A Biodegradable Implant Antenna Detecting Post-Surgical Infection

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***Abstract*—Biodegradable implants have proven to be attractive where the patient will not need to go through an additional operation for the removal of the implant. Here biodegradability is utilized further where the biodegradation process has been part of the device's operation. An implant antenna is designed to detect the post-surgical infections which increase the acidity inside the human body. The implant antenna is provisioned to be located in the operation site where it degrades at different paces depending on the existence of an infection or not. The Mg antenna is tested in cow's minced fat where the degradation is monitored using a wearable slot antenna used as a reader. The detection was possible for 1 cm deep implant with 14 MHz resolution.**

***Index Terms*—biodegradable antenna, implant antenna, slot antenna, post-surgical infection**

I. Introduction

It can be argued that the most vital application of technological innovations has always been the healthcare such as enhancing the quality of treatments, and finding alternative ways for diagnoses. Recently continuous monitoring of patients or treatment processes become an area of interest. Implantable devices play a big role in this endeavour alongside wearable devices. The use of these devices not only reduces healthcare costs, but also advances healthcare management [1].

Implantable sensors can be regarded as a big step towards monitoring the human body providing accurate and instantaneously measured data about the related body part's condition [2]. The obvious requirements of any implantable device are that it must be compatible with human tissue and durable enough against strains inside the human body. In addition to that, the implantable devices in consideration here must also be able to form wireless communication with the outside world for seamless monitoring [3]. The communication can be formed either with an active or a passive implantable counterpart. Active implants require an external power source to operate [2] [4] [5] [6], whereas passive implants form a wireless link by means of the energy provided by an external reader located outside the human body.

Providing an active implant with the needed power has not been straightforward due to the lag in battery technology. Therefore passive implants are gaining further attention. With the elimination of the battery, a fully degradable implant becomes a possibility. The degradability can automatically eliminate the risks that a second removal surgery could lead to [3]. Safe biodegradation of a device inside the human body needs nontoxic biodegradable metals such as Fe, Fe alloys, Mg and Mg alloys; polymers such as poly(L-lactide)(PLAA), polycaprolactone (PCL) and conductive polymer composites such as PLLA – polypyrrole (PPy) [3] [7].

In the literature, biodegradable implantable passive tags have been presented to be used for monitoring purposes [8] [9] [10]. All of these implants are designed to complete its mission of monitoring before the degradation starts. So the sole use of the biodegradation is to completely remove the no longer wanted implant without the need for a removal surgery.

Here we are looking into utilizing biodegradation for sensing. This approach was previously proposed in [11] where the speed of the degradation of an implantable tag is translated into information gathered inside the human body. The idea being promising, their work was not supported by realistic measurements. Here we are proposing a similar biodegradable implant where we use the degradation process to detect post-surgical infection. Our proposal differs from [11] with its implant antenna design improving the detection depth and the fact that here we have proved the efficacy of the technique through experiments using Mg strip and consumable Cow's minced fat.

Section II briefly describes the implant and the reader antennas. The process of biodegradation is observed in Section III. The simulations of the detection process are demonstrated in Section IV while the measurement set-up is explained in Section V. Section VI discusses the results and the paper concludes in Section VII.

II. Antenna Models

An implant and a wearable antenna are designed to realize the aforementioned purpose of detecting the post-surgical infection inside the human body. The implant antenna is a biodegradable structure designed on Mg (99.8 %) with a conductivity of $2.25 \times 10^7\ S/m$ [12]. The structure is optimized such that the biodegradation can be led towards a certain form. It is 0.5 cm wide and 2.5 cm long consisting of 2 narrow bridges as seen in Fig. 1(b). The narrow bridges are expected to degrade quicker than the wider main structure so the initial and the final form of the implant antenna can be considered with and without these bridges.

