A Cornered Shallow Cavity Backed Slot Antenna Suitable for Smart Hip Implants

Sema Dumanli
Telecommunication Research Lab, Toshiba Research Europe, Bristol, UK, Email: sema.dumanli@toshiba-trel.com

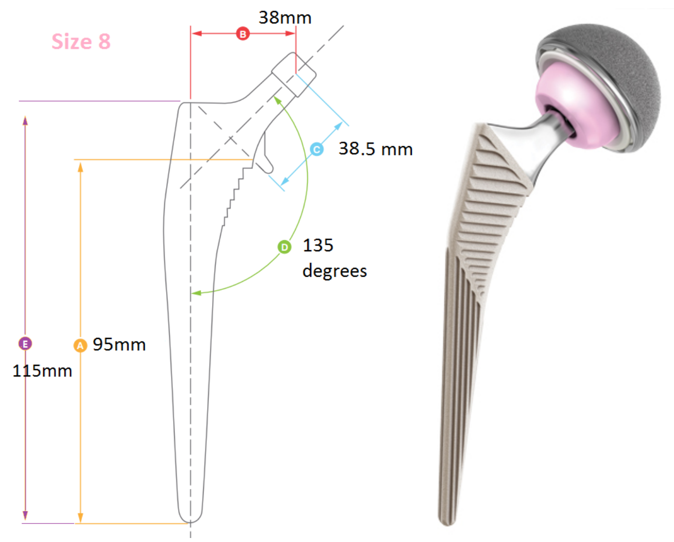
***Abstract*—A hip implant can be equipped with sensors and microelectronics forming a wireless communication link between the implant and an on-body sensor to collect continuous data or provide real-time feedback. Since the implant is positioned in a heavily RF hostile environment, the antenna is one of the most critical parts of the system design. Here, an antenna to be located on a femoral stem is presented as well as an on-body sensor antenna completing the RF link. Initial simulations demonstrate promising results with good link quality.**

I. Introduction

Medical Body Area Networks (MBAN) form three types of communication links: in-body, on-body and off body [1]. In-body links are the links formed to communicate with an implanted device collecting continuous data or provide real-time feedback [2]. Antenna design is one of the most challenging tasks to realize an in-body link since the implanted antennas should be small, bio-compatible and able to operate in a highly lossy and variable environment. The surrounding environment of the implant is subjective, changes with time and affects the characteristics of the antenna such as efficiency and impedance matching [3]. The matching of the antenna has a direct effect on the link quality and the battery life of the system.

Hip implant is one of the many orthopaedic implants which can greatly benefit from an RF link. Over 70,000 hip replacements are performed in England every year and it is estimated to increase with the ageing population [4]. Although a modern artificial hip joint is designed to last for long periods of time, 1 in 10 of these hip replacement surgeries are estimated to require revision surgery within the lifetime of the patient. At the moment,the performance of the implant is not monitored and the failure is detected by the onset of pain which most of the time is due to irreversible damage. If the loosening of the joint, wear and tear, and the temperature changes are detected by continuous monitoring, post-operative process can be improved and precautions can be taken to avoid the revision surgery.

The high magnetic near fields are less susceptible to dissipation in human body since human tissues have no magnetic losses ($\mu_r^{''} = 0$). Therefore magnetic antennas, including the slot antenna investigated in this study, are more suitable for implanting in the body [5] [6]. Here a cavity backed slot antenna with an insulating layer embedded on a femoral stem coated with a bio-compatible material is presented. An on-body antenna operating at 2.4 GHz ISM band is also included in the simulations to complete the RF link. A layered numerical hip phantom is used to asses the performance of the system.



