35th Annual International Conference of the IEEE EMBS
Osaka, Japan, 3 - 7 July, 2013

A Feasibility Study of Using Backscattering for Telemonitoring of In-Stent Restenosis

Kamyar Keikhosravy, Pouya Kamalinejad, Arash Zargaran-Yazd, Shahriar Mirabbasi, Kenichi Takahata, and Victor C.M. Leung

***Abstract*—In this work, the use of backscattering for telemonitoring of in-stent restenosis in two different types of stents, namely, conventional and antenna stents, is investigated. Various aspects of the telemonitoring approach including power consumption and reliability are studied and confirmed with *in-vitro* measurements. Experimental results confirm that the antenna stent is capable of providing −87 dBm backscattered power at 900 MHz carrier frequency for a −10.0 dBm transmitted power provided by an external antenna located at 4 cm away from the antenna stent. For the same setup the conventional stent provides −99 dBm backscattered power. The backscattered power is reduced to −103 dBm when the antenna stent is buried in 4 cm of ground beef to emulate the physical environment surrounding the stent.**

I. Introduction

Angioplasty is a method commonly used to mechanically widen narrowed or clogged arteries by inflating a balloon positioned at the tip of a catheter that is guided to the narrowed site. During the procedure, sometimes a stent is placed at the site. A stent is a mesh-like tubular structure which holds open the narrowed section of the blood vessel. However, re-narrowing of the artery at the stented site (in-stent restenosis) may occur a few months after surgery (on average 6 months [1]) by the mechanism of thrombosis, i.e., clotting of the blood inside the blood vessel, and/or excessive tissue growth at the inner wall of vessel at the stented site. Since the rate of restenosis after balloon-only angioplasty is high, stent placement (bare metal stent, also known as, BMS) is usually utilized to decrease the rate to 33% [2]. To further reduce in-stent restenosis drug-eluted stents (DES) are widely used. Recent studies show that even for DES, the rate of restenosis occurrence post surgery is 3.5% after one year and 4.9% after 2 years [3]. Moreover, Similar studies show smaller arteries (2.7 mm in diameter) have 79% higher risk of in-stent restenosis compared to larger arteries (3.4 mm in diameter) [4]. Currently, monitoring of restenosis is performed through either invasive methods (e.g., angioplasty), or by non-invasive imaging techniques (e.g., computed tomography (CT) or echocardiography) [5], [6]. Such techniques are typically costly and there is some level of patient discomfort associated with the monitoring. Therefore, telemonitoring of the stent site is emerging as a more cost-effective and patient-friendly technique. One such telemonitoring approach is to embed a miniature sensor and a corresponding transponder integrated circuit (IC) on the stent, i.e., ”smart stent” [7]. The IC enables wireless transmission of the sensor data to a receiver outside the patient’s body. While such wireless system facilitates chronic monitoring with minimal patient’s discomfort, providing power to the implanted ”smart stent” remains a challenge. Note that unlike larger implants (e.g., pace makers), employing a battery as a power source for a smart stent is not feasible due to physical limitations of the intravenous implants. Various techniques for wireless power transmission to biomedical implants have been extensively studied: e.g., power transfer based on inductive coupling (near-field) [8]–[10], electromagnetic wave propagation (far-field) [2], [11] and ultrasonic wave propagation [12]. In this paper, we focus on a backscattering-based monitoring technique.

This research is funded in part by the Natural Sciences and Engineering Research Council of Canada (NSERC), a Collaborative Health Research Project (CHRP) grant, and the Institute for Computing, Information and Cognitive Systems (ICICS) at UBC. CAD support and access to technology is facilitated by CMC Microsystems.

The authors are with the Department of Electrical and Computer Engineering, University of British Columbia, Vancouver, BC, V6T 1Z4, Canada (keikhosr, pkamali, arashz, shahriar, takahata, vleung@ece.ubc.ca).

