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A Full-Duplex Wireless Integrated Transceiver for Implant-to-Air Data Communications

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IEEE Custom Integrated Circuits Conference (CICC), San Jose, CA, September 28-30, 2015

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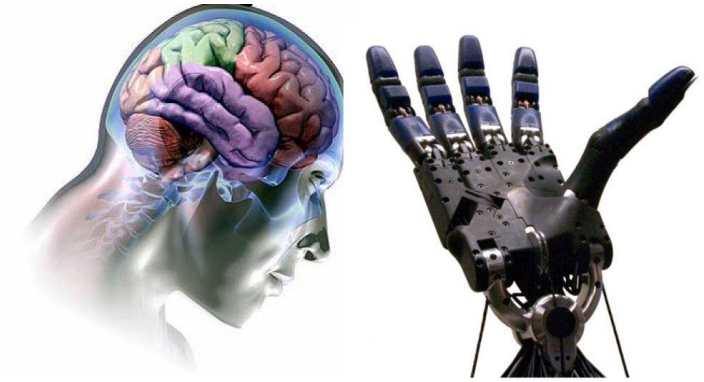
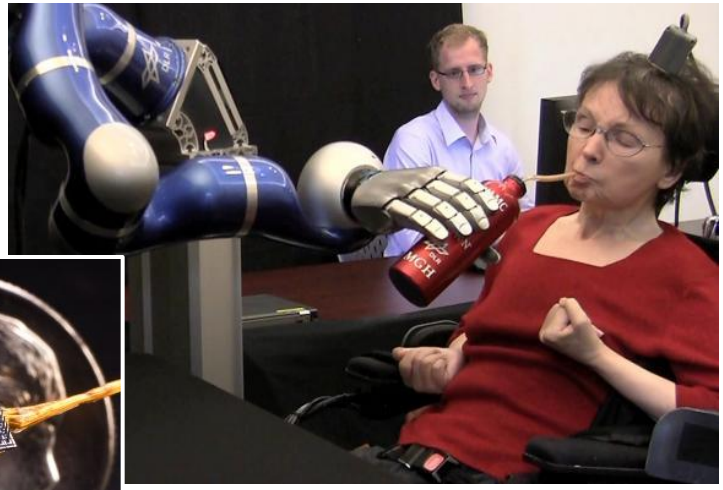
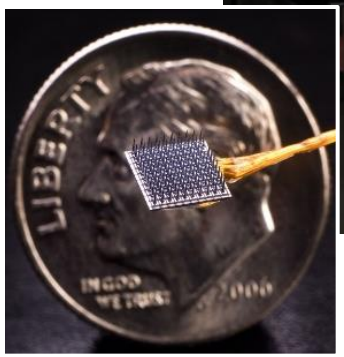
Outline

- **Motivation and Objectives**
- **Integrated Implantable Transceiver Design**
  - Full-duplex transceiver structure
  - 2.4 GHz downlink receiver
  - UWB uplink transmitter
- **Measured performance**
- **Comparison**
- **Conclusion**



