receiver antennas to wirelessly power the implant devices was conducted with near-field inductive coupling. Power transfer efficiency of the system was found to be 14 % at an antenna separation distance of 4 cm.**

***Index Terms* — Implant, flexible electronics, stimulator, gastric electrical stimulation, wireless power transfer.**

I. INTRODUCTION

Gastroparesis is a condition in which the patient suffers from delayed emptying of stomach resulting in vomiting, abdominal bloating, nausea and weight loss [1,2]. The use of prokinetic and anti-emetic drugs in treating gastroparesis remains unsatisfactory. Gastric electrical stimulation (GES) is preferred for patients with serious conditions [3]. The existing neuro-stimulator Enterra® therapy system is the only FDA approved stimulator and is implanted through laparoscopy [4]. The device is battery operated so it needs to be replaced every 3−6 years. The battery in the device (2.2”×2.4”×0.4”) contributes greatly to its size. It will be beneficial to reduce the implant size so it can be endoscopically implemented inside the stomach through mouth and esophagus. The endoscopic procedure can greatly reduce patients’ suffering from surgery and reduce healthcare costs.

A miniature implantable gastric stimulator was demonstrated with a size of 0.39”×1.38”×0.32” in animal models previously [5, 6]. Although the device size was significantly reduced, the device was rigid so that it could not conform to the stomach curvature. This presented an issue when stomach motility was resumed as the electrodes could not maintain a firm contact to the tissues for electrical current delivery. In this work, we present a new gastric stimulator based on flexible substrate to overcome the aforementioned clinical issues.

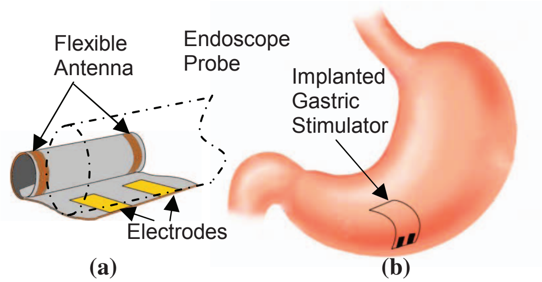

Fig. 1. The configuration of the flexible gastric stimulator. (a) The stimulator can be rolled into a capsule with a diameter of 7.95 mm. (b) Implanted gastric stimulator onto the stomach wall.

II. SYSTEM

The device concept for the flexible gastric stimulator, which can be rolled into a cylinder-shape capsule to fit into the plastic tubing in the front end of an endoscope, is shown in Fig. 1(a). After the endoscope carries the stimulator into the stomach, a gripper through the working channel of the endoscope grabs the capsule and places it on the stomach wall. The stress of the flexible substrate opens the stimulator which returns to its flat condition. The device can be stapled onto the stomach tissues. Owing to the flexible nature, the substrate can conform to tissues and deform along with the stomach motion, as shown in Fig. 1(b). Electromagnetic energy will be delivered from a transmitter antenna placed in belt which patient wears while eating. The flat stimulator consists of a coil to harvest inductively coupling energy, circuits to generate regulated stimulation pulses and electrodes in contact with tissues to deliver electrical currents. Stimulator will be turned on from outside the body while consuming food and it will provide stimulation dosage as set by doctor.

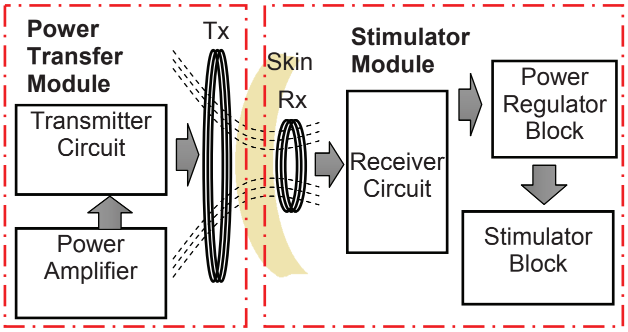

Fig. 2. Block diagram of gastric stimulator.

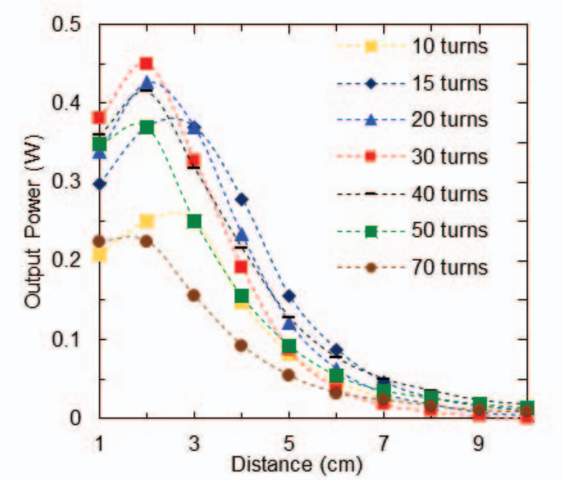

Fig. 3. Output power with different number of turns in the receiver coil.