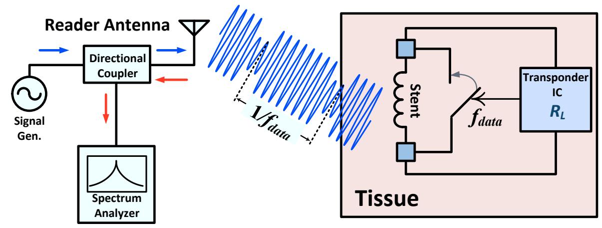

Fig. 1. Schematic diagram of backscattering telemonitoring system using stent antenna

The organization of this paper is as follows: Section II reviews the commonly used telemonitoring techniques and discuss backscattering scheme for two types of stents, namely, conventional and antenna stents. Section III presents the experimental results on the two aforementioned types of stents. Finally, Section IV presents concluding remarks.

II. Telemonitoring of In-Stent Restenosis

Fig. 1 illustrates the system-level schematic of the proposed backscattering-based in-stent restenosis telemonitoring system. Backscattering refers to reflecting of the incident power (wave) back to the direction of the transmit power (wave). Backscattering can be used as a power-efficient means for communication [13], [14] . As shown in the figure, the external transmitter radiates a radio-frequency (RF) carrier signal that

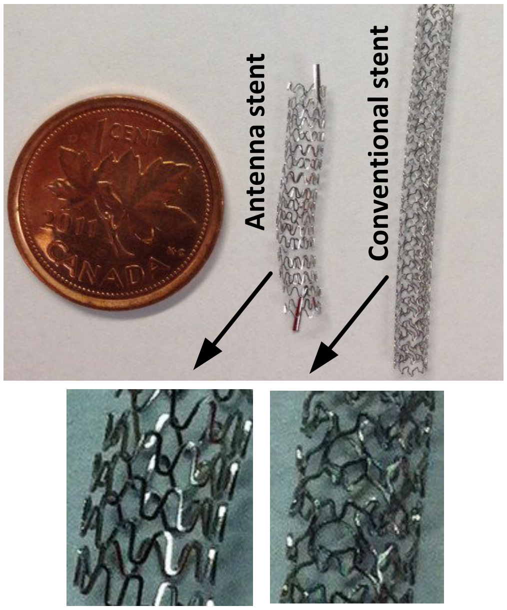

Fig. 2. Comparison of the mesh of medical stent and antenna stent

penetrates into the patient's body. The RF signal is used for harvesting energy to operate the implanted transponder IC embedded on the "smart stent" (i.e., the stent with embedded sensors and IC) [7]. The sensors embedded on each end of the stent (typically capacitive sensors) will help monitoring the blood flow through the stent. The change of capacitance of these sensors can be used as an indicator of the status of restenosis. The stent itself is used for RF energy harvesting as well as an antenna for transmitting sensory data to the external reader. The task of the transponder IC is to facilitate RF energy harvesting and control data transmission. The data transmission is performed through varying the impedance seen by the stent. This is achieved by selectively opening or closing the switch as shown in Fig. 1. Backscattering can accommodate various modulation schemes including amplitude, frequency and phase shift keying [13].

As mentioned above, RF power transmission in biomedical implants is typically achieved through one of the following techniques: inductive coupling (near-field), electromagnetic wave propagation (far-field), and ultrasonic wave propagation. The ultrasonic-based power harvesting has been used in various biomedical applications [12], however, due to the physical geometry and dimensions of the arteries using this method is impractical. Compared to inductive coupling, electromagnetic wave propagation does not require exact alignment of the primary and the secondary coils to achieve maximum power delivery. Although electromagnetic based systems provide better power transmission efficiency for longer telemetry distances [2], for implants within 4 cm of the skin where most of the transmitted power is absorbed by tissues, the inductive coupling can be a viable approach [7].

The conventional stent is a mesh-like tubular device shown in Fig. 2 which is similar to a coil whose turns are linked together. Although this linking bridges improve the structural strength of the stent they significantly reduce its effective inductance. Therefore, to achieve a higher inductance for the purpose of establishing a better inductive link, antenna stents (Fig. 2) have been proposed [15] which resemble the structure of a helical coil. In this work, we will experimentally compare the performance of monitoring systems based on both conventional and antenna stents.