Robotic arms connected to the brain using a BMI

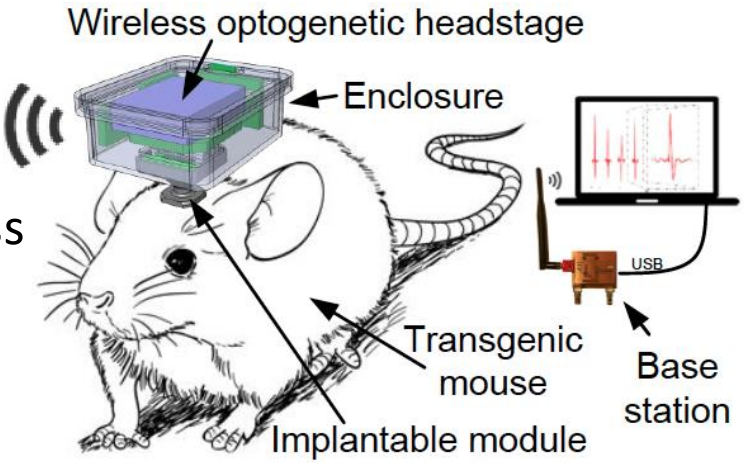




Brown University

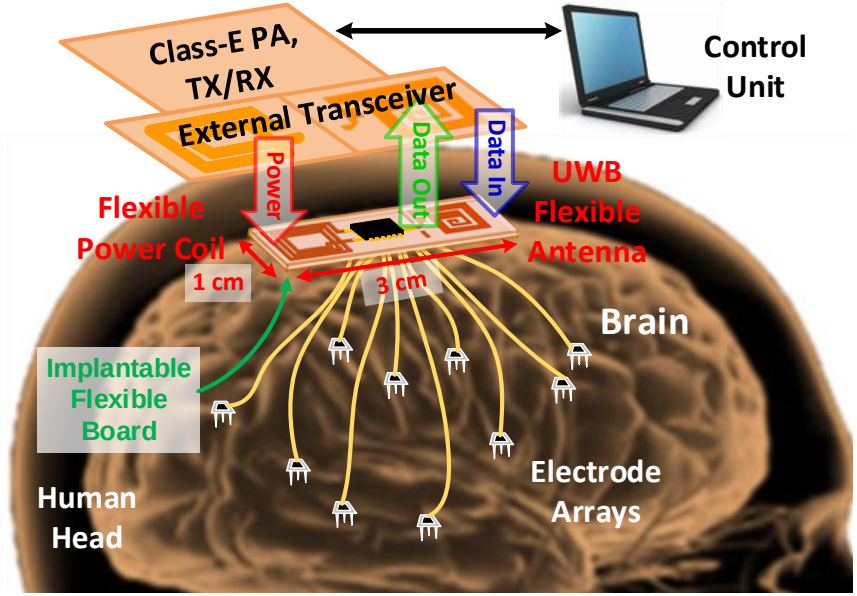
Motivation and Objectives

- Wireless brain computer interfaces (BMI)
  - The development of wireless BMI technology into a reliable, small-scale and chronically implantable device.
  - Studying the brain of freely moving animals.
- Objectives of this work
  - Bidirectional data transmission
  - High data rate
  - Low power consumption



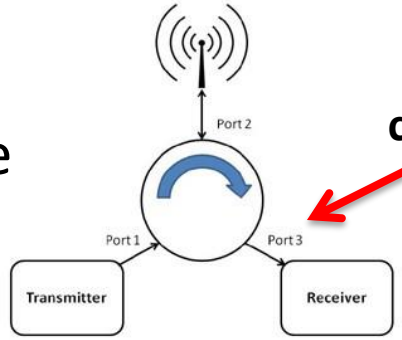

Powered Wheelchair


Prosthetic Devices



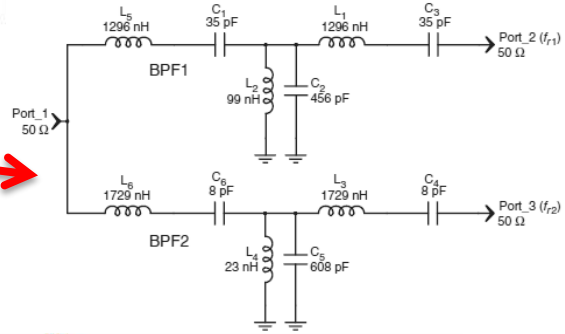
Prior arts

- Sharing an antenna inside a full-duplex transceiver scheme necessitates either:
  - A circulator (Passive or Active)
  - Or a diplexer
- Passive circulator:
  - Ferrite: not compatible with CMOS technology,
  - increases the size
- Active circulator:
  - increases size, noise and power consumption

