EMBEDDED ANTENNAS INTO AORTIC VALVE BIOPROSTHESES FOR RFID-BASED WIRELESS MONITORING

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Abstract

A wrapped C-dipole, with a triangular impedance transformer, is closely integrated with the polymeric stent and with the cuspid of the valve, which is suitable to host electronics. Preliminary experiments demonstrated the possibility to establish a robust communication link, based on Radio-Frequency Identification in the UHF band, with a wearable antenna placed onto the thorax.

Index Terms *– Battery-Less, Implantable Antenna, Pervasive Healthcare*

I. INTRODUCTION

A failing native cardiac valve is routinely replaced surgically with a prosthesis [1] to restore the normal heart function. The monitoring of the prosthetic device is performed through standard periodic screenings by chest X-ray and echocardiography, which are however time-consuming, invasive, and operator dependent [2]. An alternative diagnostic approach based on in-situ embedded sensors and wireless passive communications could allow early detection of anomalies, improving the patient's life expectancy. In this scenario, Radio-Frequency Identification (RFID) technology in the UHF band ($860 - 960$ MHz) can play a crucial role as it permits miniaturizing the sensor and minimizing the required electronics. For example, in [3] an endovascular stent was augmented with sensing and communication capabilities or in [4] and [5] concerning an orthopedic prosthesis and dental implant, respectively. The valve prosthesis, itself provided with a metallic wireframe inside has been already preliminarily investigated by exploiting the stent itself as an energy harvester [6]. This paper, instead, will consider the case of a metal-free valve equipped with a polymeric stent. The leading idea is to achieve a reliable trans-cardiac RFID-based communication link through a minimally invasive embedded antenna wrapped around the body of the valve.

II. Model

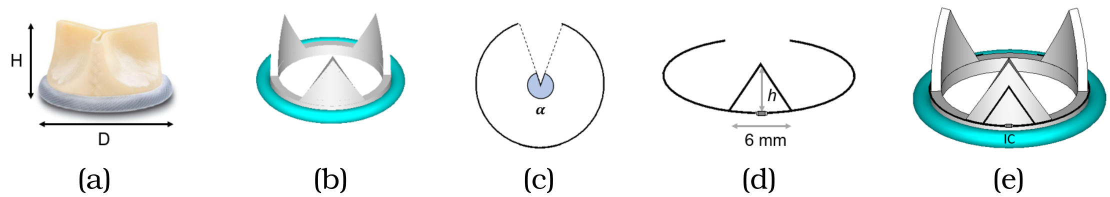
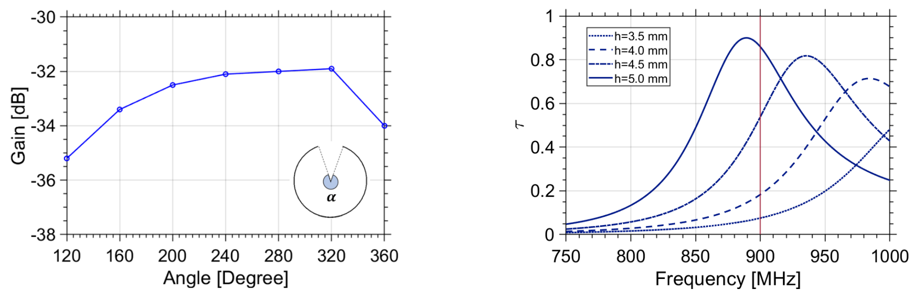


Figure 1: (a) The reference biological aortic valve prosthesis ($D = 21$ mm, $H = 11$ mm). (b) The simplified electromagnetic model of the valve. The antenna layout: (c) aperture angle of the C-dipole and (d) triangular T-match. (e) The antennified-valve.

The reference valve bioprosthesis is produced by LivaNova (model: Crown PRT, Fig. 1(a)). It is composed of a single bovine pericardium layer mounted outside the dielectric-covered acetal homopolymeric stent. Establishing the communication through backscattering is critical since the antenna is located at a depth of 7 cm from the skin within a highly lossy environment that mostly comprises muscles and blood. Antenna design constraints include the small available space imposed by the valve geometry as well as the minimal variation of the structural integrity. We assume that the antenna can be embedded below the external dielectric coating interposed between the structure and the leaflets, which is hence insulated from the surrounding tissues. For the sake of simplicity, the reference prosthetic device is hereafter emulated by a polymeric stent with three cusps and a silicone suture ring (Fig. 1(b)). The electromagnetic model of the abdomen is the same as in [6] with dielectric properties of the human tissues at 900 MHz from [7]. All the geometries are modeled by CST Microwave Studio.

