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

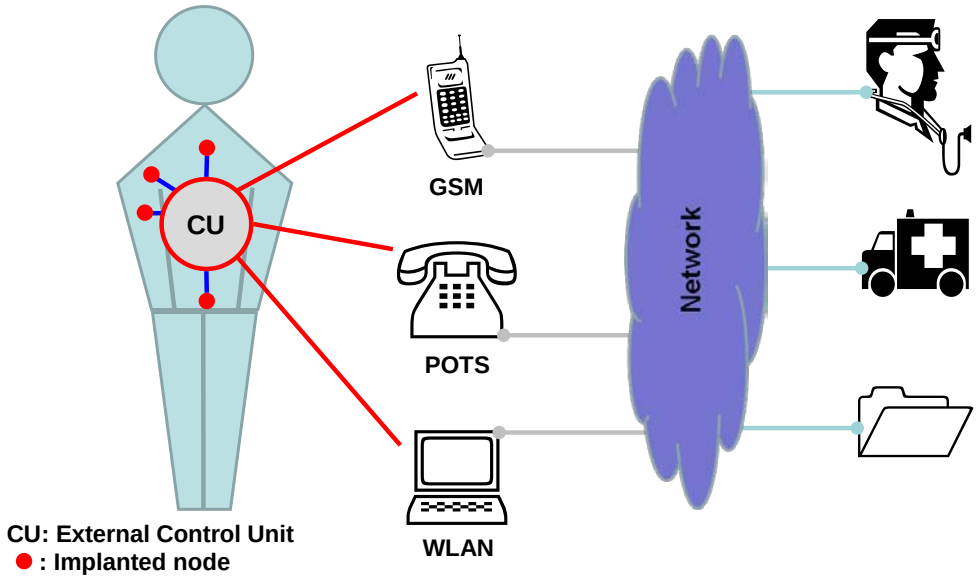
Outline:

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
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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:

	Attenuation @ 10-20 cm
ACOUSTIC	**8-16 dB (@ 1 MHz)[1]**
RF	**60-90 dB (@ 2.45 GHz)[2]**
MAGNETIC	**50 dB (@ 1 MHz)[2]**

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

[1] Francis A. Duck., Physical Properties of Tissue, 1990.

[2] Tomohiro Yamada et al., JJAP, 44(7A), 2005.

2.3 Rechargeable Battery

Long Autonomy

Battery Energy Density (Wh/liter)

Rechargeable Battery (# recharge cycles)

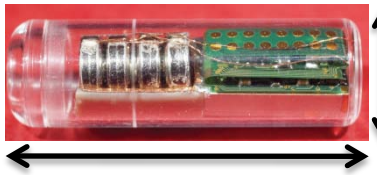
Long Term Implant (longevity)

 # batteries (primary + secondary)

1 2 3 4

Battery Size and Shape

Implant Size



Source: Leandre Bolomey, Thèse EPFL, no 4692 (2010)

170 µm thick
25.4 mm x 12.7 mm

Source: www.infinitepowersolutions.com

2.4 Modulation Technique

- Backscattering modulation also known as load or impedance modulation.
- Low power ~ µW[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.

[3] Giovanni de Vita et al., JM, 37(7), 2006.