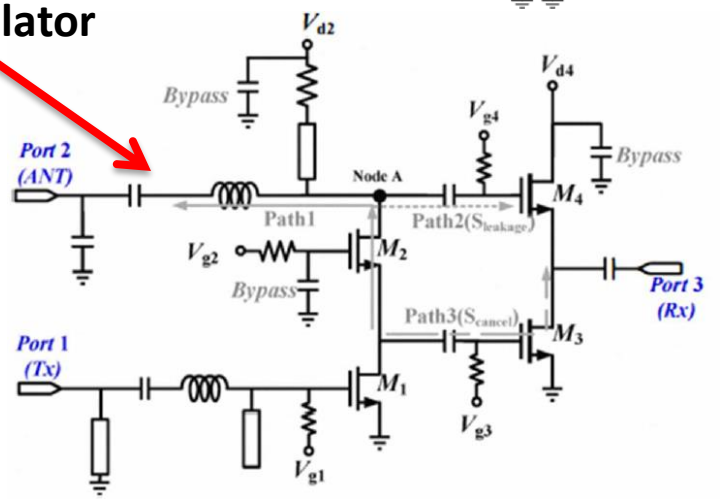


Passive circulator

Diplexer

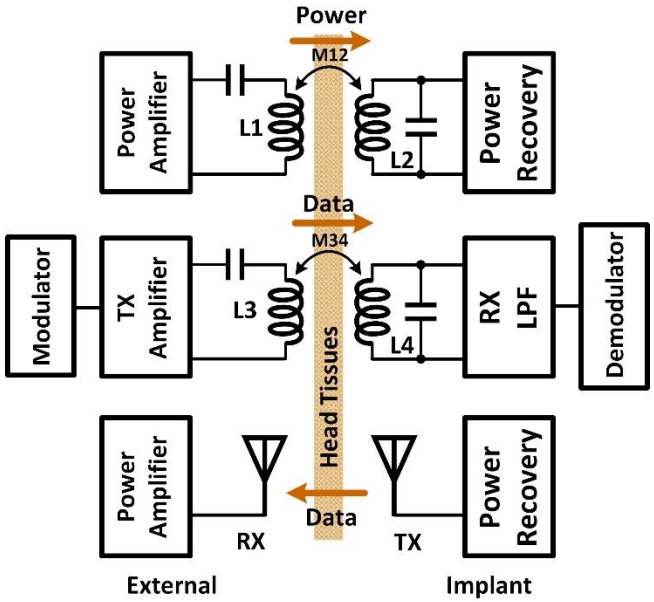


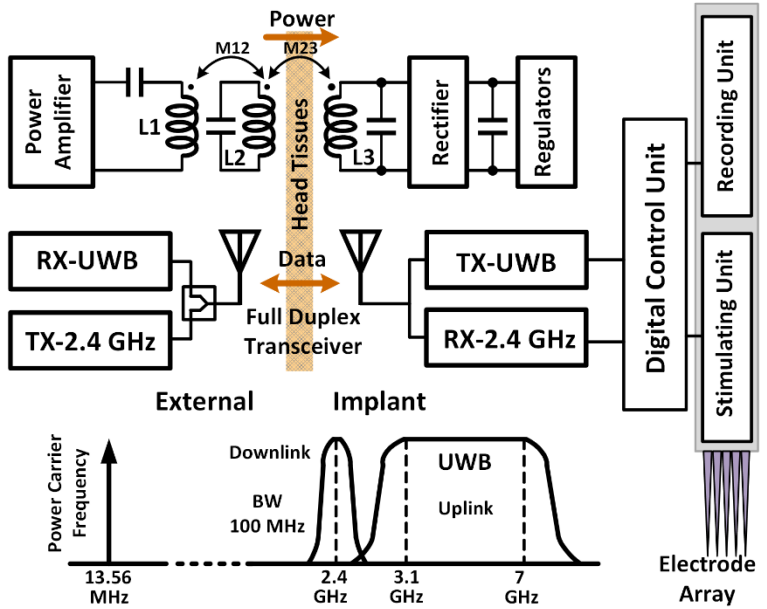
Active circulator



Proposed Approach

- Problem statement and contributions:
  - Using two antennas for downlink and uplink is not size efficient





