Characterization of Passive Wireless Electrocardiogram Acquisition in Adult Zebrafish

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***Abstract*—Zebrafish have been demonstrated as an ideal vertebrate model system for a wide range of bio-studies. Along with conventional approaches, monitoring and analysis of zebrafish electrocardiogram (ECG) have been utilized for cardio-physiological screening and elucidation. However, existing approaches involving the use of anesthesia failed to provide intrinsic ECG signals. In this work, we propose and characterize wireless power transfer (WPT) via inductive coupling to power an ECG zebrafish implant and a backscattering mechanism for data communication. The inductive link was realized using the solenoid configuration to resolve misalignment issues. Power transfer efficiency (PTE) was characterized and test data were successfully obtained in different practical scenario. Therefore, we speculate our approach would pave the way for continuous ECG monitoring of freely-swimming zebrafish without disrupting their normal activities, supporting various biological investigations.**

***Index Terms*— Zebrafish; Electrocardiogram; Inductive Coupling; Wireless Power Transfer; Backscattering.**

I. Introduction

THE zebrafish (*Dario rerio*) model has played an important role in various biological studies, due to the fact that zebrafish hearts can fully regenerate after ventricular injuries.

In the last several years, our laboratory and others have been demonstrating the use of electrocardiogram (ECG) to study zebrafish hearts in long term and continuously to observe healing as a process rather than in discrete points of time as with a heart slide. However many methods of ECG extraction involve processes sedating and restraining the fish and thus affecting the ECG.

Our group has been pioneering in the development of wireless ECG systems for real-time ECG monitoring in small animal models, such as zebrafish and neonatal mice [1-4]. Our system consists of transmitter and receiver units, with resonating transmitter solenoid (TX) and receiver solenoid (RX), respectively. ECG data communication were realized via backscattering using the same inductive link. We characterized the entire system in various practical settings and used a simulated ECG signal to validate the communication link. The overall system with components and the conceptual design are illustrated in **Fig. 1**.

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II. Design And Implementation

The TX is 72 mm long with a diameter of *Φ*53 mm. It was made by winding AWG18 magnet wire around the cylindrical customized fish housing, providing a 58-turn 100-µH inductor [1]. The RX is a *Φ*3 mm × 20 mm solenoid made of 74 turns of AWG31 magnet wire, resulting in an inductance of 1.5 µH.

Our TX and RX coils were tuned to resonate at 1 MHz. We drove our Tx with a Class E amplifier and implemented a full wave rectifier to obtain DC power at the RX. The ECG output would be feedback to the RX for backscattering communication.

III. Experiments, Results and Discussion

A. PTE Characterization

We used a Vector Network Analyzer (*8753ES*, *Agilent Technologies, Santa Clara, CA*) to measure S_{21} at the resonance frequency (1 MHz) to characterize PTE. We measured at various misalignment angles between the TX and RX distributed symmetrically between −90 and 90 degrees.

Knowing our implant would need ~200 μW of power to operate, and knowing our max power output to be limited to 1W the S_{21} value for our system (in dB) would need to be above

$$S_{21} > 10\log\left(\frac{200\ \mu W}{1\ W}\right) = -37\ dB$$

Therefore, our system should be able to achieve $S_{21}>-37$ dB for every misalignment angle between the transmitter and receiver in order for the implant to receive adequate power.

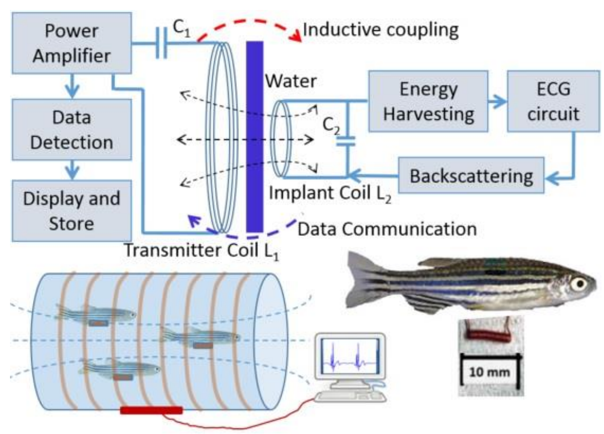

Fig. 1. Conceptual design of the entire system.

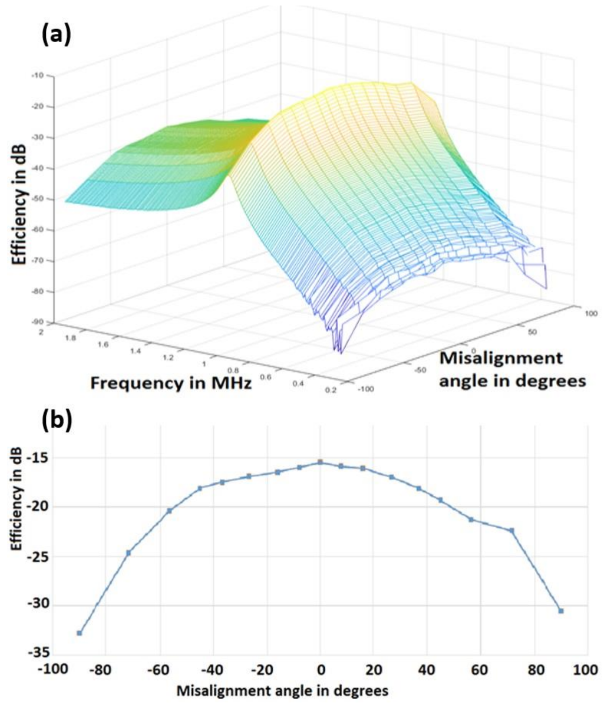

Fig. 2. a) 3D plot showing PTE at various misalignment angles and frequencies. **b)** PTE at 1 MHz at misalignment angles.

In **Fig. 2** we can see that at our resonance frequency of 1 MHz the efficiency is always above -37 dB.

B. Backscattering Communication

We characterized the backscattering communication in both air and water environments for ECG data transfer via the inductive link at various degrees of misalignment angles between the TX and RX.

Inductive coupling and resonance was established between our TX and RX coils by driving the TX coil at the previously established frequency of 1 MHz. A simulated ECG signal was injected back through the Full Wave Rectifier and modulate onto the resonating AC voltage of the RX antenna causing an identical modulation on the voltage across the TX antenna.

We found that for both air and aquatic environments adequate signal transmission was achieved only at misalignment angles between 0 and 45 degrees, which through symmetry represents 50% of all misalignment angles.

IV. Conclusions

Our setup is capable of powering our implant for 100% of misalignment angles, but is only capable of establishing communication for 50% of misalignment angles. As Zebrafish are very mobile it is not likely that they would stay at any particular misalignment angle for too long and therefore the system may be practical. Additional possibilities include implementing an ADC and DAC setup to transmit digital rather than analog signals to improve SNR and increase transmittable misalignment angles >50%. Another possibility would be improving the TX and RX setup to reduce the percentage of useless misalignment angles.

V. Additional comments

This project resulted in a paper published and presented at IMBioC 2018. This was a part of the the MTT-S conference. I very much enjoyed both presenting my own work and watching other presentations, it felt like I was in a true academic conversation. By allowing me to work on a system of wireless power transfer the MTT-S scholarship has had me read about RF technology and techniques. Although my own research involved signals far below the RF level I have become very fascinated with RF engineering. I want to move on to an industry setting and eventually pursue a Masters possibly in RF Engineering or Antenna Engineering.

References

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