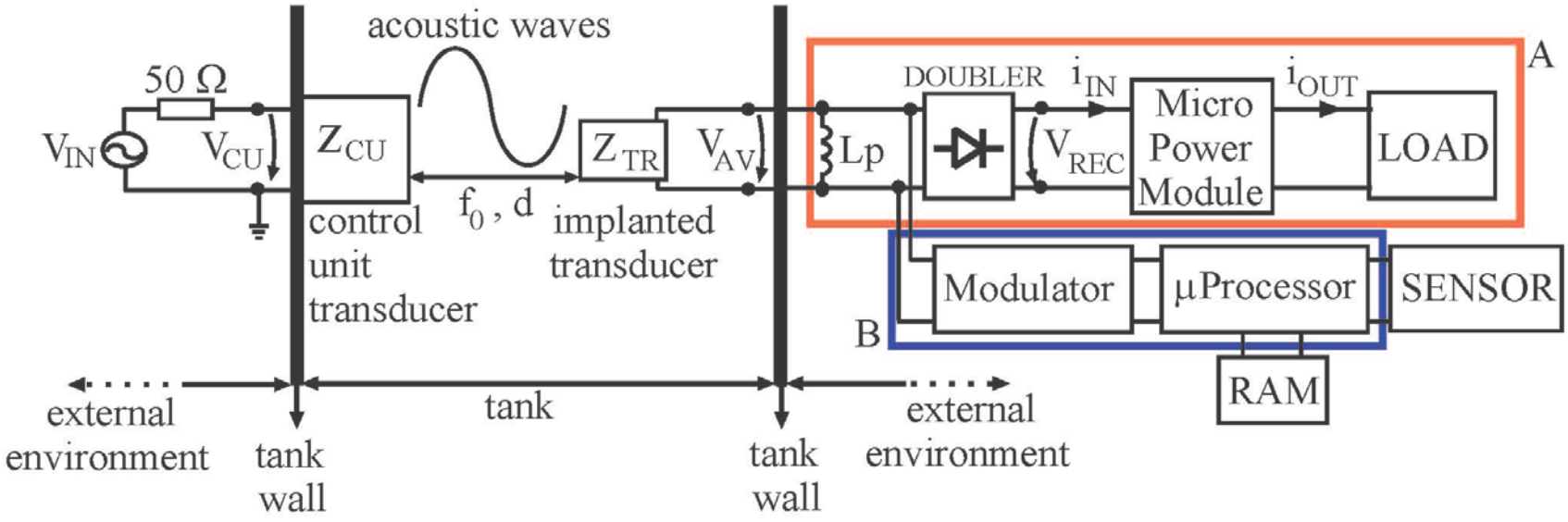
Outline:

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**)



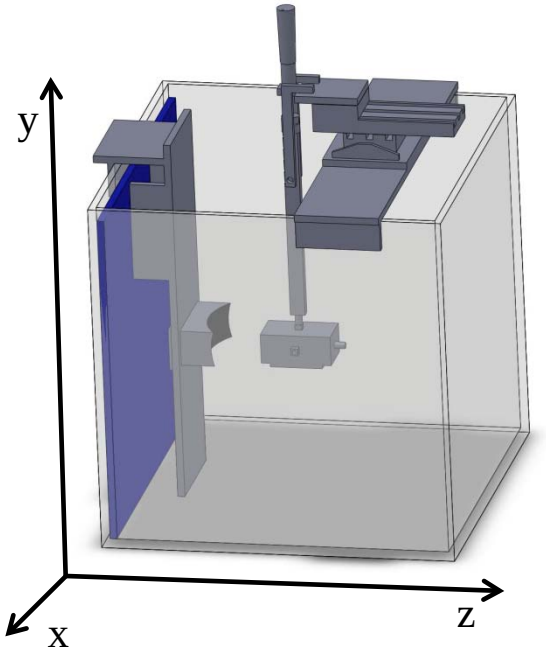
[4] Francesco Mazzilli et al., EMBC, 2010