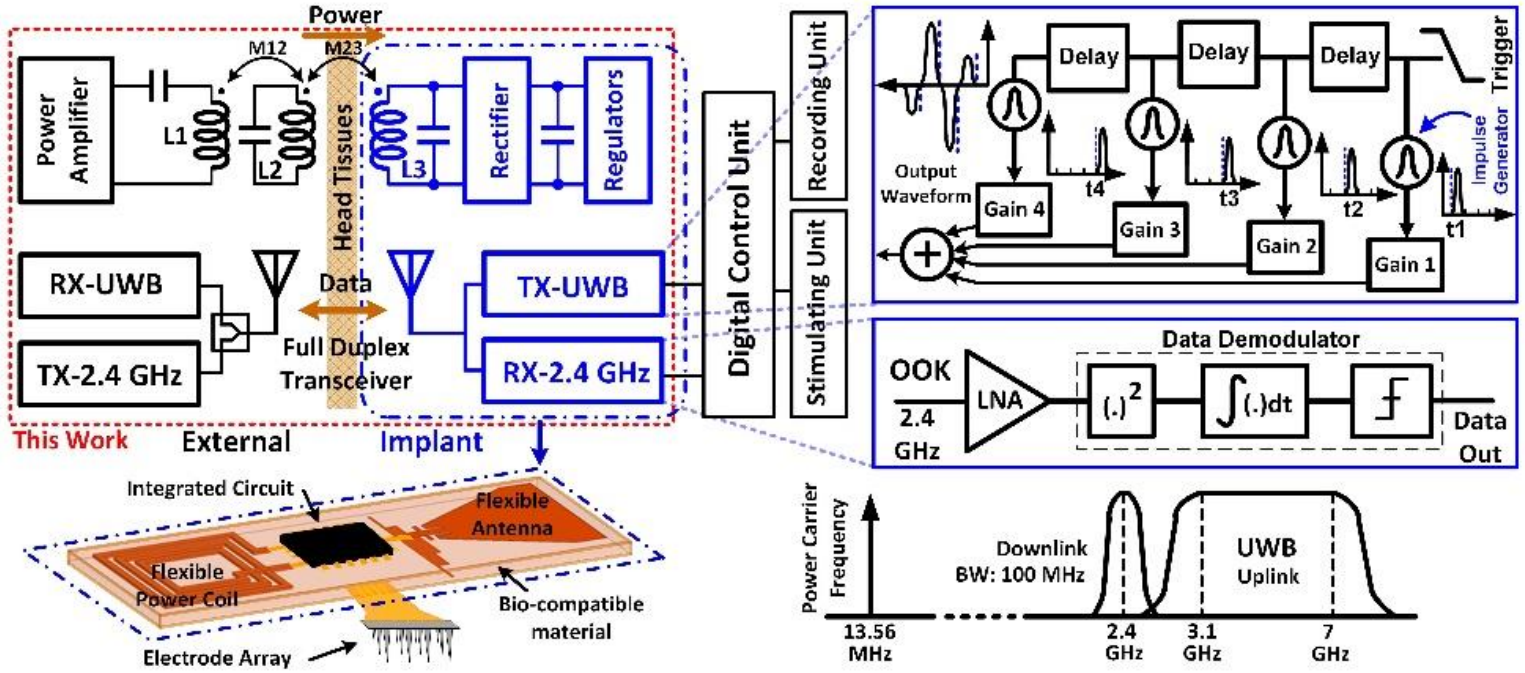
Conventional implementation of power and data links.
U. M. Jow , et al, IEEE TBioCAS, 2010.

Proposed structure for power and data links.

  - The uplink data rate requirement for 1000 microelectrodes can reach 500 Mbps (ksps sampling rate × 12 bits of resolution per sample + 5% overhead = 504 Mbps).