(a) (b)

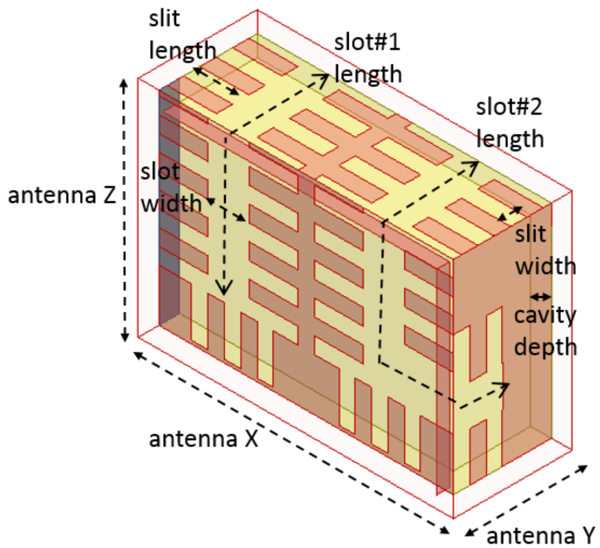
Fig. 1: A diagram (a) and a photo (b) of a femoral stem [7]

The implant antenna design will be detailed in Section II. The in-body communication scenario with an implant antenna, an on-body antenna and a layered numerical hip phantom is simulated in Section III. The paper concludes with Section IV.

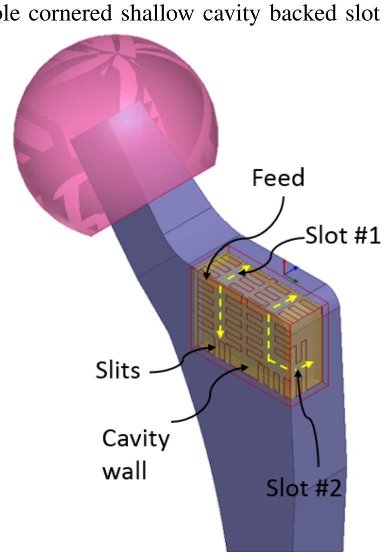
II. Antenna Design

A cavity backed slot antenna located on a femoral stem is designed. A standard collarless stem is modelled according to the dimensions given in [7]. Size 8 is chosen for the simulations where $A = 95$ mm, $B = 38$ mm, $C = 38.5$ mm, $D = 135^0$ of Figure 1. The stem is chosen to be Perfect Electric Conductor (PEC). The femoral head is zirconia-toughened, platelet-reinforced alumina ceramic (ZPTA) containing approx. 74% alumina and 25% zirconia [8]. The electrical properties of the femoral head is taken as $\epsilon_r = 12.4$ and $tan\sigma = 0.0005$ [9].

Conventionally a slot is etched onto one face of a rectangular or a cylindrical metallic cavity in order to form a cavity backed slot. There are some examples of slot antennas where the slot is etched on multiple surfaces of the cavity as described in [12] and [11]. In [11] multiple half wavelength



(a) Implantable cornered shallow cavity backed slot antenna layout



(b) Implanted antenna located on the hip stem

Fig. 2: Implant antenna

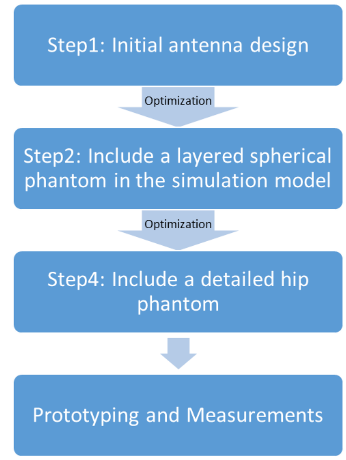


Fig. 3: The design flow followed during the optimization of the antenna parameters