3.3 Platform Requirements

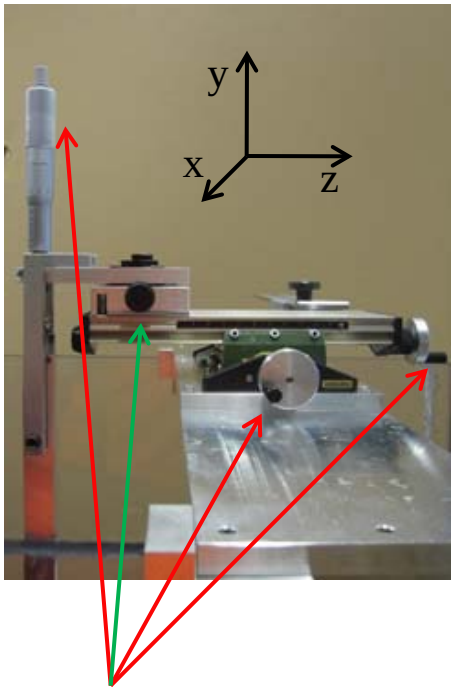
Anechoicity

APTFLEX 28[5]

Dimension (125 liter)



Flexibility of motion



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

[5] http://www.acoustics.co.uk/products/aptflex-28

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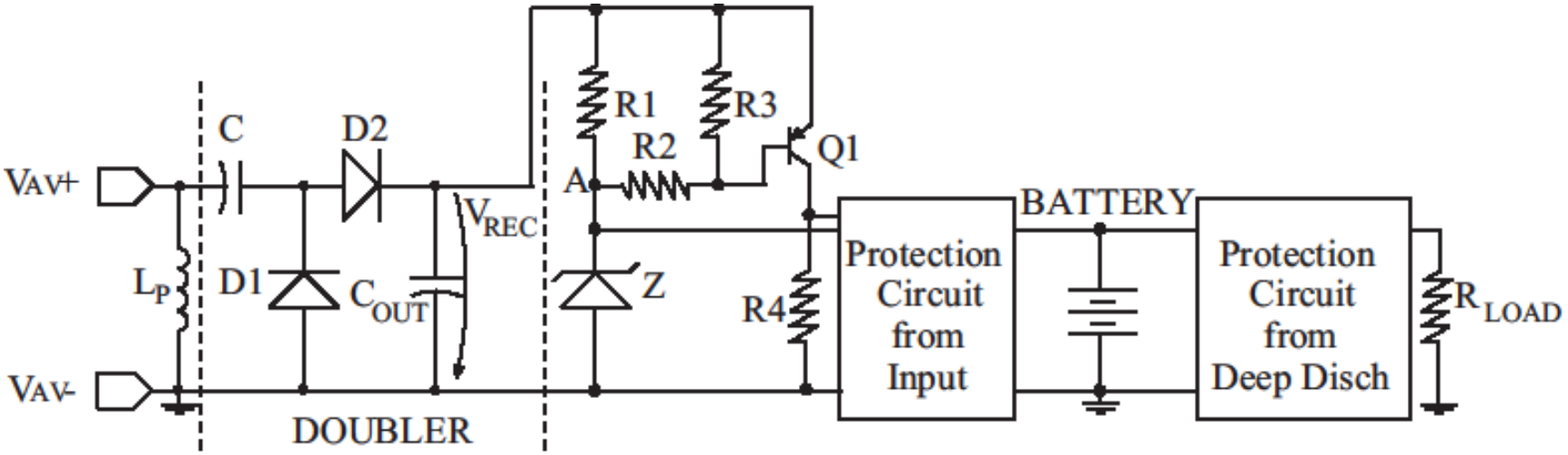
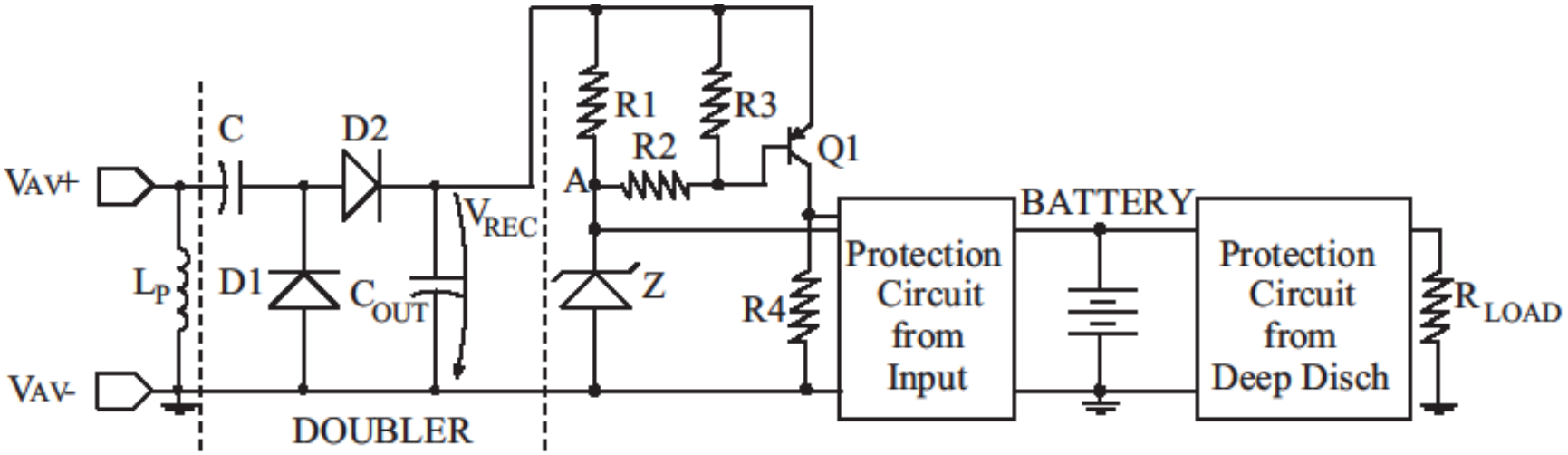
4.1 Energy Harvesting: Circuit (1/5)