From the frequency of operation point of view, a recent study shows that the optimum frequency for power transmission through tissues using antenna stent as an inductive receiver is in the range of 800 MHz to 1.5 GHz [7]. This relatively high range of frequency can be attributed to the small dimension of the stent [16]. From the standpoint of data transmission techniques, the up link which transfers sensory data back to the external reader can be established either using an active transmitter (e.g., oscillator) [2], [8]–[11] or electromagnetic back-scattering approach in which a passive transmitter such as relaxation oscillator [14], [17] or a simple LC filter [18]–[20] are used. The active transmitters are relatively power hungry, e.g., more than two order of magnitude higher in [8] than the backscattering-based counterpart [14]. The higher required power can adversely impact the reliability of the telemetry system.

III. Experimental Results

To investigate the feasibility of backscattering-based telemonitoring approach, a proof-of-concept setup has been used. Fig. 3 shows the *in-vitro* experimental setup used for measurements. A 100 kHz square-wave clock signal drives a discreet quadruple bilateral analog switch (Texas Instrument-74HC4066N) which modulates the impedance seen by the stent through opening and closing the switch across the stent (Fig. 1). To observe (retrieve) the backscattered modulated sensory data a spectrum analyzer (Anritsu MS2034A) has been used along with a directional coupler (Mini Circuits 15542 ZFDC-SMA) that separates the received signal from the transmitted signal. The experiments are performed in a RF enclosure (ETS-Lindgren Table Top Enclosure). Both conventional and antenna stents are tested in free space. The antenna stent is also tested while covered by different thicknesses of ground beef to mimic different implant depth.

All experiments are performed at 900 MHz. Fig. 4 shows the experimental backscattered power versus different load resistances. This results show that having a transponder IC with lower power consumption can improve the backscattering reflected power and hence the performance of the telemonitoring system. In addition, Fig. 4 verifies that the efficiency of transmission is independent of the transmitted power level of reader antenna as changing the transmitted power by 10 dB results in approximately 10 dB change in the received backscattered power. For the rest of experiments, the antenna is switched between short and 100 kΩ which is close to the load seen by the stent (e.g., assuming that the transponder IC draws a current of 10 μA from a harvested

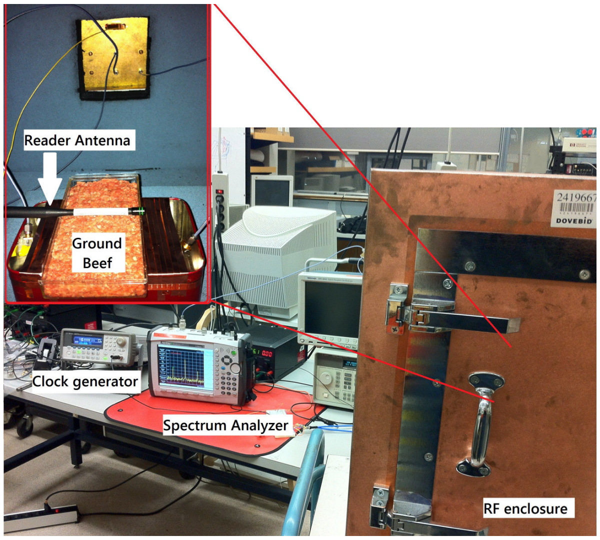

Fig. 3. *In-vitro* measurement setup.

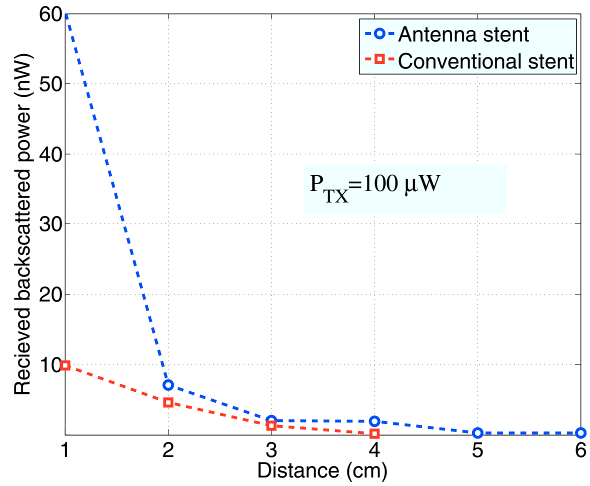

Fig. 5. Backscattered power of antenna stent compered to conventional stent.