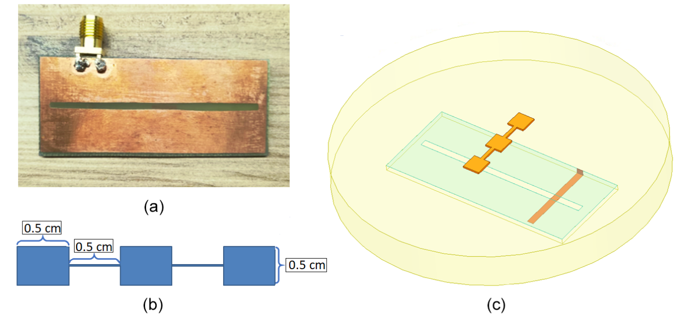

Fig. 1: (a) The reader antenna, (b) The implant antenna, (c) The HFSS model of the overall measurement set-up including the reader and implant antennas and the fat tissue in a petri dish

The wearable reader antenna on the other hand is designed on 0.1575 cm thick FR4 Epoxy, ϵ_r of 4.4. Magnetic antennas are often preferred for implant communications so that the near-field loss is minimized. Since the reader antenna faces the human body, with a similar approach a slot antenna is used here. The slot size is optimized through ANSYS HFSS using a numerical phantom representing fat tissue. For the optimum operation at 1.5 GHz, the final value of the slot length, the slot width, the feed line offset from the center, the feed line length and the feed line width are found to be 5.1, 0.2, 1.53, 2.25 and 0.19 cm respectively. The prototyped antenna can be seen in Fig. 1(a).

III. The Biodegradation Process

The main objective here is to detect post-surgical infection. It is known that the acidity of a tissue increases when the tissue is infected via bacterial activity which causes releasing of the permeable organic acid such as butyric, propionic and succinic acids [13]. Acidity also is among the determinants of degradation speed. Hence the speed of degradation can be related to infection.

In order to further analyze the degradation process, the implant Mg antenna is observed under different acidic conditions. Hydrochloric acid and deionized water are used to prepare three solutions with pH of 7, 5 and 3. Three identical antennas are located inside these solutions and the biodegradation process is observed. As expected [14], the degradation is indeed faster under more acidic conditions. More importantly, the bridged structure has degraded into the aimed final form. As seen in Fig. 2 (c), the antenna in acidic solutions broke in three distinct parts faster than the antenna in neutral solution. Note that the antennas are held in the solutions for 14 days before the most acidic solution degraded the antenna into three pieces.

IV. Simulation Set-Up

Building onto the findings presented in Section III, the speed of degradation is the key information that we need to extract in this process. To demonstrate that the degradation can be tracked outside the human body, the reflection coefficient of the reader antenna will be observed with the initial and the final form of the implant antenna.

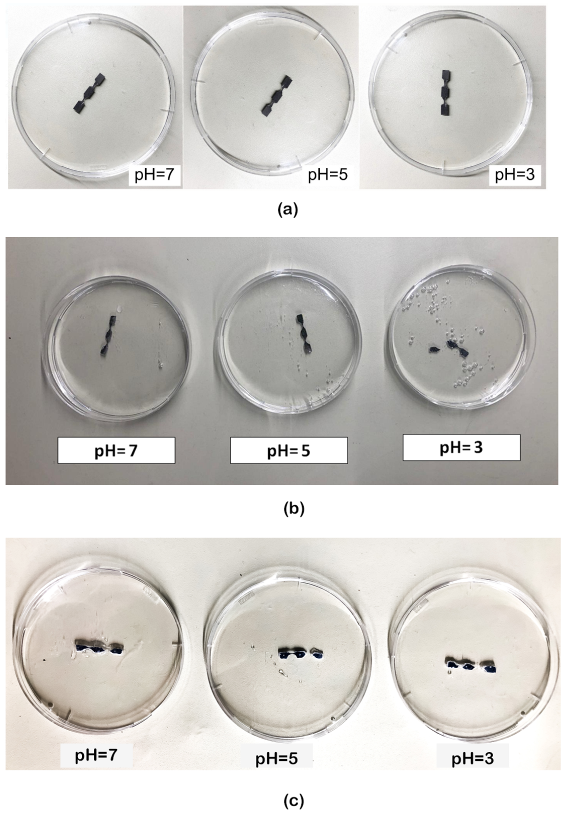

Fig. 2: (a) The first day of antennas located in solutions, (b) The first break off occurs in the most acidic solution (c) The last day of sensors located in solutions

