# Implant Antenna Reconfigured by Engineered Skeletal Muscle Tissue

Cagla Karabulut*, Ahmet Bilir*, Macit Emre Lacin*, Sema Dumanli*
*Electrical and Electronics Engineering, Bogazici University, Istanbul, Turkey
*cagla.karabulut@boun.edu.tr*

***Abstract*—Synthetic biology opens new research opportunities for a brand-new generation of sensing systems and devices. With advancements in this area, it is now possible to realize living devices that can undertake sensing at a molecular level. However, the utilization of these devices inside the human body has never been achieved. Moreover, the wireless transfer of the data that the living devices collect remains an open challenge. This work presents a novel bio-hybrid implant that can achieve molecular sensing and wireless communication. The implant consists of an in-body antenna and skeletal muscle tissue. The skeletal tissue is engineered to contract in the presence of molecules of interest. The implant antenna is designed around the engineered tissue to be mechanically deformed as the contraction takes place. This deformation changes the resonance behavior of the implant antenna, which is detected by an on-body antenna. The proposed sensing system is novel in integrating engineered living cells with an implant antenna for wireless real-time monitoring of chemicals in-vivo as well as a novel in the utilization of skeletal muscle tissue for bio-sensing.**

***Index Terms*—in-body sensing, bio-sensors, engineered living cells, skeletal muscle tissue.**

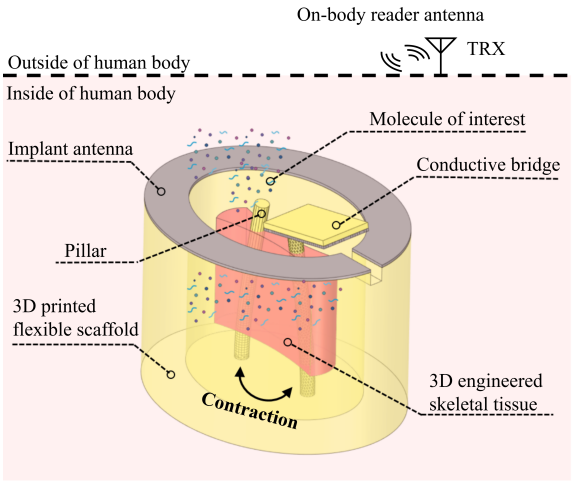


Fig. 1. Sensing and implant antenna reconfiguration mechanisms.

## I. Introduction

Wireless implant devices that collect information about physiological functions have been attracting interest in the medical field in recent years. Conventionally, implants conduct sensing using electro-mechanical and chemical sensors and send the collected data wirelessly to an off-body device using electromagnetic or acoustic waves, which include separate communication, processing, sensing units as well as a power supply. There are various drawbacks related to existing technology such as implanting alien components to the human body and using batteries that limit the lifetime of the implant [1][2]. The bio-hybrid implant proposed here is expected to replace the conventional implants in the future where in-body sensing and processing tasks are pushed to living cells eliminating batteries. Hence, this new technique will enable continuous sensing at a molecular level [3][4].

The recent advances in synthetic biology made it possible to manipulate and engineer the genetic circuitry of cells, thus paving the way for new transgenic biosensors specific for desired molecular targets [5]. So far genetically engineered living cells that have been employed as biosensors are capable of detecting chemicals in the medium are limited to bacteria [6]. The most common outputs of such biosensors have either been of optical or electrochemical origin [7][8]. Here, we propose to use the skeletal muscle tissue with its mechanical contractile response as an output.

In the literature, the skeletal muscle tissue has previously been used as micro-robots and micro-pumps to propel the robot forward, pick objects or pump fluid [9]-[13]. This study is a first in its usage for bio-sensing purposes.

The proposed sensing and communication platform is a bio-hybrid device consisting of an in-body passive implant antenna (printed on a flexible bio-compatible material) and engineered muscle tissue. The tissue is engineered to be sensitive to the molecule of interest and the presence of this molecule triggers a contraction within the tissue. This mechanical contraction and the relaxation of the tissue are used to reconfigure the resonance frequency of the passive implant antenna.