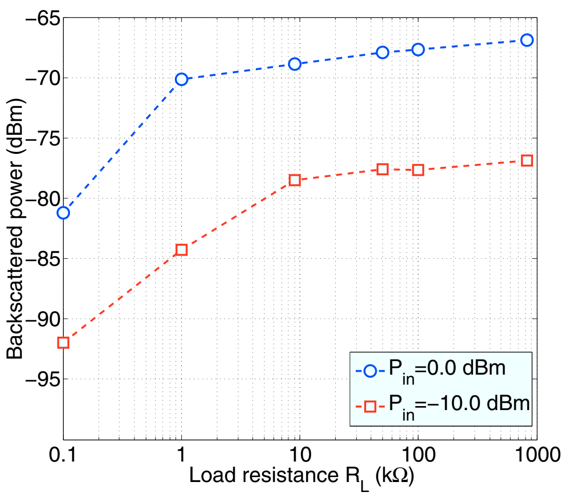

Fig. 4. Measured backscattered power level versus different load values and input powers.

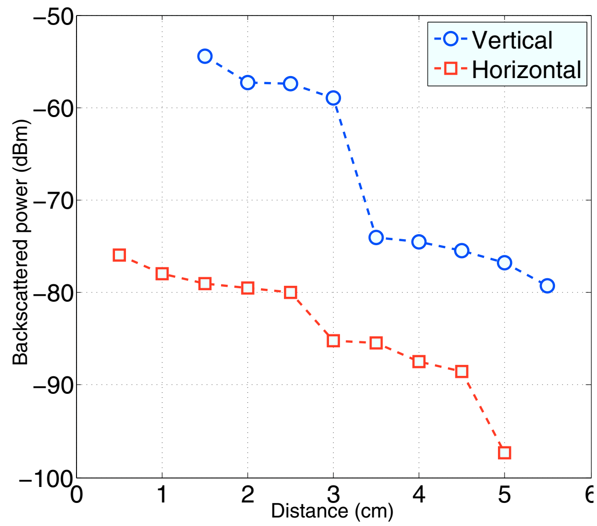

Fig. 6. The Measured backscattered power from antenna stent along vertical and horizontal axes.

1 V supply). As shown in Fig. 5, for a transmission power of 100 μW, the antenna stent provides better performance as compared to conventional stent for typical distances between the reader and the stent. This experiment has been performed in air (free space).

To analyze the radiation pattern of the antenna stent, the backscattered power level of the antenna stent are measured in two directions (vertical and horizontal directions relative to the stent) as shown in Fig. 6. The experimental results reveal that the external reader should be positioned above the stent in order to achieve a better transmission efficiency.

Fig. 7 illustrates the normalized received backscattered power as a function of implant depths. To calculate the normalized power, the measured received backscattered power of the antenna stent in the presence of a layer of ground beef between the stent and the reader antenna is divided by the received backscattered power measured for the same geometry without the ground beef layer. Fig. 8 shows the results of the aforementioned two experiments (with and without a layer of ground beef). For the experiment with no layer of ground beef the distance between the antenna and the stent is given on the right axis.

IV. Conclusion

In this paper, a backscattering-based technique for telemonitoring of in-stent restenosis using smart stents is investigated. The preliminary in-vitro measurements are performed for both conventional and antenna stents. To mimic the real environment of the stent, the stent is covered with different thicknesses of ground beef. The measured results confirm the feasibility of the backscattering technique for telemonitoring of restenosis using smart stents.