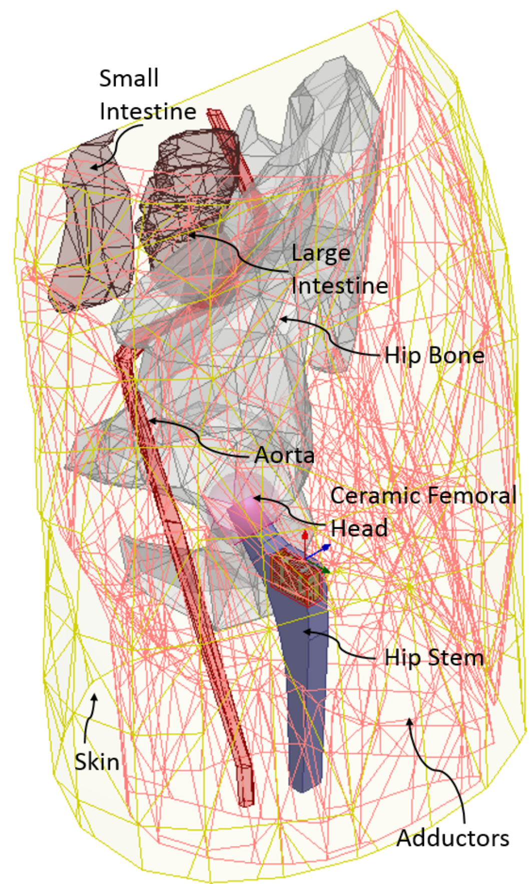


Fig. 4: The antenna located in Ansys Human Body Phantom on the Corail hip stem model

slots were etched onto multiple faces of a cuboid cavity and they are activated or deactivated in order to reconfigure the pattern. In [12], a long multiple wavelength slot was etched onto multiple faces of a cuboid. The aim is again to reconfigure the pattern. Both of these antennas have bulky cubic cavities. Here the aim is to miniaturize the structure so that it is suitable for implanting. Therefore a half wavelength slot is meandered on multiple faces of a shallow cavity as seen in Figure 2. It differs from the literature not only because it is a resonant slot on multiple faces of a cavity, but also because the cavity here is a 3D shallow cavity which, is formed by uniting 3 perpendicular dielectric blocks. The cavity is not resonant at the operating band and the lowest cavity mode occurs at 3.66 GHz. From here on this cavity is referred to as a shallow cornered cavity here. This is useful especially when the space is restricted and isolation is needed between the antenna and the structure it is located on, in this case the stem. It saves a lot of space for the rest of the electronics as well.

The slots are excited by a suspended stripline which is sandwiched between the walls of the cavity and it is

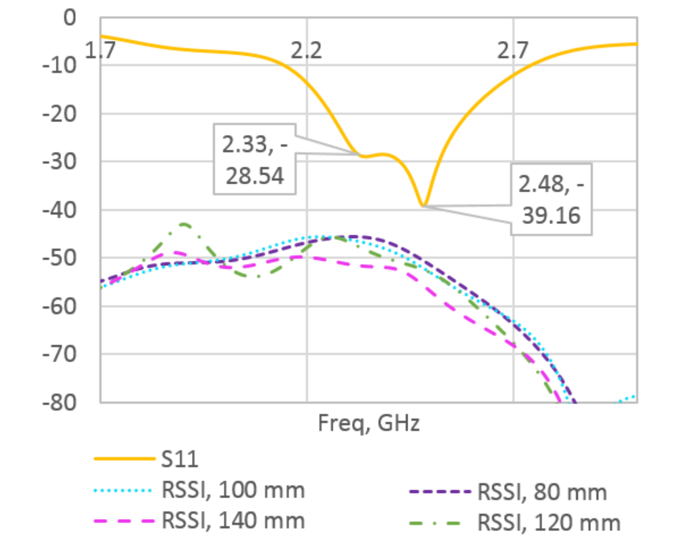


Fig. 5: —s11— in dB vs frequency (GHz) of the implanted antenna

shorted to one of the lower side walls. Two slots with a difference in length are etched on the outer walls which are excited simultaneously with the same stripline. It creates two resonances and supports a larger bandwidth. Note that large bandwidth is required for implantable applications, in order to tackle detuning which is caused by the changing surrounding of the implant.

The substrate is chosen to be 1.27 mm thick with a dielectric constant of 6.15. The antenna is further miniaturized using slits. As the slot is loaded with slits, the current travels a longer distance therefore the electrical length becomes larger. The slit width and slit length can be tuned to adjust the operating frequency of the antenna together with the length of the slots. The length of the first slot is between 0.45 and 0.55 guided wavelength before it is loaded with slits. The recommended slit length is the same as the slot width and the slit width is chosen to be 1/6th of the slit length. The length of the second slot is chosen to be 20% longer than the first slot. This creates a larger bandwidth. The design flow can be seen in Figure 3. Finally, the a superstrate is located on the outer faces of the cornered cavity to provide a lossless medium in the strong near-field region. It minimizes the changes during healing as well as the losses due to human tissues.