The skeletal tissue is grown and accommodated inside the 3D printed flexible scaffold that consists of an ellipse micro-well studded with two thin pillars, one of which carries a conductive bridge. In the presence of the molecule of interest, the tissue starts contracting and deflecting the pillars. During the deflection, short circuit connection between the implant antenna and the conductive bridge breaks hence the resonance of the implant antenna is detuned. On-body reader antenna is located outside the human body to monitor these changes in the resonance behavior. The sensing and the reconfiguration mechanisms of the system are depicted in Fig1.

This proposal presents the initial studies as the proof of concept for this novel sensing and communication platform. The rest of the paper is organized as follows, Section II

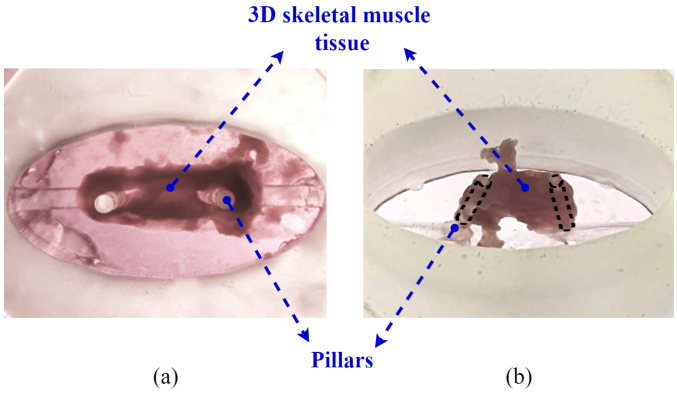


Fig. 2. (a) Top view (b) Trimetric view of the skeletal muscle tissue that is grown in 3D printed flexible scaffold.

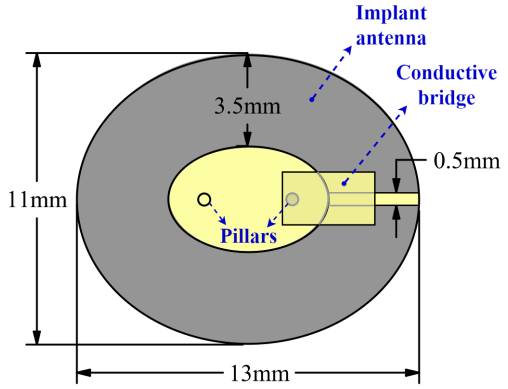


Fig. 3. Dimensions of the implant antenna.

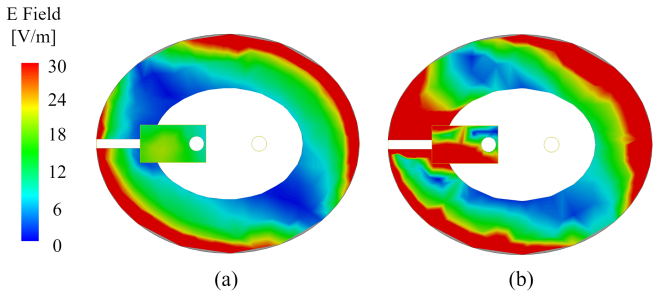


Fig. 4. E-field distribution (a) for the relaxed (b) contracted muscle cases.

describes the skeletal muscle tissue generation protocol and the reconfiguration of the implant antenna. Section III presents the on-body reader antenna and the numerical model. Section IV discusses the electromagnetic simulation results for wireless tracking and Section V concludes the paper.