- 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 → Capacity 300 µAh (manufacturer Infinite Power Solutions).



4.1 Energy Harvesting: Transducers (3/5)

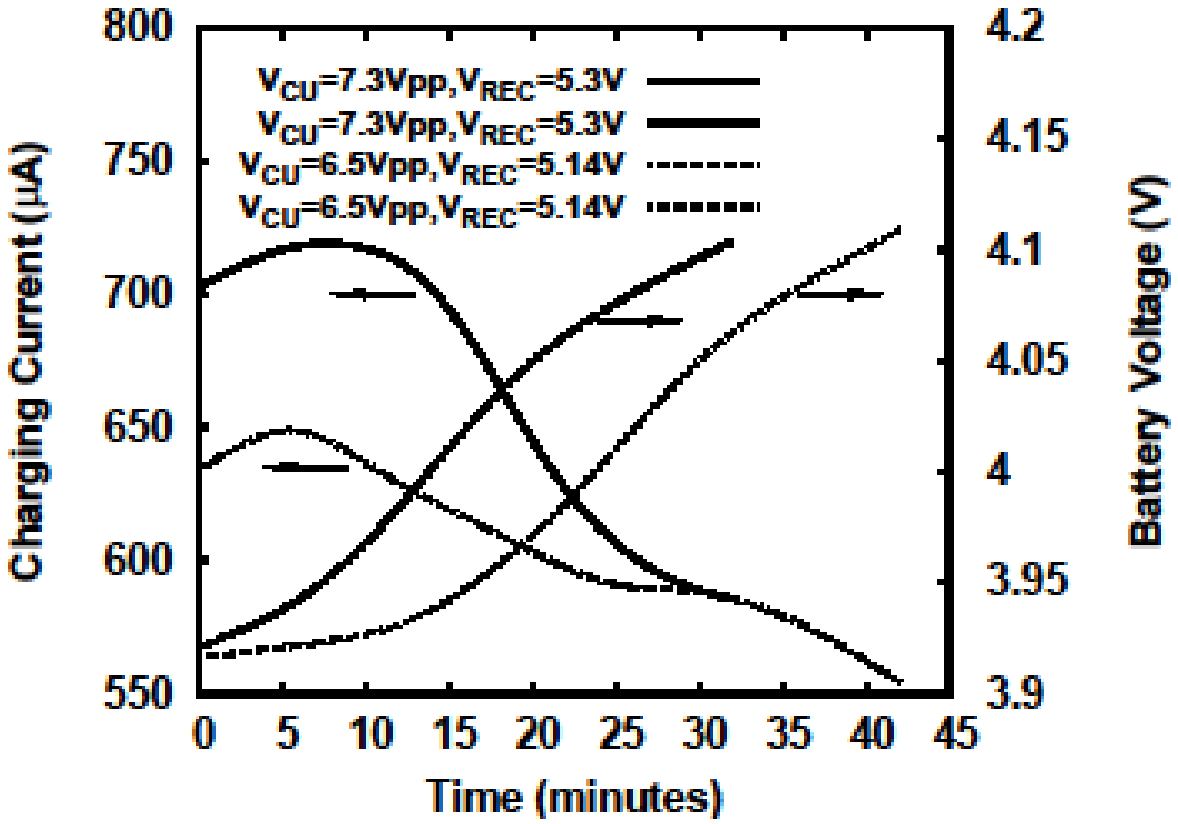
Single element focused transducer:
Central frequency = 1.1 MHz
Diameter = 50 mm
Focal distance = 50 mm
Thickness = 2 mm
Piezo material = Ferroperm Pz28 [6]