The overall measurement set-up is modelled using ANSYS HFSS as seen in Fig. 1(c). The implant antenna is located inside a petri dish sized cylindrical box which represents the cow's fat tissue in the experiment. The depth of the implant inside the fat tissue is changed between 0.25 cm and 1 cm with 0.25 cm steps to demonstrate the limits of the efficacy of the proposed technique. Note that the reader antenna is aligned with the implant antenna for all cases while the depth of the implant is changed. For simulation purposes, the fat tissue is assumed to have a dielectric constant of $5.2853\ F/m$ while the conductivity value is taken to be $0.10235\ S/m$.

V. Measurement Set-Up

The measurement set-up consists of the initial and the final form of the implant as seen in Fig. 3 and the wearable antenna separated with cow's fat. The reflection coefficient of the reader antenna is measured for different thicknesses of fat tissue. The minced cow's fat used to represent the electromagnetic properties of fat tissue is compressed to create petri dish sized cylinders with different implant depths as in Fig. 4.

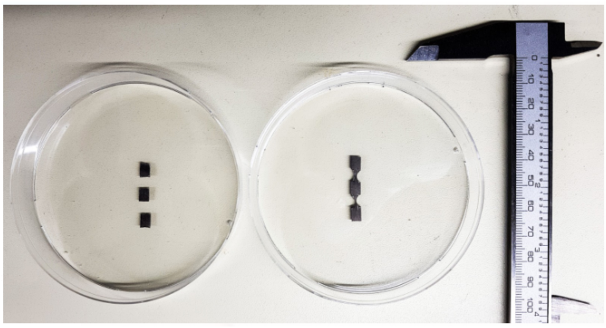

Fig. 3: The first and the final stages of the implant antenna

Fig. 4: Minced cow's fat shaped into 90 mm diameter petri dish with different thicknesses: 1.00 cm, 0.75 cm, 0.50 cm, 0.25 cm from left to right

VI. Result

As explained earlier, the aim is to track the speed of degradation which can be related to infection. The reflected signal read from the reader antenna is used to predict the wanted information. The simulated and measured results are plotted in Fig. 5 for 4 different implant depths. In Fig. 5a where the tissue thickness is 0.25 cm, the shift in resonant frequency during the biodegradation process is 137 MHz in simulation and the shift in resonant frequency is 169 MHz in experimental setup. In Fig. 5b once the shift in resonant frequency is 77 MHz for simulation, the resonant frequency shifts 38 MHz during the experiment. In Fig. 5c the shift in resonant frequency is 60 MHz and 32 MHz for simulation and experiment respectively. The same situation is also for 45 and 14 MHz in Fig. 5d. Although the degradation can be detected up to 1 cm with measurements as predicted by the simulations, the prediction by the simulations gets worse as the implant depth increases. That is due to the fact that the fat tissue defined in the simulations is an isotropic uniform medium which is not the same as the real measurement set-up. This discrepancy becomes more visible as the thickness increases.

VII. Conclusion

A biodegradable implant antenna is designed to degrade in a controllable fashion. The degradation is conducted under different acidic conditions and the initial and final forms of the implant before and after the degradation process has been observed. The speed of the degradation is mapped to acidity in order to relate it to infection. Finally, the reflection coefficient of the reader antenna is shown to change as it is shone on to the initial and final forms of the implant antenna. The shift in resonant frequency is proven to be trackable up to 1 cm of implant depth inside fat tissue.