## II. Bio-Hybrid Implant Design

### A. Engineered Skeletal Muscle Tissue

The cell line proposed to culture and grow the engineered skeletal muscle tissue is the immortalized mouse myoblast cell line of, C2C12. This cell line offers several advantages over primary cells and induced pluripotent stem cells (iPSCs), including eliminating the need to sacrifice animals and reduced costs of maintaining and differentiation. The myoblast differentiation and 3D skeletal muscle tissue generation protocol was adapted from [14]. The myoblast cells are maintained at 37°C in a saturated humidity atmosphere containing 5% $CO_2$ in growth medium (GM) which consists of 20% fetal bovine serum, 100 IU/mL penicillin and, 100ug/mL Streptomycin and 1% L-glutamine in Dulbecco's Modified Eagle Medium (DMEM). Once the cells reach 60-70% confluency inside their expansion flasks, they are harvested with 0.25% Trypsin 0.01% EDTA solution.

Harvested cells are then resuspended in collagen-matrigel mixture composed of 65% collagen (4mg/mL), 20% matrigel (9.5mg/mL), 10% 10X PBS and 5% GM. The prepared cell-gell mixture is loaded into the micro-well inside the 3D-printed flexible scaffold. The scaffold is designed to support the 3D growth of the skeletal muscle tissue and facilitate the implant antenna which will be discussed in the following section. After 1-2hr incubation, the gel within the micro-well is overlaid with warm GM and left here for 2 days. On day-2, GM is replaced by a low-serum differentiation medium composed of DMEM supplemented with 2% horse serum, 100 IU/mL penicillin and 100ug/mL and 1% L-glutamine. After 12-14 days in differentiation medium the skeletal muscle tissue is matured. Generated sample tissues are shown in Fig.2.

### B. Implant Antenna

A passive loop antenna is designed on the top surface of the 3D printed flexible scaffold with a thin film of conductive ink. One of the pillars has a conductive bridge extending toward the loop antenna as seen in Fig.3, which shorts and opens circuits the loop antenna. When the molecule of interest is not present in the medium, the tissue is relaxed and the pillars stand upright. In this case, the loop antenna operates as intended. When the molecule of interest arrives, the engineered muscle tissue contracts and pulls the conductive bridge by deforming the pillars. In this case, the loop antenna is detuned, which is tracked by the on-body antenna.

In the relaxed case, the implant antenna is a resonant loop with a circumference of 37 mm, the guided wavelength at the operating frequency of 903 MHz medical ISM band. The guided wavelength is calculated with (1), where c is the speed of light and $\varepsilon_{eff}$ is the effective permittivity. The effective permittivity calculation is not straightforward as the loop is exposed to multiple mediums. For this design, it is numerically calculated to be 78.37.

$$\lambda = \frac{c}{f\sqrt{\varepsilon_{eff}}} \tag{1}$$

Electric field distribution on the implant antenna is shown in Fig.4 for relaxed and contracted cases. The detuning is visible in the field plots.

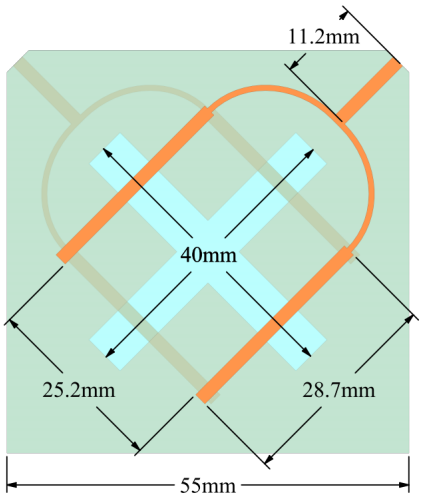


Fig. 5. On-body antenna geometry.

## III. On-Body Antenna Design and Numerical Model of the System

The wireless tracking of the implant antenna resonance is conducted with an on-body antenna. The on-body antenna is a dual-feed crossed-slot antenna as reported in [15]. The slot is fed by two microstrip lines that are located on the opposite faces of the antenna as seen in Fig.5. This antenna is preferred because the coupling between its ports is low while the phase center for each radiation mode is identical. S parameters of the on-body antenna are shown in Fig.6.

