Cyber-Tooth: Antennified Dental Implant for RFID Wireless Temperature Monitoring

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***Abstract*—The implantation of devices and prostheses is considerably rising in recent years. When an implanted medical prosthesis is equipped with a local wireless sensor, an early-onset identification of possible infections could be achieved. This paper proposes a method to transform a metallic dental implant into an antenna integrating a temperature UHF RFID sensor. A sensorized add-on disk, fully embedded in the dental implant's crown, collects the external interrogating electromagnetic field and transforms the implant itself into a top-excited dipole. After simulations, a preliminary prototype of the resulting *Cyber-Tooth* is experimented with a near-filed interrogation by means of an on-cheek antenna. Results are promising for the establishment of a robust backscattering link, as a good margin in the link budget is achievable with further improvements in the tuning of the disk harvester.**

***Keywords*—implantable antenna, Radio Frequency Identification (RFID), smart dental implant, cyber-prosthesis, infection**

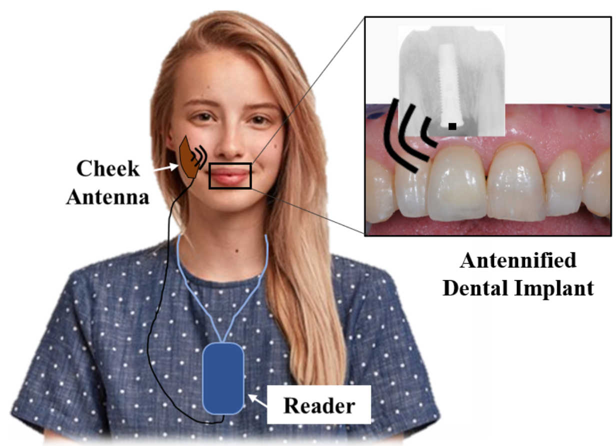


Fig. 1. *Cyber-Tooth* concept.

I. Introduction

Providing a passive implanted medical prosthesis with embedded sensor capability and wireless connectivity is a new frontier of the *Precision Medicine* [1] at the purpose to earn an unprecedented physiological insight of the human body's health and of the status of the implanted device itself. The Ultra High Frequency (UHF) Radio Frequency Identification (RFID) technology has been already involved for data acquisition and communication through-the-body [2]–[4]. More recently, the innovative trend is to *antennify* the implanted prosthesis [5] by transforming the device itself, with negligible modifications, into an antenna that collects the electromagnetic field coming from an external reader to power up simple sensor-oriented electronics (i.e. RFID ICs).

The purpose of this paper is to show how to antennify a dental implant to transform it into a wireless local sensor of biophysical parameters of the mouth cavity [6]. For example, temperature measurements can be exploited to early detect possible post-implantation infections [7], or the onset of specific pathologies such as perimplantitis, mucositis, or gingivitis. The monitoring of the oral cavity is an already explored topic [8]–[11], but, so far, only few studies concerned the implantation of an RFID sensor into a human tooth. The considered RFID links operated at 134.2 kHz in [12], [13] and 13.56 MHz in [14]. Moreover, the insertion of the sensor was invasive since RFID devices, originally made for other applications (e.g. veterinary), were adjusted and implanted in

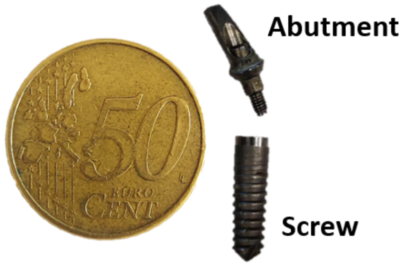


Fig. 2. Reference dental implant.

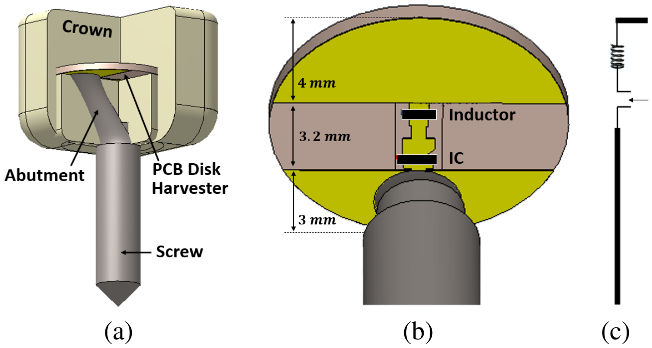


Fig. 3. (a) *Cyber-Tooth* model. (b) Harvester add-on disk. (c) Equivalent dipole of the antennified dental implant.