Acknowledgment

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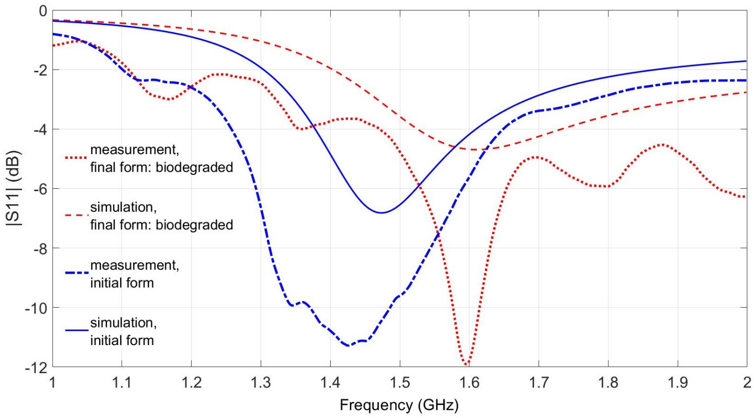
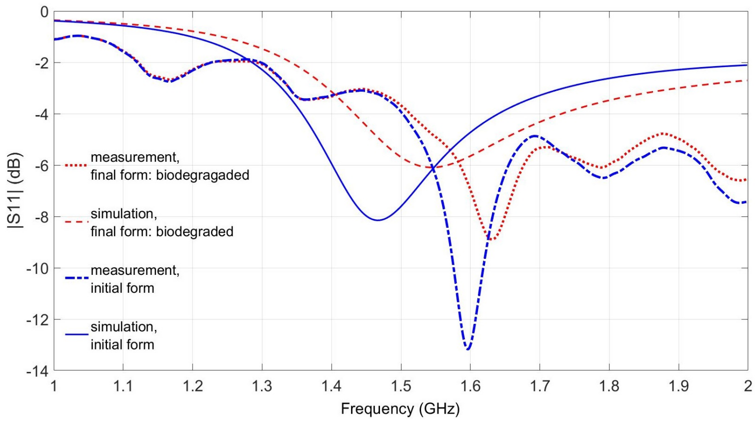
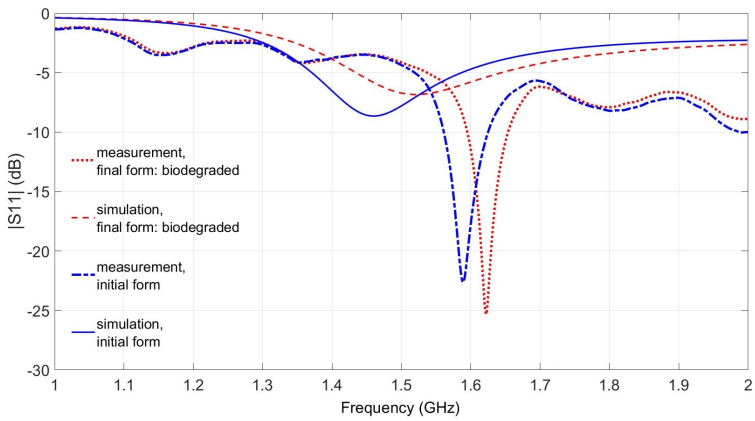


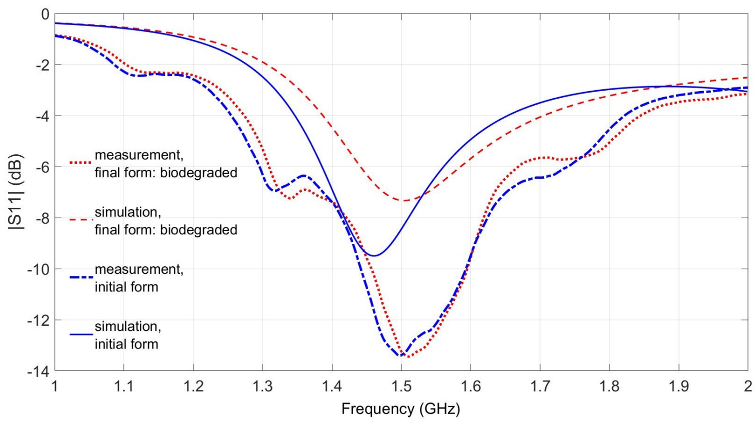
(a) Implant depth of 0.25 cm



(b) Implant depth of 0.5 cm



(c) Implant depth of 0.75 cm



(d) Implant depth of 1 cm

Fig. 5: Measured and simulated reflection coefficient of the reader antenna as for the initial and final forms of the implant antenna