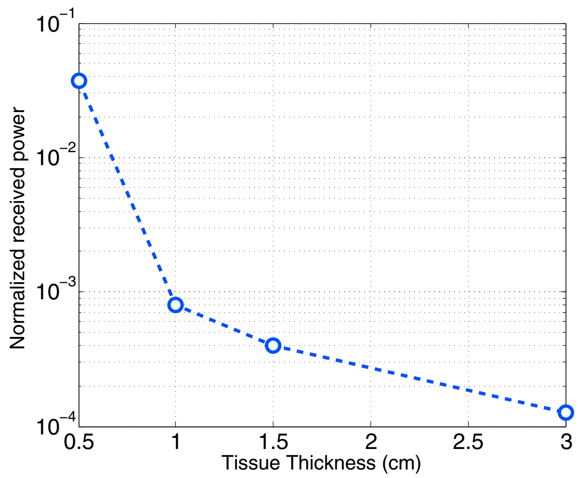

Fig. 7. The measured normalized backscattered power received from the antenna stent versus tissue thickness.

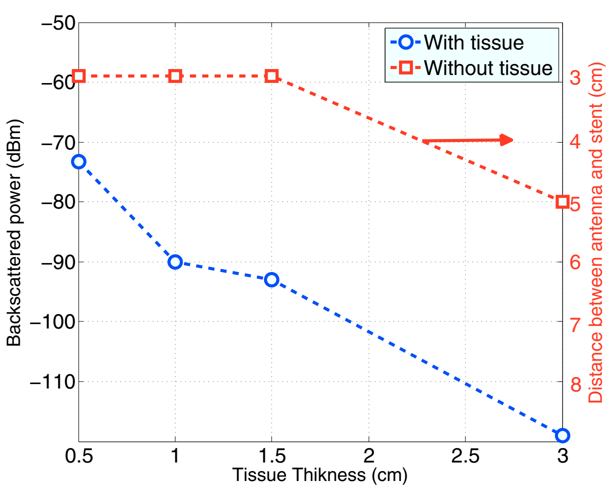

Fig. 8. Measured backscattered power with/without layers of ground beef.

V. Acknowledgements

The authors would like to thank Dr. Roberto Rosales and Professor David Michelson from the Department of Electrical and Computer Engineering at the University of British Columbia for technical support and providing access to the test equipment.

References

[1] P. W. Serruys, H. E. Luijten, K. J. Beatt, and et al., "Incidence of restenosis after successful coronary angioplasty: a time-related phenomenon: a quantitative angiographic study in 342 consecutive patients at 1, 2, 3, and 4 months," *Circulation*, pp. 361–371, 1988.

[2] E. Y. Chow, A. L. Chlebowski, S. Chakraborty, W. J. Chappell, and P. P. Irazoqui, "Fully wireless implantable cardiovascular pressure monitor integrated with a medical stent." *IEEE Transactions on Biomedical Engineering*, vol. 57, no. 6, pp. 1487–96, Jun. 2010. [Online]. Available: http://www.ncbi.nlm.nih.gov/pubmed/20172781

[3] O. Frobert, B. Lagerqvist, J. Carlsson, J. Lindback, U. Stenestrand, and S. K. James, "Differences in restenosis rate with different drug-eluting stents in patients with and without diabetes mellitus: A report from the SCAAR (Swedish Angiography and Angioplasty Registry)," *Journal of American College of Cardiology*, vol. 53, no. 18, pp. 1660–1667, 2009. [Online]. Available: http://content.onlinejacc.org/cgi/content/abstract/53/18/1660

[4] A. Kastrati, J. Mehilli, J. Dirschinger, J. Pache, K. Ulm, H. Schuhlen, M. Seyfarth, C. Schmitt, R. Blasini, F. Neumann, and A. Schomig, "Restenosis after coronary placement of various stent types," *The American Journal of Cardiology*, vol. 87, pp. 34–39, January 1 2001.

[5] Z. Sun and A. M. D. Almutairi, "Diagnostic accuracy of 64 multislice ct angiography in the assessment of coronary in-stent restenosis: A meta-analysis," *European Journal of Radiology*, vol. 73, no. 2, pp. 266–273, 2010. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0720048X08005822

[6] M. Ruscazio, R. Montisci, P. Colonna, and et al., "Detection of coronary restenosis after coronary angioplasty by contrast-enhanced transthoracic echocardiographic doppler assessment of coronary flow velocity reserve," *Journal of the Amierican College of Cardiology*, vol. 40, no. 5, pp. 896–903, May 2002.