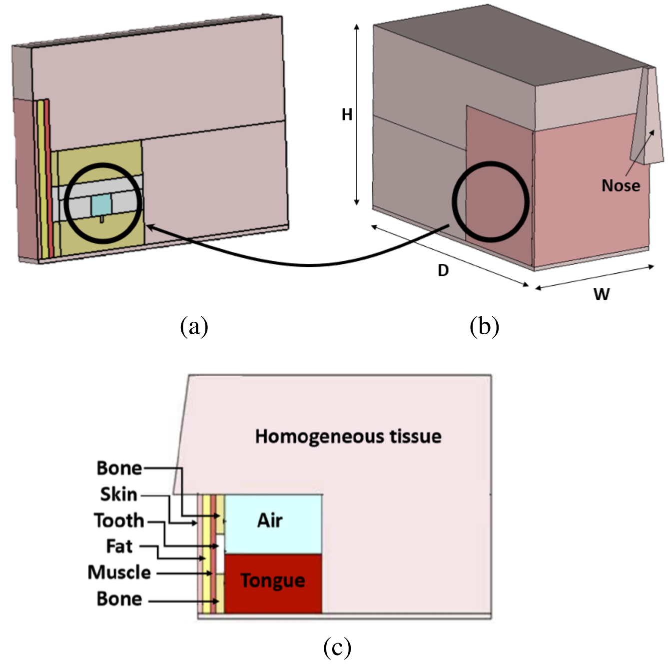


Fig. 4. (a) Numerical phantom of the dental arch, and (b) of the half human head. Principal sizes: $W = 9\,cm$, $H = 12\,cm$, $D = 18\,cm$. For other geometrical and dielectric parameters refer to [15]. (c) Detail of the stratification of the model.

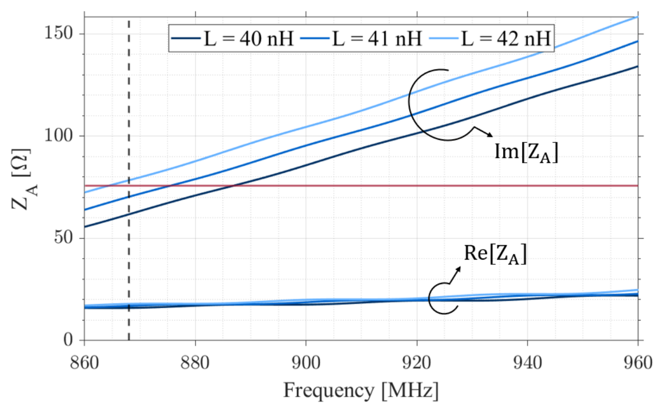


Fig. 5. Simulated real and imaginary part of the input impedance of the antennified dental implant, simulated for different values of the tuning inductor. The dashed line indicates the reference working frequency (868 MHz) and the horizontal red line indicates the conjugate reactance of the chip (75.7 Ω).

a molar tooth, hence compromising its integrity. In this paper, instead, a dental implant (Fig. 2) is exploited to host the sensor. It replaces a missing tooth and is made of three components. The *screw* works as a replacement of the tooth root. It is usually made of titanium for biocompatibility requirements. Then there is the *abutment*, placed on the top of the dental implant to connect it to the replacement tooth. It can be made of both metallic or polymeric material. Finally, there is the *crown*, which is the custom-fabricated replacement tooth. It is generally made of ceramic material.

The screw and the abutment can be engineered to work as an harvesting antenna tuned in the UHF band (860-960 MHz). By connecting a temperature-sensing RFID IC, a *Cyber-Tooth* will be hence achieved. This could be interrogated from the outside by an hand-held reader or even by an on-cheek skin antenna (Fig. 1) for a continuous overnight monitoring.