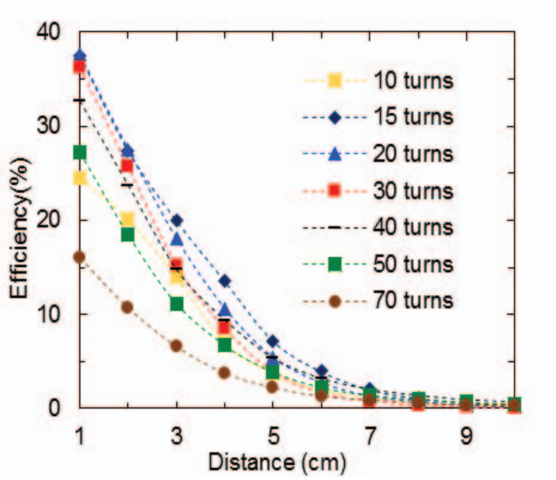

Fig. 4. Power transfer efficiency with different number of turns in the receiver coil.

Figure 2 shows the block diagram of the flexible gastric stimulator system. It consisted of two modules: a wearable power transfer module and the stimulator inside the stomach. The wearable power transfer module was built for inductive coupling where a class-E power amplifier (IRF 510, Vishay Semiconductors) was used to feed the transmitter coil. The transmitter circuit consisted of a LC circuit to be resonant at 1.3 MHz because the maximum possible exposure of human tissue to electromagnetic fields is highest in the band of 1.3−30 MHz [7]. Shunt capacitor was used to suppress harmonic components of the carrier frequency. A spiral planar coil with a radius of 6 cm was used as the transmitter antenna. On the receiver side, a coil on the flexible receiver substrate was tuned to harvest the electromagnetic energy. A load resistor was used to measure output voltage for output power calculation. Total DC input voltage and current were measured to calculate the efficiency of the system. The signals were rectified and regulated by a power regulator block and converted to a DC voltage of 3.3 V to power the stimulator block. A microcontroller (PIC12F1840, Microchip) was programmed to generate desired stimulation pulse trains.

Since wireless power transfer efficiency is strongly dependent on the coil size, it is challenging to harvest sufficient energy with a miniature implant antenna. Tradeoff factors among inductance, resistance, coil physical size, number of coil turns, rigidity of the substrate, distance between transmitter and receiver, and the curvature radius of receiver coil were taken into account. The objective was to achieve a high quality factor. Litz wires were used for the transmitter coil owing to its lower AC resistance. On the receiver side, AWG-40 gauge copper wires (79.9-µm diameter) were used to make an elliptical shaped coil with a size of 27 mm × 11 mm. The elliptical shape is to be rolled and placed in the tip of the endoscopic tube which has an insertion tube diameter of 12.8 mm [8]. Electrical parameters of the transmitter and receiver circuits were measured using an HP 4192a impedance analyzer, as shown in Table I.

TABLE I. COIL PARAMETERS

Parameter	**Transmitter**	**Receiver**
Inductance	104 µH	13.24 µH
Resistance	18 Ω	9.92 Ω
Quality factor	46.5	10.9
Number of turns	54	15

III. EXPERIMENTS

Characterization of receiver antennas was conducted to investigate optimal power transfer for gastric stimulator applications in which average distance between the transmitter and receiver is about 4 cm [6]. All the receiver coils with different number of turns were tested by tuning the transmitter and receiver to find the optimal number of turns required to deliver a maximum power with the highest efficiency. Output voltage was measured across a 500-Ω load mimicking the tissue impedance to calculate the output power Pr and wireless power transfer efficiency ηeff by

$$P_r = \frac{V_{rms}^2}{R_L} \tag{2}$$

$$\eta_{eff} = \frac{P_{out}}{P_{in}} = \frac{P_r}{V_{dd} \times I_{dd}} \tag{3}$$