The transmission coefficient between the ports of the antenna is used to identify the change that occurs in the resonance of the implant antenna. The system is modeled and analyzed in ANSYS HFSS. The bio-hybrid implant is placed inside a 150 mm $\times$ 150 mm $\times$ 70 mm DMEM serum block at a depth of 30 mm. The electrical properties of DMEM serum are shown in Fig.7. Speag's DAKS 3.5 dielectric measurement kit was used to measure these properties. The on-body reader antenna is located 1 mm above the serum block as seen in Fig.8.

## IV. Results

The change in the transmission coefficient between the ports of the on-body antenna in response to the implant antenna's detuning is shown in Fig 9. Around 8 dB difference is observed. The resonance of the loop is also visible in the phase response of the transmission coefficient as seen Fig 10. Sensitivity of tracking to misalignment between the on-body reader antenna and the bio-hybrid implant is also analyzed. It has been shown that up to 10 mm of misalignment is acceptable as shown in Fig.11.

## V. Conclusions

This work presented a novel sensing and communication system that is designed to operate in the human body and conduct sensing at a molecular level. The key element of the system is the bio-hybrid implant where the skeletal muscle

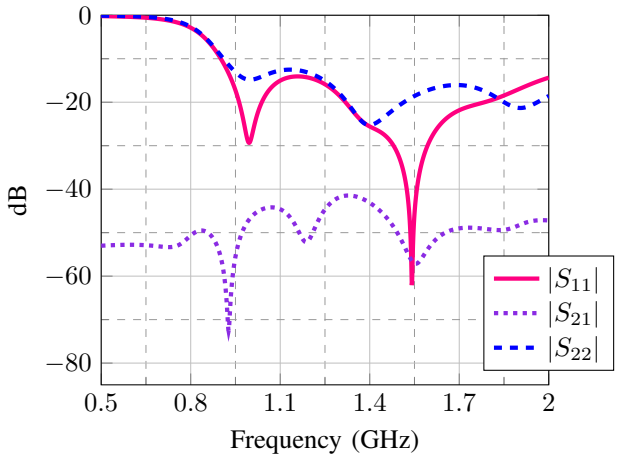


Fig. 6. S parameters of the on-body antenna.

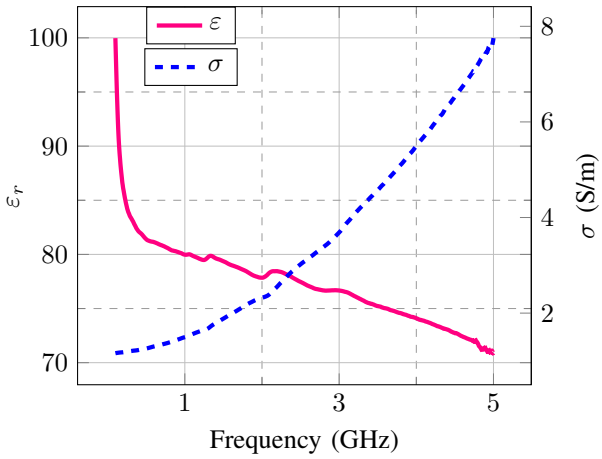


Fig. 7. Electric properties of DMEM serum.

tissue is triggered with the molecule of interest which reconfigures a passive implant antenna.

We have shown that if the engineered muscle can realize the reconfiguration upon trigger, the reader antenna can track this reconfiguration up to an implant depth of 30 mm. We have

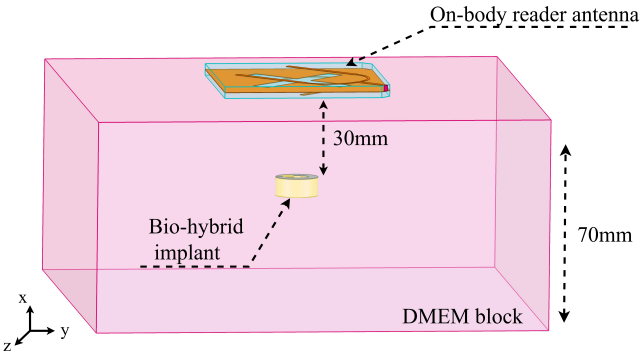


Fig. 8. Simulation setup for the wireless tracking system.