II. Antenna Design and Simulations

The reference dental implant is shown in Fig. 2. It is made of titanium ($\sigma = 1.8 \times 10^6\, S/m$), and the overall sizes are $1.4\,cm$ (length) and $4\,mm$ (diameter). To transform the dental implant into an RFID sensor, an add-on element is placed inside the tooth crown (Fig. 3.a). It consists of an FR-4 PCB disk (diameter $10.2\,mm$, thickness $0.6\,mm$), with proper copper carvings. The microchip transponder and a tuning inductor are connected in series between the two main metallizations of the disk (Fig. 3.b). In this way, the assembly of screw + abutment + PCB disk will work as a top-excited dipole (Fig. 3.c). The galvanic connection between the abutment and the smaller copper region is obtained by simply putting the two structures in contact as in Fig. 3.a.

For simulation purpose, the antennified assembly is inserted in a simplified multi-layer model of the human head (Fig. 4.c), borrowed from [15]. The right dental arch is modified (Fig. 4.a) so that it can host both the implant and the $14 \times 14 \times 12\,mm$ tooth capsule. The latter is made of porcelain ($\varepsilon = 6$, $\sigma = 1 \times 10^{-15}\, S/m$) and embeds the PCB disk face-down.

The temperature sensor IC is the Axzon's Magnus-S3 [16] (chip sensitivity $-16.6\,dBm$), featuring an auto-tuning capability to maximize the harvested power. For design purpose,

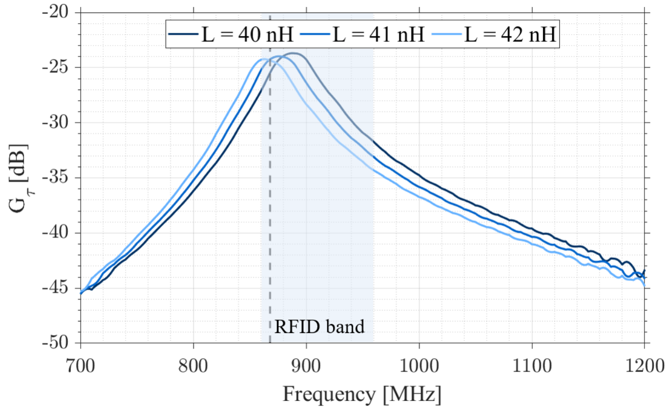


Fig. 6. Simulated realized gain of the antennified dental implant for different values of the tuning inductor. The dashed line indicates the reference working frequency (868 MHz).

the middle-range IC's impedance $Z_{IC} = 2.8 - j75.7\,\Omega$ in the European UHF band is hereafter considered.

Fig. 5 shows the simulated[1] antenna resistance and reactance in the UHF band by varying the inductance. Despite the good matching of the imaginary part ($78\,\Omega$ in the best case), the power transmission coefficient at 868 MHz is limited at 0.5 due to the high value of the real part (16-18 Ω). The optimal realized gain ($-24\,dB$) is obtained for a tuning inductor value of 41-42 nH (Fig. 6). This resulting gain is in line with typical implanted RFID devices [17], and, by considering an external reader emitting $3.2\,W\;EIRP$, it could enable a remote reading up to $30\,cm$.

III. Prototype Characterization

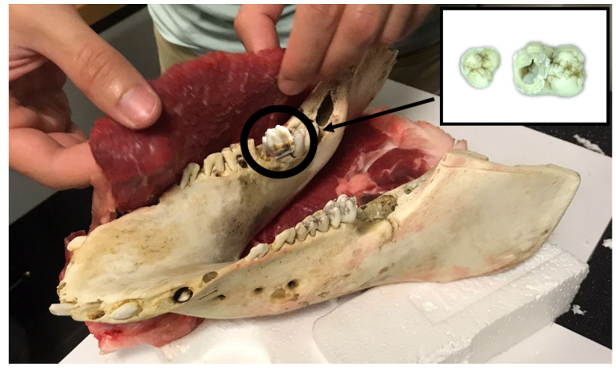
A preliminary experimental evaluation of the *Cyber-Tooth* is carried out by means of an epidermal cheek-antenna (Fig. 7.b), which activates near-field interrogation. It is a $4 \times 2.5\,cm$ patch antenna [18], separated from the meat by a $2\,mm$ silicone substrate. The electromagnetic characterization is performed by means of the Voyantic Tagformance station in the 700-1200 MHz frequency band.