System Overview

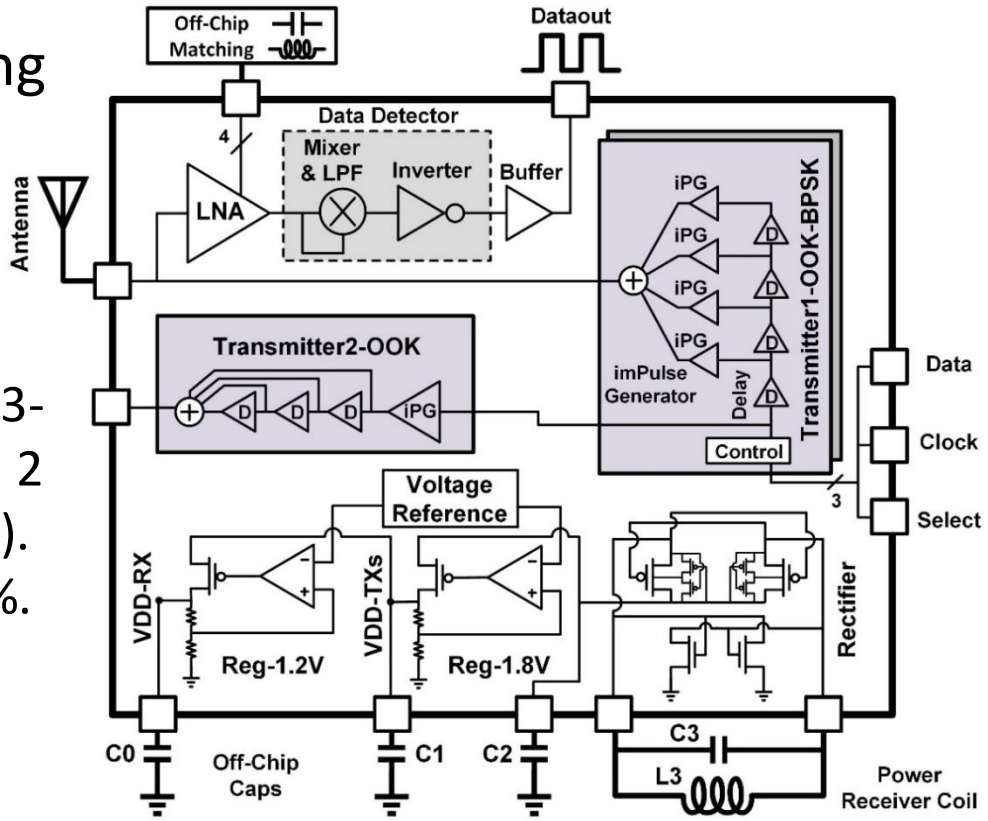
- Proposed solution:
  - Proposing a novel full-duplex data transceiver architecture for high-density neuro-electronic interfaces
    - Designing of integrated 2.4 GHz receiver for the proposed architecture
    - UWB transmitter design and implementation for the novel full-duplex transceiver



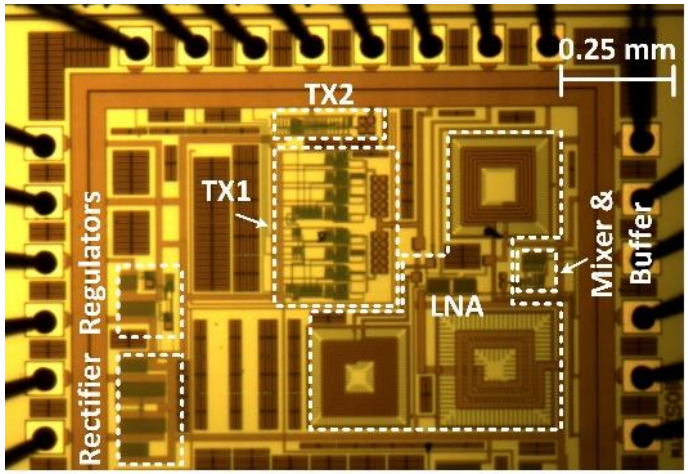
The proposed full-duplex transceiver

System Design

- The integrated circuit building blocks consists of:
  - Full duplex data transceiver
    - UWB high-data rate TX
    - 2.4-GHz RX
  - Power recovery unit includes a 3-coil link, a voltage rectifier and 2 voltage regulators (V_{DD}=1.2/1.8V).
  - Total power link efficiency: 41.6%.