III. Results

Several numerical phantoms have been reported in the literature from simple flat uniform models to MRI based voxel models [10]. Here Ansys Computational Male Phantom in High Resolution is used. The simulated frequency response of the antenna while it is located in the hip on the stem as seen in Figure 4 is plotted in Figure 5. The bandwidth is wide and the two resonances due to the two slots are visible at 2.33 GHz and 2.48 GHz. The received signal levels by the on-body repeater antenna are also plotted as the on-body antenna and body separation is changed from 8 cm to 14 cm. The results are promising as the receive sensitivity of a TelosB Mote [13], an off-the-shelf wireless sensor is -90 dBm.

IV. Conclusion

A 3D slot antenna suitable for using on a smart hip implant is proposed here. The antenna is isolated from the backing stem by a conformal shallow cavity. It is miniaturized using meandering, slit loading as well as dielectric loading. The antenna is optimized using Ansys Electronics Desktop and Ansys Human Body Phantom. It achieves large bandwidth and the transmission coefficients measured are promising for the realization of a smart hip implant.

References

[1] T. Zasowski, F. Althaus, M. Stager, A. Wittneben, and G. Troster, "UWB for noninvasive wireless body area networks: channel measurements and results," IEEE Conference on Ultra Wide-band Systems and Technologies, Nov. 2003, pp. 285-289.

[2] S. Dumanli, S. Gormus, I. J. Craddock, "Energy efficient body area networking for mHealth applications," 6th International Symposium on Medical Information and Communication Technology (ISMICT), pp.1-4, 25-29 March 2012.

[3] T. Dissanayake, K. P. Esselle, M. R. Yuce, "Dielectric Loaded Impedance Matching for Wideband Implanted Antennas", IEEE Transactions on Microwave Theory and Techniques, vol.57, no.10, pp.2480-2487, Oct. 2009.

[4] Hip Replacements, NHS Choices [Online] Available: *http : //www.nhs.uk/conditions/Hip − replacement/Pages/Introduction.aspx*, accessed Dec 2013.

[5] F. Merli, B. Fuchs, J. R. Mosig, A. K. Skriverviky, "The Effect of Insulating Layers on the Performance of Implanted Antennas," IEEE Transactions on Antennas and Propagation, vol.59, no.1, pp.21-31, Jan. 2011.

[6] W. Xia, K. Saito, M. Takahashi, K. Ito, "Performances of an Implanted Cavity Slot Antenna Embedded in the Human Arm", IEEE Transactions on Antennas and Propagation, vol.57, no.4, pp.894-899, April 2009.

[7] Corail Hip System, Surgical Technique [Online]. Available: *http : //www.depuy.com/sites/default/files/products/*, accessed Dec 2013.

[8] Biolox delta Ceramic Femoral Heads [Online]. Available: *http : //www.depuy.com/sites/default/files/products/*, accessed Dec 2013.

[9] Zirconia Toughened Alumina (ZTA) [Online]. Available: *http : //www.ceramics.net/sites/default/files/files/zta.pdf* , accessed Dec 2013.

[10] S. Dumanli, C. J. Railton, "On-Body Transmission at 5.2 GHz: Simulations Using FDTD With a Time Domain Huygens' Technique," Antennas and Propagation, IEEE Transactions on , vol.59, no.10, pp.3910,3917, Oct. 2011

[11] Julien Sarrazin, Yann Mahe, Stephane Avrillon, Serge Toutain, "Pattern Reconfigurable Cubic Antenna", IEEE Transactions on Antennas and Propagation, Vol. 57, No. 2, Feb 2009.

[12] Souren Shamsinejad, Pedram Mousavi ,"3D Folded Cubical Slot Antenna", IEEE Antennas and Propagation Society International Symposium (APSURSI), 2014.

[13] "TELOSB Mote Platform", [Online] *http : //www.memsic.com/userfiles/files/Datasheets/WSN/*, accessed in Jan 2016.