[6] Ferroperm Piezoceramics A/S

Single element piston transducer:
Central frequency 1.05 MHz
Diameter = 6.35 mm
Thickness = 2 mm
Piezo material = Ferroperm Pz26 [6]

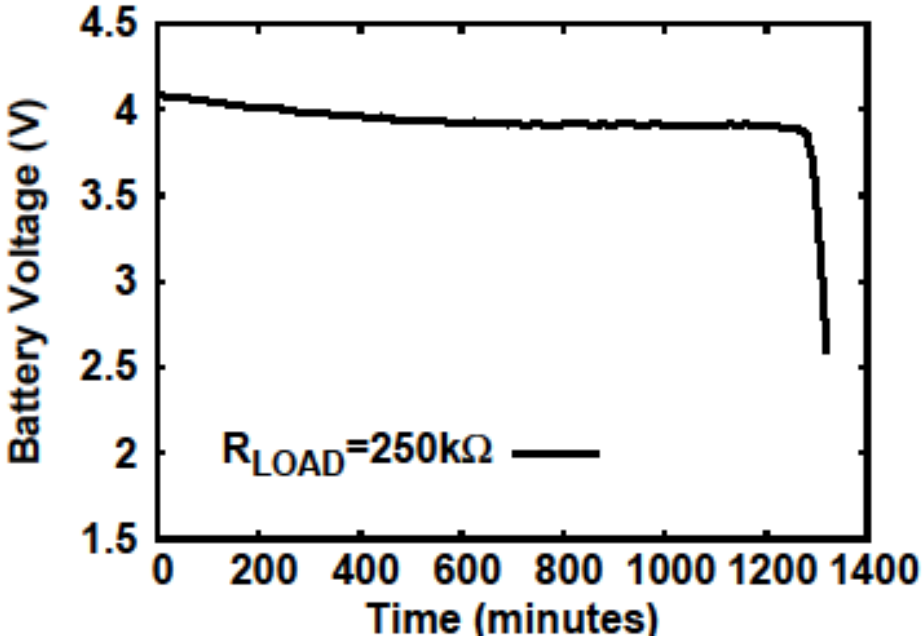
4.1 Energy Harvesting: Charge (4/5)