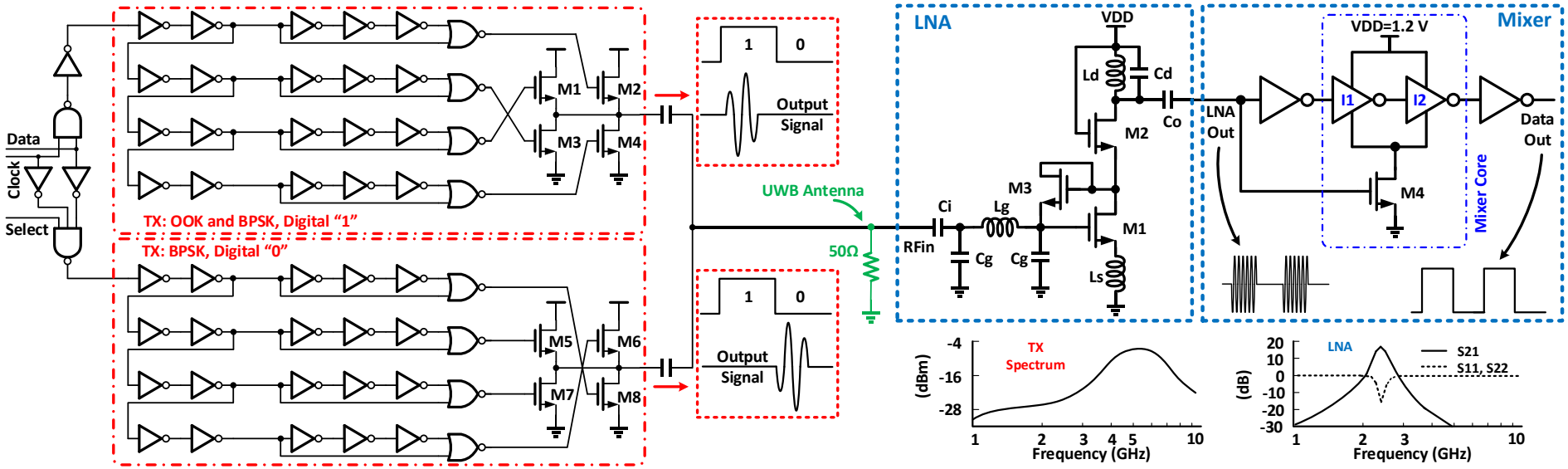
Integrated circuit building blocks



The chip micrograph fabricated in a TSMC 0.18-um CMOS technology, with a total die size of 1.0 × 0.8 mm^2.

Full-duplex transceiver design

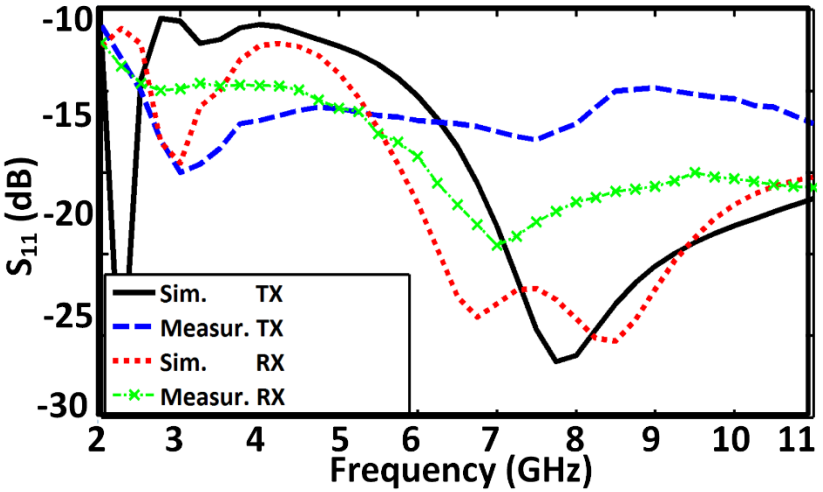
- The integrated circuit design of the full-duplex transceiver:
  - 2.4 GHz receiver (OOK)
  - UWB transmitter (OOK and BPSK)



Circuit level implementation of the full-duplex transceiver including the selectable OOK/BPSK UWB transmitter and the 2.4-GHz receiver.