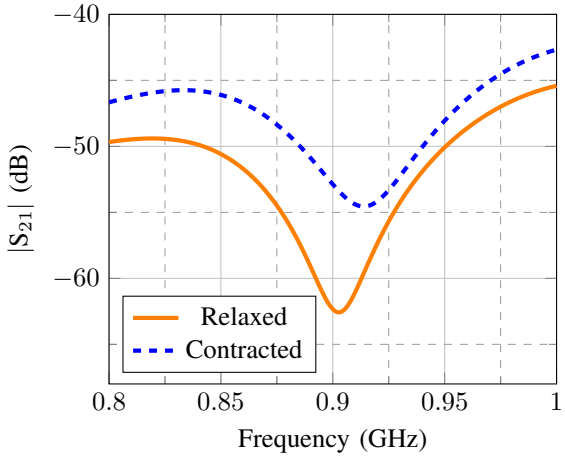


Fig. 9. The magnitude of transmission coefficient as the reconfiguration takes place.

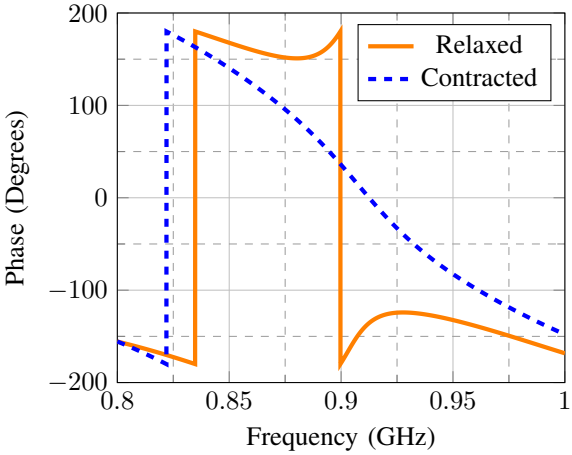


Fig. 10. The phase of the transmission coefficient as the reconfiguration takes place.

also presented the 3D skeletal muscle tissue growth procedure where we observed contraction with the acetylcholine which is a natural trigger agent.

In the future, we are going to print the implant antenna on the 3D flexible scaffold where the skeletal muscle tissue is grown. The reconfiguration upon trigger will be realized. Finally, the arrival of the molecule of interest will be wirelessly tracked by the on-body reader antenna. This is going to be a proof of concept for our novel sensing and communication platform which can be engineered for any molecule of interest through the tools of synthetic biology.

## ACKNOWLEDGMENT

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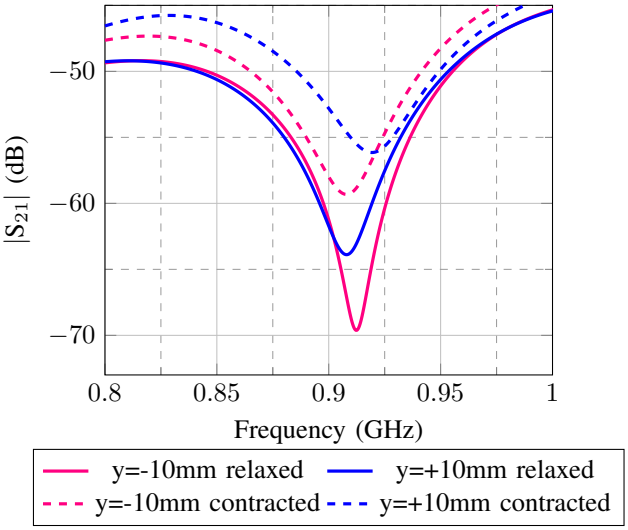


Fig. 11. Misalignment analysis: the change in the transmission coefficient as the reconfiguration takes place when the reader antenna and the implant are misaligned.

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