[7] K. Keikhosravy, A. Zargaran-Yazd, and S. Mirabbasi, "On the use of smart stents for monitoring in-stent restenosis," in *International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*, 28 2012-sept. 1 2012, pp. 3231 –3234.

[8] P. Cong, N. Chaimanonart, W. Ko, and D. Young, "A wireless and batteryless 130mg 300 uw 10b implantable blood-pressure-sensing microsystem for real-time genetically engineered mice monitoring," in *IEEE International Solid-State Circuits Conference (ISSCC)*, feb. 2009, pp. 428 –429,429a.

[9] A. DeHennis and K. Wise, "A fully integrated multisite pressure sensor for wireless arterial flow characterization," *Microelectromechanical Systems, Journal of*, vol. 15, no. 3, pp. 678–685, 2006.

[10] J. Riistama, J. Väisänen, S. Heinisuo, H. Harjunpää, S. Arra, K. Kokko, M. Mäntylä, J. Kaihilahti, P. Heino, M. Kellomäki, O. Vainio, J. Vanhala, J. Lekkala, and J. Hyttinen, "Wireless and inductively powered implant for measuring electrocardiogram." *Medical & Biological Engineering & Computing*, vol. 45, no. 12, pp. 1163–74, Dec. 2007. [Online]. Available: http://www.ncbi.nlm.nih.gov/pubmed/17929070

[11] A. R. Kahn, E. Y. Chow, O. Abdel-Latief, and P. P. Irazoqui, "Low-power, high data rate transceiver system for implantable prostheses." *International Journal of Telemedicine and Applications*, p. 563903, Jan. 2010. [Online]. Available: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=3026970

[12] A. Denisov and E. Yeatman, "Ultrasonic vs. Inductive Power Delivery for Miniature Biomedical Implants," *2010 International Conference on Body Sensor Networks*, pp. 84–89, Jun. 2010.

[13] P. Nikitin and K. Rao, "Theory and measurement of backscattering from RFID tags," *IEEE Antennas and Propagation Magazine,*, vol. 48, no. 6, pp. 212–218, Dec. 2006.

[14] Y.-C. Shih, T. Shen, and B. Otis, "A 2.3 μW wireless intraocular pressure/temperature monitor," *IEEE Journal of Solid-State Circuits*, vol. 46, no. 11, pp. 2592 –2601, Nov. 2011.

[15] K. Takahata, A. DeHennis, K. Wise, and Y. Gianchandani, "A wireless microsensor for monitoring flow and pressure in a blood vessel utilizing a dual-inductor antenna stent and two pressure sensors," *IEEE International Conference on Micro Electro Mechanical Systems (MEMS)*, pp. 216–219, 2004.

[16] A. Poon, S. O'Driscoll, and T. Meng, "Optimal frequency for wireless power transmission into dispersive tissue," *IEEE Transactions on Antennas and Propagation*, vol. 58, no. 5, pp. 1739–1750, 2010.

[17] A. DeHennis and K. Wise, "A fully integrated multisite pressure sensor for wireless arterial flow characterization," *Journal of Microelectromechanical Systems*, vol. 15, no. 3, pp. 678–685, 2006.

[18] A. DeHennis and K. D. Wise, "A double-sided single-chip wireless pressure sensor," *IEEE International Conference on Micro Electro Mechanical Systems (MEMS)*, pp. 252–255, 2002.

[19] O. Akar, T. Akin, and K. Najafi, "A wireless batch sealed absolute capacitive pressure sensor," *Sensors and Actuators A: Physical*, vol. 95, no. 1, pp. 29–38, 2001. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0924424701007531

[20] K. Takahata, Y. Gianchandani, and K. Wise, "Micromachined Antenna Stents and Cuffs for Monitoring Intraluminal Pressure and Flow," *Journal of Microelectromechanical Systems*, vol. 15, no. 5, pp. 1289–1298, Oct. 2006.