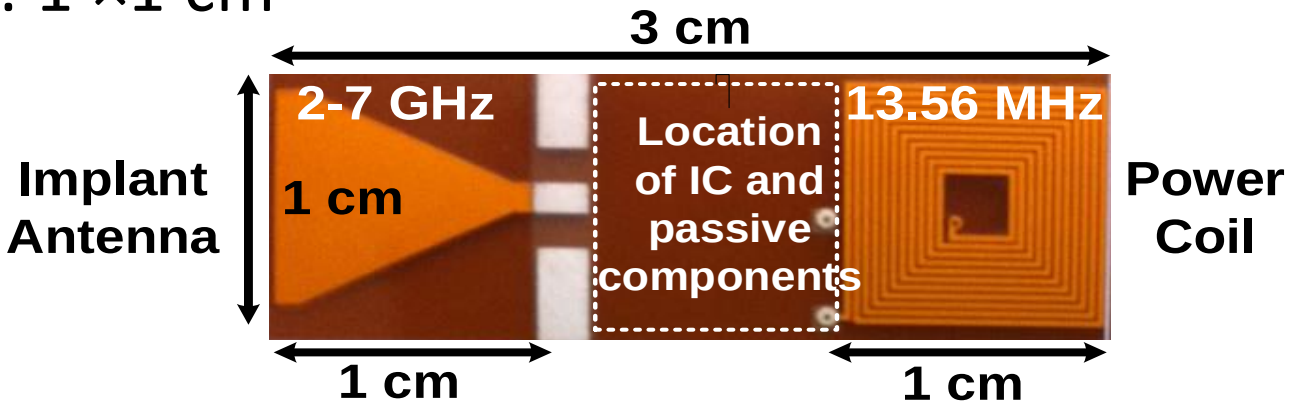
Flex PCB integration

- Flex PCB including:
  - UWB antenna (3.1-7 GHz)
  - RX power receiver coil (13.56 MHz)
- Size (total: 1 × 3 cm^2):
  - Antenna: 1 ×1 cm^2
  - Power coil: 1 ×1 cm^2



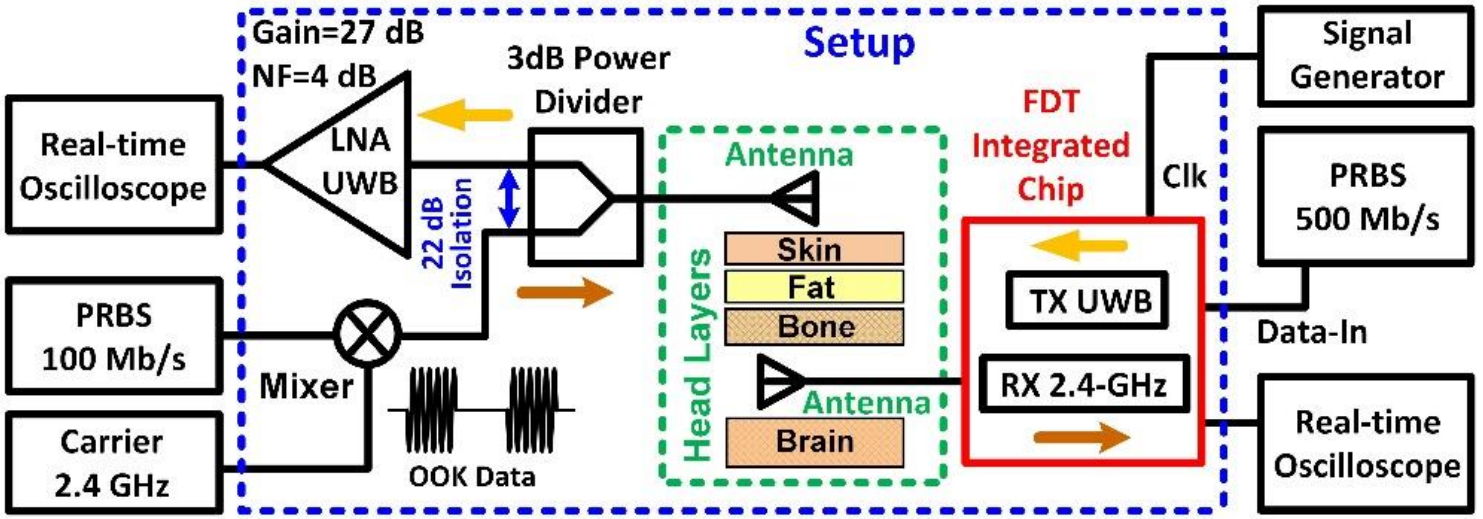
Reflection coefficient (S11) simulation and measured results for implant antenna (TX) and external antenna (RX).

