Ultrasound for Wireless Energy Transfer and Communication for Implanted Medical Devices

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Outline:

1. Introduction
2. Description of the System
3. In-Vitro Platform
4. Measurements
5. Conclusion
1. Introduction
   1.1 Aspects of Implanted Medical Devices
   1.2 ULTRAsponder Goals

2. Description of the System

3. In-Vitro Platform

4. Measurements

5. Conclusion
1.1 IMDs Aspects: What is an Implanted Medical Device?

- Health care solution.
- Partially/totally introduced, surgically/medically, into the human body.
- Remain in the body after the procedure for many years.
- Treat/monitor physiological condition, such as temperature, pressure, or fluid flow.
- Different kinds of IMDs: pacemakers, implantable cardiac defibrillator (ICD), drug delivery systems and neurostimulators.
1.2 ULTRAsponder Goals

- Continuous monitoring system to help patients lead a normal and healthy life.
- Wireless communication would help monitor patients during normal activity.

*source: www.ultrasponder.org*
Outline:

1. Introduction

2. Description of the System
   2.1 Requirements
   2.2 Why Ultrasound?
   2.3 Rechargeable battery
   2.4 Modulator

3. In-Vitro Platform

4. Measurements

5. Conclusion
2.1 System Requirements

IMD deeply and totally introduced into the human body:

- Type of AC Source
- Implant Size
- Long Term Implant
- Long Autonomy
- Low-Power Circuitry (Modulator)
2.2 Why Ultrasound?

• To overcome electromagnetic attenuation limit in water:

<table>
<thead>
<tr>
<th>Type</th>
<th>Attenuation @ 10-20 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACOUSTIC</td>
<td>8-16 dB (@ 1 MHz)[1]</td>
</tr>
<tr>
<td>RF</td>
<td>60-90 dB (@ 2.45 GHz)[2]</td>
</tr>
<tr>
<td>MAGNETIC</td>
<td>50 dB (@ 1 MHz)[2]</td>
</tr>
</tbody>
</table>

• Inherently avoid interference with other medical systems (magnetic resonance imaging, pacemaker, …).

2.3 Rechargeable Battery

- Battery Energy Density (Wh/liter)
- Long Term Implant (longevity)
- Implant Size
- Battery Size and Shape
- Long Autonomy

Rechargeable Battery (# recharge cycles)

*10 mm

40 mm


Source:
www.infinitepowersolutions.com

170 µm thick
25.4 mm x 12.7 mm

# batteries (primary + secondary)

1 2 3 4

Source:
2.4 Modulation Technique

- Backscattering modulation also known as load or impedance modulation.
- Low power $\sim \mu W^{[3]}$.
- Concept is well-known in RF:
  1) A continuous or pulsed wave is transmitted from a control unit towards a transponder.
  2) The transponder reflects the wave back by changing its load impedance.
  3) The received echo at the control unit is demodulated.

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3. In-Vitro Platform
   3.1 In-Vitro Before In-Vivo
   3.2 Overview
   3.3 Requirements
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3.1 In-Vitro Before In-Vivo

- Primary analysis of side effects.
- Helps in the various design stages of the IMD.
- User requirements (medical doctor, patient) and system specifications are defined.
3.2 Platform Overview[4]

- Ultrasound energy harvesting (module A)
- Ultrasound wireless communication (module B)

3.3 Platform Requirements

Anechoicity

Dimension (125 liter)

Flexibility of motion

- $x$, $y$ and $z$ displacement
- $x$ rotation

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   4.1 Energy Harvesting
   4.2 Wireless Communication
5. Conclusion
4.1 Energy Harvesting: Circuit (1/5)

- \( V_{AV} \) is the output signal yielded by the piston transducer (Pz26);
- \( V_{REC} \) is the output of the doubler;
- Voltage at node A is set to 4.1 V by the Zener diode;
- Two circuits to protect the battery against no input supply (\( V_{AV} < 4.7 \) V) and to avoid excessive discharge.
4.1 Energy Harvesting: Circuit (2/5)

- No matching network at the interface between the doubler and the transducer;
- \( L_p \) (ferrite coil) is used to tune out imaginary parts, both transducer and input recharging circuits at 1 MHz;
- Lithium Polymer Ion (LIPON) Battery \( \rightarrow \) Capacity 300 \( \mu \)Ah (manufacturer Infinite Power Solutions).
4.1 Energy Harvesting: Transducers (3/5)

Single element focused transducer:
Central frequency = 1.1 MHz
Diameter = 50 mm
Focal distance = 50 mm
Thickness = 2 mm
Piezo material = Ferroperm Pz28 [6]


Single element piston transducer:
Central frequency 1.05 MHz
Diameter = 6.35 mm
Thickness = 2 mm
Piezo material = Ferroperm Pz26 [6]
4.1 Energy Harvesting: Charge (4/5)

- Charging voltage 4.1 V.
- End of charge detected at 4.1 V battery voltage.
4.1 Energy Harvesting: Discharge (5/5)

- Discharging under **constant load**.
- Cut-off battery voltage at 2.5 V.

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Discharge time ~ 22 hours
Discharge current ~ 16µA

Discharge time ~ 20 minutes
Discharge current ~ 730µA
Different pair of transducers.

An array of elements is used for the control unit (READER), one element is used as transmitter and a second element is used as receiver.

The transponder (TAG) modulates the incident wave (back-scattering modulation).

On-Off Keying (OOK) modulation.

Data rate 20 Kbps.

The demodulator is present on the READER side, two amplifiers are used (gain of 20 dB per amplifier) to raise the amplitude of the received wave.
4.2 Wireless Communication: Transducers (2/4)

Single element piston transducer:
- Central frequency = 1 MHz
- Diameter = 13 mm
- Manufacturer IMASONIC

Linear phase array – 64 elements:
- Central frequency = 1 MHz
- Manufacturer IMASONIC

20 cm
4.2 Wireless Communication: Modulator (3/4)

data signal yielded by a $\mu$-controller that controls the switches.

- $V_{\text{ctrl}} = 1$, switch S1 & S2 in position A: The transducer is made stiffer and reflects back the incoming signal so a **high state is transmitted** to the CU receiver.

- $V_{\text{ctrl}} = 0$, switch S1 & S2 in position B: The transducer is allowed to vibrate so that the incoming signal is absorbed, thus a **low state is transmitted** to the CU receiver.
4.2 Wireless Communication: Results (4/4)
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Conclusion

- Platform for in-vitro testing of IMDs.
- Energy Harvesting via Ultrasound.
- Wireless Communication via Ultrasound.
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