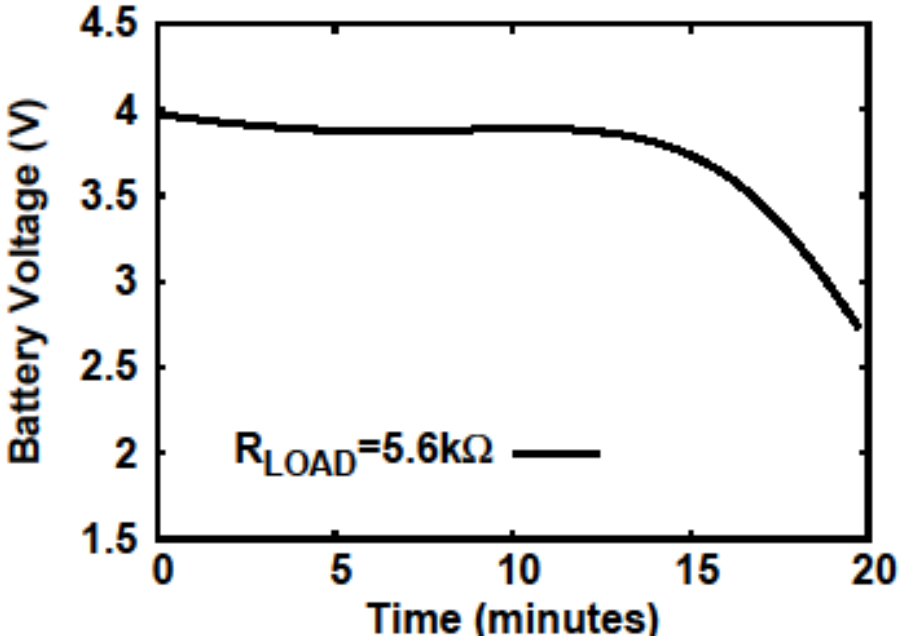
- Charging voltage 4.1 V.
- End of charge detected at 4.1 V battery voltage.



4.1 Energy Harvesting: Discharge (5/5)

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





Discharge time ~ 22 hours

Discharge current ~ 16µA

Discharge time ~ 20 minutes

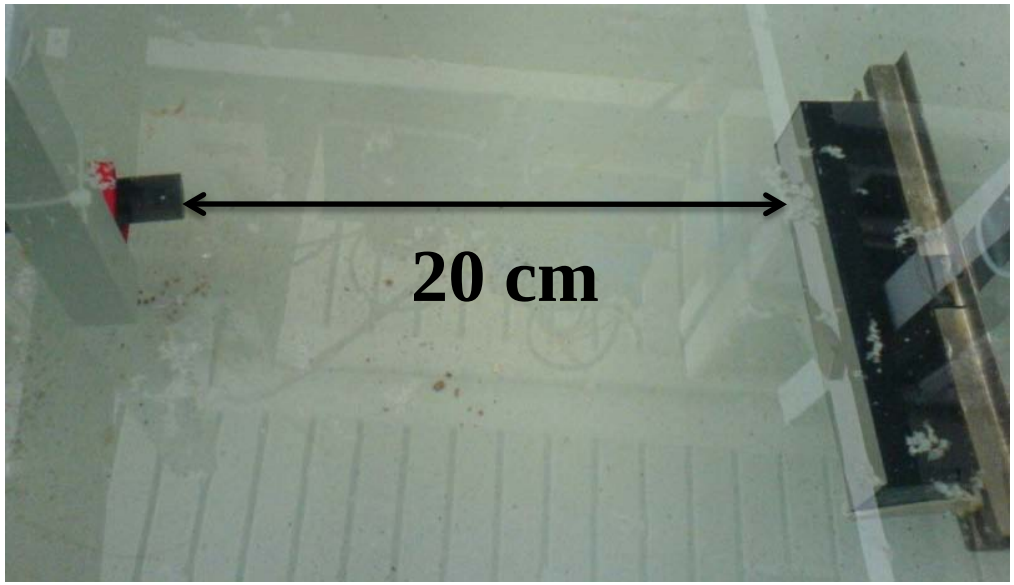
Discharge current ~ 730µA

4.2 Wireless Communication: Specifications (1/4)

- 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)