The human head is emulated by the skeleton of a porcine jaw, covered with a slice of heifer meat to homogeneously embody the cheek tissues (Fig. 7.a). A molar tooth of the same skeleton is used to embody the capsule itself. A hole is drilled in the tooth to house the screw and the abutment. Then, the tooth is cut along the longitudinal axis to insert the harvesting disk (inset of Fig. 7.a).

The disk is fabricated with a milling machine on a FR4 substrate ($0.6\,mm$ thickness), and the IC and inductor are mounted on the strips with a conductive paste (Fig. 8.a).

The dental implant (screw+abutment) was inserted in the hole of the tooth. Then, the fabricated add-on was placed face-down on top of it, and was covered by the top remaining crown of the sectioned tooth. The prototype of the *Cyber-Tooth* is shown in Fig. 8.b.

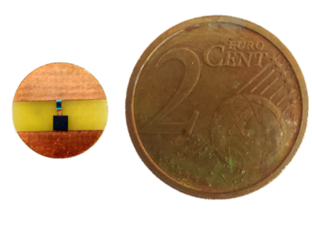
[1]All the electromagnetic simulations are performed with Dassault's CST Microwave Studio.



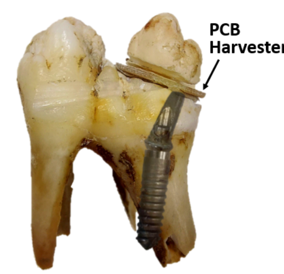
(a)

(b)

Fig. 7. (a) Experimental head phantom for the electromagnetic measurements. Inset: molar tooth prepared for the measurements. (b) Interrogating cheek-antenna from [18].



(a)



(b)

Fig. 8. (a) Disk harvester prototype. (b) *Cyber-Tooth* prototype.

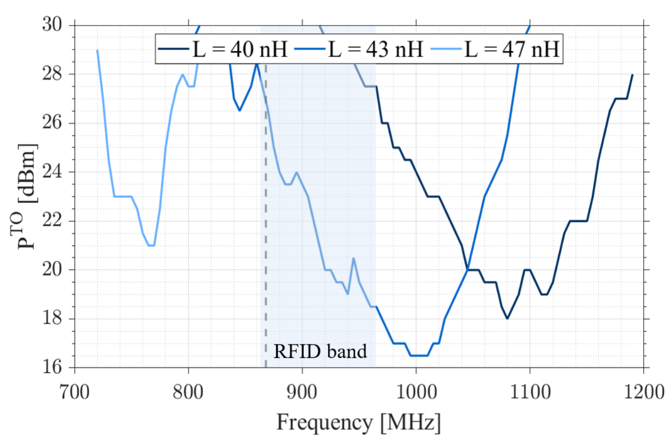


Fig. 9. Measured turn-on power of the antennified dental implant, interrogated by an on-cheek PIFA antenna, for different values of the tuning inductor. The dashed line indicates the reference working frequency (868 MHz).

Fig. 9 shows the measured turn-on power of the *Cyber-Tooth* for some different inductors, namely the minimum power that must be emitted frequency by frequency from the transmitter side to make the RFID sensor responding. Due to the approximation of the head phantom and to possible fabrication defects, a frequency shift from the desired working frequency of 868 MHz occurs. Nevertheless, provided that the device is better tuned, a turn-on power of up to $17\,dBm$ could be achieved, thus suggesting the establishment of a robust backscattering link.

IV. Conclusion

The paper has presented a preliminary design and evaluation of a *Cyber-Tooth*, that is a dental implant transformed into an implanted sensor by inserting an RFID add-on inside the crown. The main strengths of the proposed prototype are *(i)* the absence of structural or material modifications of the prosthesis itself, and *(ii)* the possibility to embed other sensors inside the capsule, for example to measure pH in addition to temperature. The first experimental evaluation was promising, but further design adjustments will be needed to improve the antenna matching and to provide some post-manufacturing tuning mechanisms to manage possible frequency shifts on-the-field.

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