III. Antenna Layout and Parametric Analysis

The antenna to be embedded comprises a thin wire (diameter 0.035 mm) curvilinear dipole (C-dipole) that is defined by the aperture angle, α (Fig. 1(c)). For the impedance matching to the desired $Z_{chip} = 2.6 - j73.6$ at 900 MHz [8], the C-dipole is connected in the middle to a triangular T-match such to be hosted by a cuspid scaffold (Fig. 1(d),(e)). The antenna parameters are therefore α of the C-dipole and the height, h, of the triangular loop. The optimal radiation gain (31.9 dB, Fig. 2(a)) is obtained for α=$320°$ and it is in line with typical values of implanted RFID passive devices [9]. By fixing α=$320°$, the optimal value of the power transfer coefficient (τ), namely to maximize the power delivered by the antenna to the IC, is obtained by a numerical parametric analysis (Fig. 2(b)). By increasing h, resonant frequency moves towards lower frequencies with a shift of 50 MHz/0.5 mm. Noticeably, the case with $h = 5$ mm returns the useful value of $\tau = 0.86$ at 900 MHz.



(a) (b)

Figure 2: (a) Radiation gain at 900 MHz vs aperture angle of the wrapped C-dipole. (b) Simulated power transfer coefficient for different values of the T-match height.

IV. Near-Field Telemetry Link

The near-field telemetry link will occur between the antennified-valve and an external reader antenna (linearly polarized microstrip slot from [6]) placed on the patient's thorax, at heart level. By assuming a lossy two-port network, the electromagnetic interaction is quantified by the Transducer Power Gain (G_T). The reference RFID IC is the Axon Magnus S3 [8] (power sensitivity $P_{chip} = 13.6$ dBm) which includes an integrated temperature sensor. By exploiting the self-tuning feature of the IC, G_T is expressed as [10]

$$G_T = (4G_g G_{IC}|Y_{12}|^2)/(|(Y_{11} + Y_g)(Y_{22} + Y_{IC}) - Y_{12}^2|^2) \quad (1)$$

being $Y_g = G_g + jB_g$ the admittance of the reader and $Y_{IC} = G_{IC} + jB_{IC}$ the admittance of the IC. A reliable communication link can be established by providing a communication margin M_{dB}

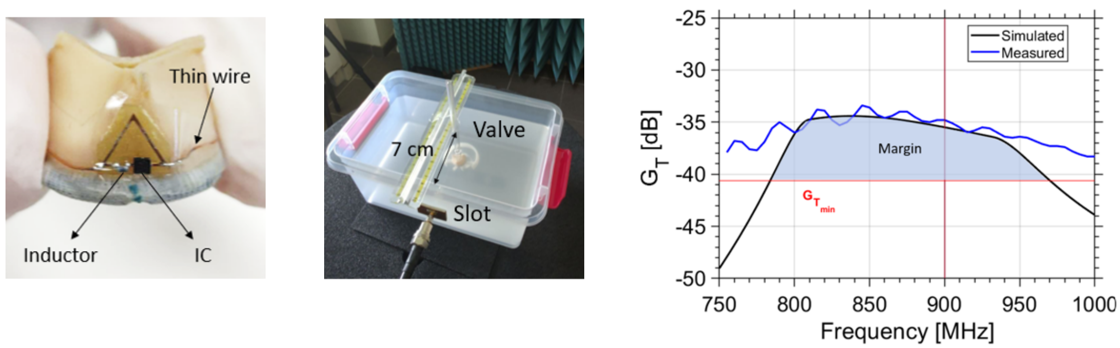
$$M_{dB} = P_{av,G_{dB}} - P_{chip_{dB}} + G_{T_{dB}} - M_{0_{dB}} \geq 0_{dB} \quad (2)$$

where $P_{av,G_{dB}} = 0$ dB is the power emitted by the reader and $M_{0dB} = 3$dB is a conservative safe value. In the considered arrangement, the resulting minimum value of G_{TdB} to establish the link is 40.6 dB.