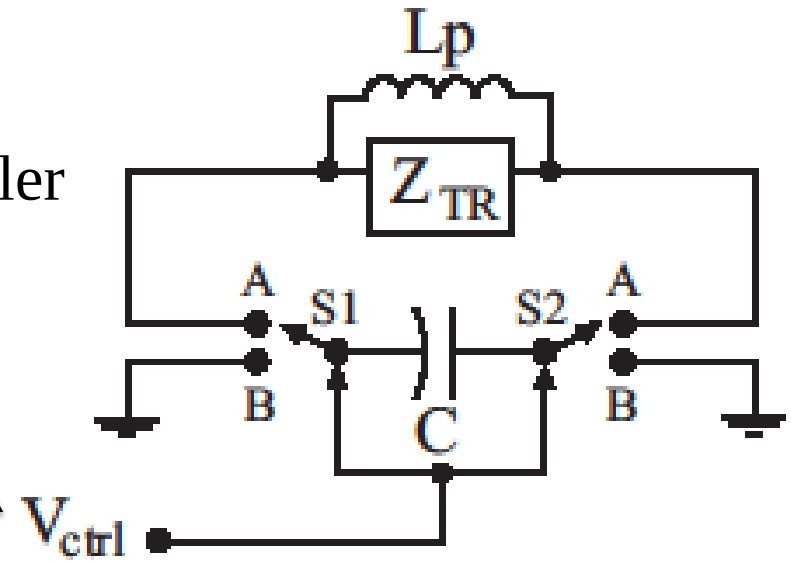
Linear phase array – 64 elements:
Central frequency = 1 MHz
Manufacturer IMASONIC



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

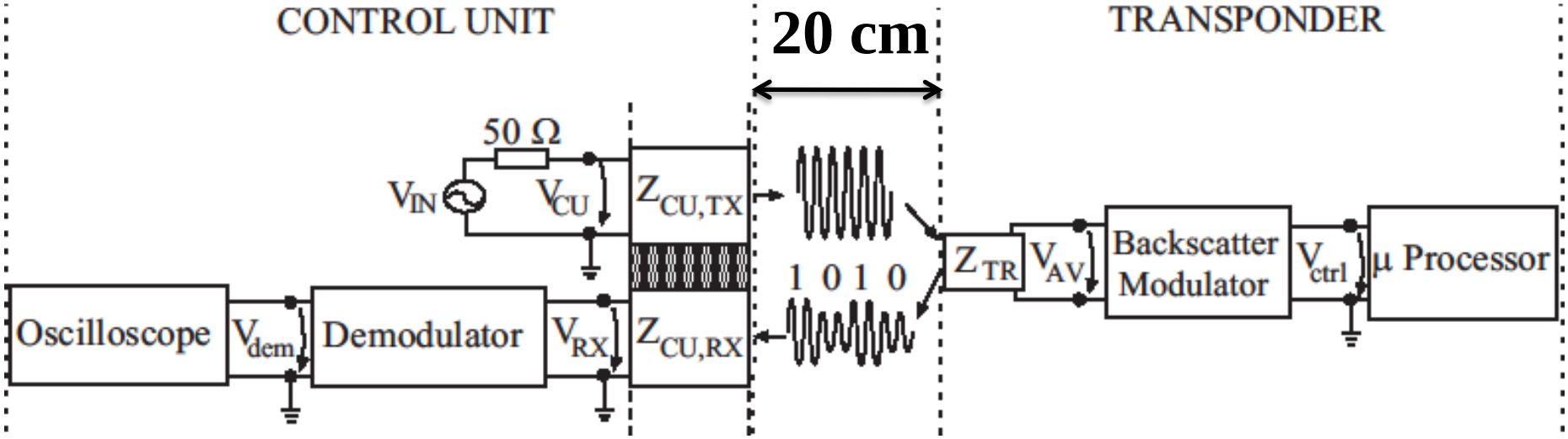
4.2 Wireless Communication: Modulator (3/4)