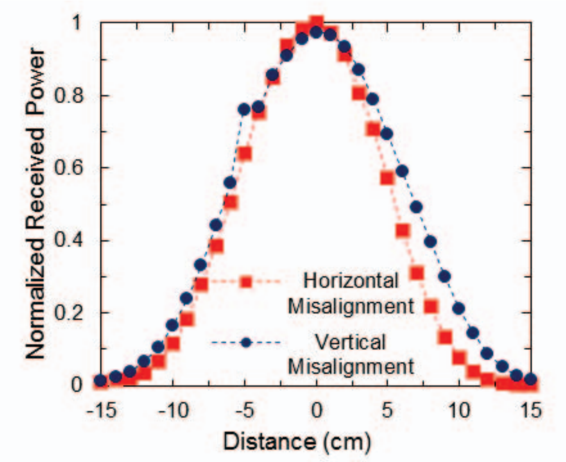

Fig. 5. Misalignment effect on wireless power transfer.

where V_{Lrms} is the output rms voltage, V_{dd} and I_{dd} are the DC input voltage and current.

Figures 3 and 4 show the output powers at the receiver and system efficiencies for different turn numbers of receiver coils. Powers were maximum at 300 mW for the distance range of 4−6 cm with the receiver with 15 turns of coil. Power transfer efficiency was 38% at the peak with 1-cm coil separation. A 14% efficiency was achieved with 15 turns at a 4-cm coil separation. Thus, the 15-turns receiver antenna was used for further experiments.

Since the gastric stimulator changes its position when the stomach moves, it is important to find the effect from misalignment between the antennas. By moving the receiver antenna in the cross section plane facing the transmitter coil at a 4-cm antenna separation distance, received powers and transfer efficiencies were obtained. Shown in Fig. 5, 60 % of the maximum harvested power, which was the power received with perfect misalignment, was maintained within a 5 cm × 5 cm area on the cross section plane.

The coil and integrated circuits were integrated on a flexible 12-µm thick polyimide substrate. The AWG coil wire was replaced with a planar coil. The planar coil has a copper thickness of 9 µm. The entire device was made with standard photolithography and wet etching. The integrated circuit components were soldered before the device was encapsulated with PDMS (Poly-dimethyl-siloxane).

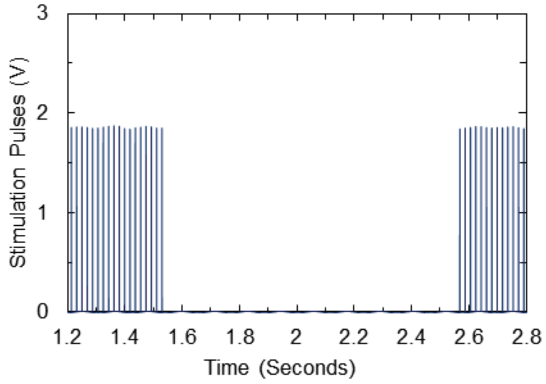

Fig. 6. Stimulation pulses from the flexible gastric stimulator.

The prototype was rolled into the capsule form and then spread into its original flat status. Transmitter coil was placed 4 cm away from the device. The stimulation pulses were measured at the 500-Ω load, as shown in Fig. 6. The result achieved the required parameters for stomach stimulation [5].

IV. CONCLUSION

We successfully developed and characterized a batteryless wirelessly-powered gastric stimulator based on flexible substrate. Owing to the flexibility and small dimensions of the device, it is feasible to implant it through endoscopic procedures, eliminating the needs for major surgeries. Wireless power transfer at certain conditions was investigated. 14% efficiency was achieved at a 4-cm distance spacing and misalignment effects were examined. The stimulator generated required electrical pulses with sufficient power. Future works focus on the optimization of the wireless power transfer in animal tissues.

REFERENCES

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

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

[3] T. L. Abell, *et. al.*, “Gastric electrical stimulation in intractable symptomatic gastroparesis,” *Digestion 66(4),* pp. 204-212, 2002.

[4] M. P. Jones, *et al.*, “Enterra for gastroparesis,” *Am. J. Gastroenterol. 98(11),* pp. 2578, 2003.

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

[6] S. Rao, *et. al.*, "Wireless gastric stimulators," *2014 Texas Symposium on Wireless and Microwave Circuits and Systems (WMCS),* pp. 1-4, April 2014.

[7] 2005 IEEE Standard for Safety Levels With Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz, IEEE Standard C95.1, 2006.

[8] S Varadarajulu, *et. al.*, “GI Endoscopes,” Gastrointestinal Endoscopy, vol. 74, no. 1, pp. 1-6.e6, Jul 2011.

[9] MJ Ferrua, *et. al.*, “Modeling the Fluid Dynamics in a Human Stomach to Gain Insight of Food Digestion,” *J Food Sci.,* vol. 75, no. 7, pp. R151–R162, Sep 2010.