V. Prototype and Experimentation

For the sake of simplicity, the triangular T-match is fabricated on a 0.8 mm thick FR4 substrate, and the C-dipole is made of copper wires. The input impedance of the resulting antenna is tuned by a series inductor ($L =$

1.8 nH). Finally, the prototype to be tested is placed on the real valve, as shown in Fig. 3(a). The chest is emulated by a PET box filled with a liquid phantom ($\epsilon = 54 + j21; \sigma = 1.05$ [S/m] [11]). The antennified-valve is immersed at a distance of 7 cm from the external reader antenna (Fig. 3 (b)) as in realistic conditions. Fig. 3 (c) shows the G_T results versus frequency. There is a good agreement between the simulation and the measurement. Thanks to the self-tuning property of the IC, the transducer power gain G_T exhibits the typical nearly flat profile over broadband with a power margin of 5 dB w.r.t. the minimum value to establish the communication.



(a) (b) (c)

Figure 3: (a) The antennified-valve prototype. (b) Measurement setup. (c) Simulated and measured transducer power gain G_T for the antennified-valve placed in the liquid phantom, interrogated by an on-body slot.

VI. Conclusion

We have presented the integration of a wrapped C-dipole within a metal-free cardiac valve. Numerical simulations and an early test with a prototype demonstrated the achievable communication performance of the trans-cardiac RFID-based link. The antenna and IC are inserted in the valve leaving the structural integrity of the device unaltered, hence making the requalification of the device easier. This resulting augmented medical device could enable early identification of infections by using an IC that samples the local temperature and can be further augmented with a pressure sensor for a more specific health monitoring from the inside.

References

[1] B. Vennemann, D. Obrist, and T. Rösgen, “A smartphone-enabled wireless and batteryless implantable blood flow sensor for remote mon-

itoring of prosthetic heart valve function," *PLoS One*, vol. 15, no. 1, e0227372, 2020.

[2] E. G. Butchart, C. Gohlke-Bärwolf, M. J. Antunes, *et al.*, "Recommendations for the management of patients after heart valve surgery," *European Heart Journal*, vol. 26, no. 22, pp. 2463–2471, Aug. 2005, ISSN: 0195-668X.

[3] C. Occhiuzzi, G. Contri, and G. Marrocco, "Design of implanted RFID tags for passive sensing of human body: The STENTag," *IEEE Transactions on Antennas and Propagation*, vol. 60, no. 7, pp. 3146–3154, 2012.

[4] S. Nappi, L. Gargale, F. Naccarata, P. P. Valentini, and G. Marrocco, "A fractal-RFID based sensing tattoo for the early detection of cracks in implanted metal prostheses," *IEEE Journal of Electromagnetics, RF and Microwaves in Medicine and Biology*, 2021.

[5] N. Panunzio, G. Ligresti, M. Losardo, *et al.*, "Cyber-tooth: Antennified dental implant for RFID wireless temperature monitoring," in *2021 IEEE International Conference on RFID Technology and Applications (RFID-TA)*, IEEE, 2021, pp. 211–214.

[6] M. Gagliardi, C. Occhiuzzi, R. Verzicco, and G. Marrocco, "How to transform an aortic valve prostheses into an UHF antenna for the RFID-based wireless monitoring of the cardiac health," in *16th European Conference on Antennas and Propagation (EUCAP), Madrid, 2022.*

[7] IFAC-CNR., *Calculation of the dielectric properties of body tissues in the frequency range 10 Hz - 100 GHz*, Mar. 2022. [Online]. Available: http://niremf.ifac.cnr.it/.

[8] M. S. Axon, May 2022. [Online]. Available: https://axzon.com/rfm3300-d-magnus-s3-m3d-passive-sensor-ic/.

[9] N. A. Malik, P. Sant, T. Ajmal, and M. Ur-Rehman, "Implantable antennas for bio-medical applications," *IEEE Journal of Electromagnetics, RF and Microwaves in Medicine and Biology*, vol. 5, no. 1, pp. 84–96, 2021.

[10] G. M. Bianco, S. Amendola, and G. Marrocco, "Near-field constrained design for self-tuning UHF-RFID antennas," *IEEE Transactions on Antennas and Propagation*, vol. 68, no. 10, pp. 6906–6911, 2020.

[11] S. Swiss, Apr. 2022. [Online]. Available: https://speag.swiss/components/materials-liquids/msl/.