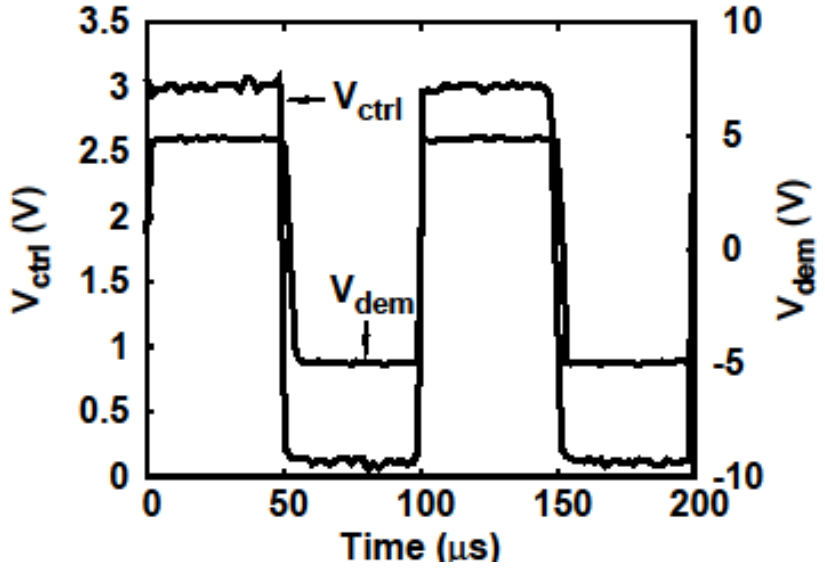
data signal yielded by a µ-controller that controls the switches.

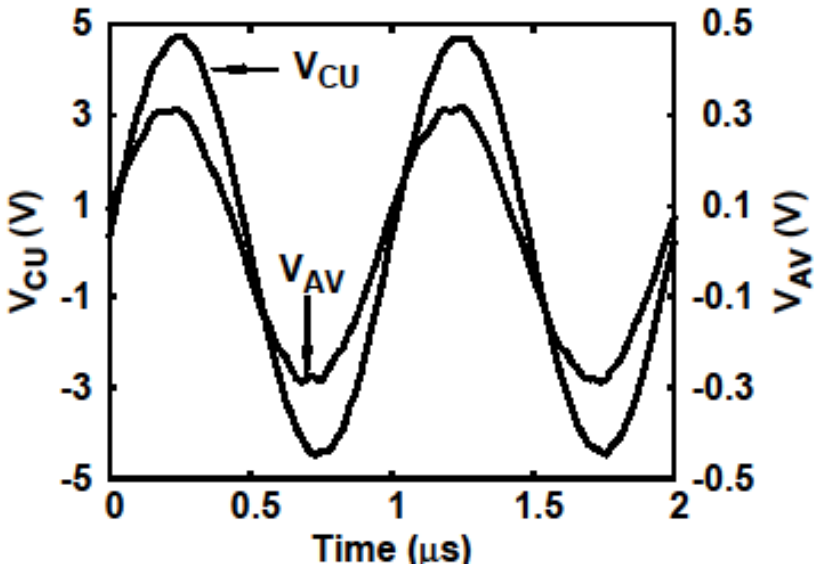


- **V_{ctrl} = 1, switch S1 & S2 in position A**: The transducer is made stiffer and reflects back the incoming signal so a **high state is transmitted** to the CU receiver.
- **V_{ctrl} = 0, switch S1 & S2 in position B**: The transducer is allowed to vibrate so that the incoming signal is absorbed, thus a **low state is transmitted** to the CU receiver.

4.2 Wireless Communication: Results (4/4)







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5 Conclusion

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

Acknowledgement

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