Fabricated receiver coil and antenna on flexible Polyimide PCB layer with a thickness of 100-µm.



Measurement setup

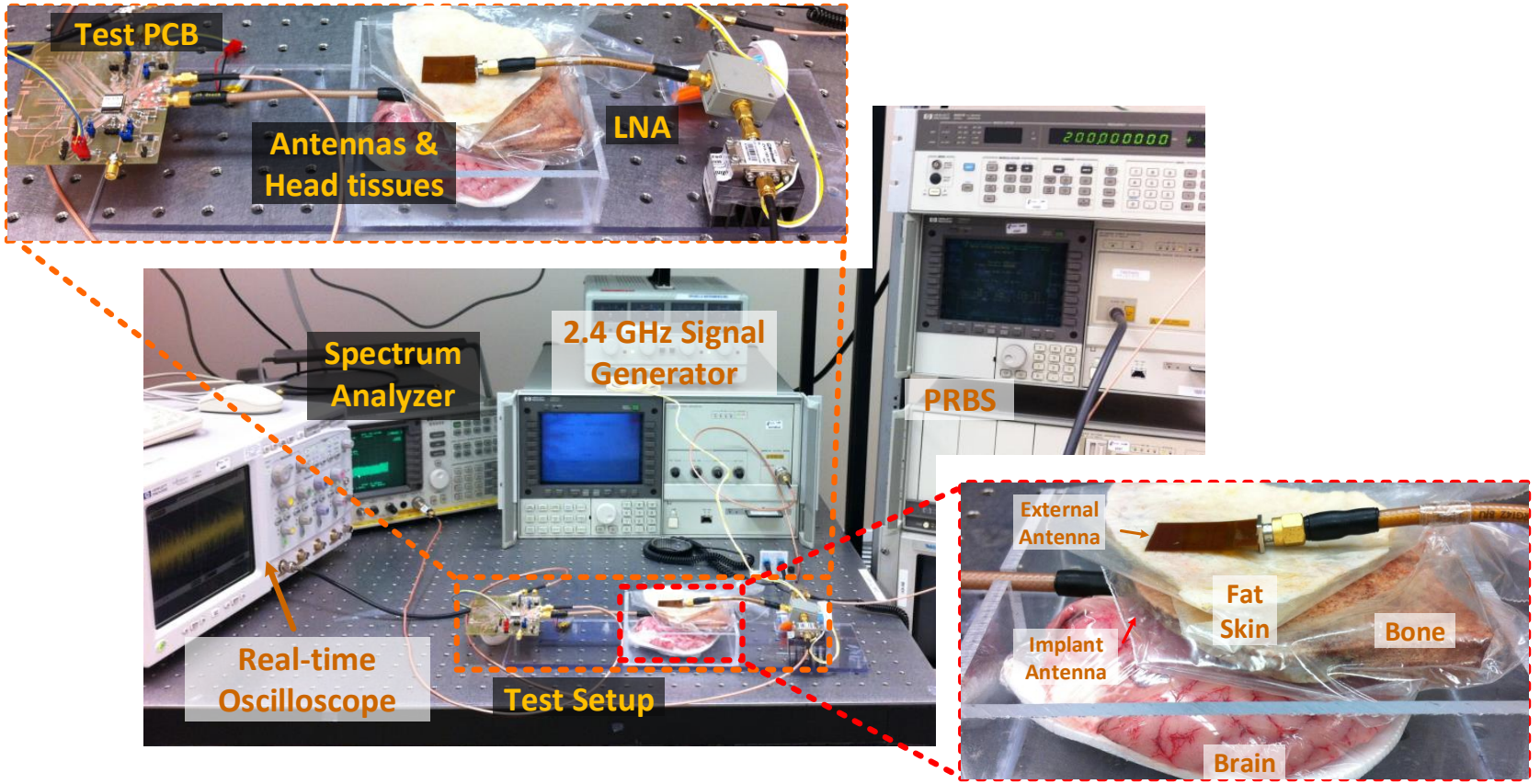
- Experimental setup block diagram showing the required equipment.
  - Signal Generator
  - PRBS
  - Real-time Oscilloscope



Measurement setup block diagram.

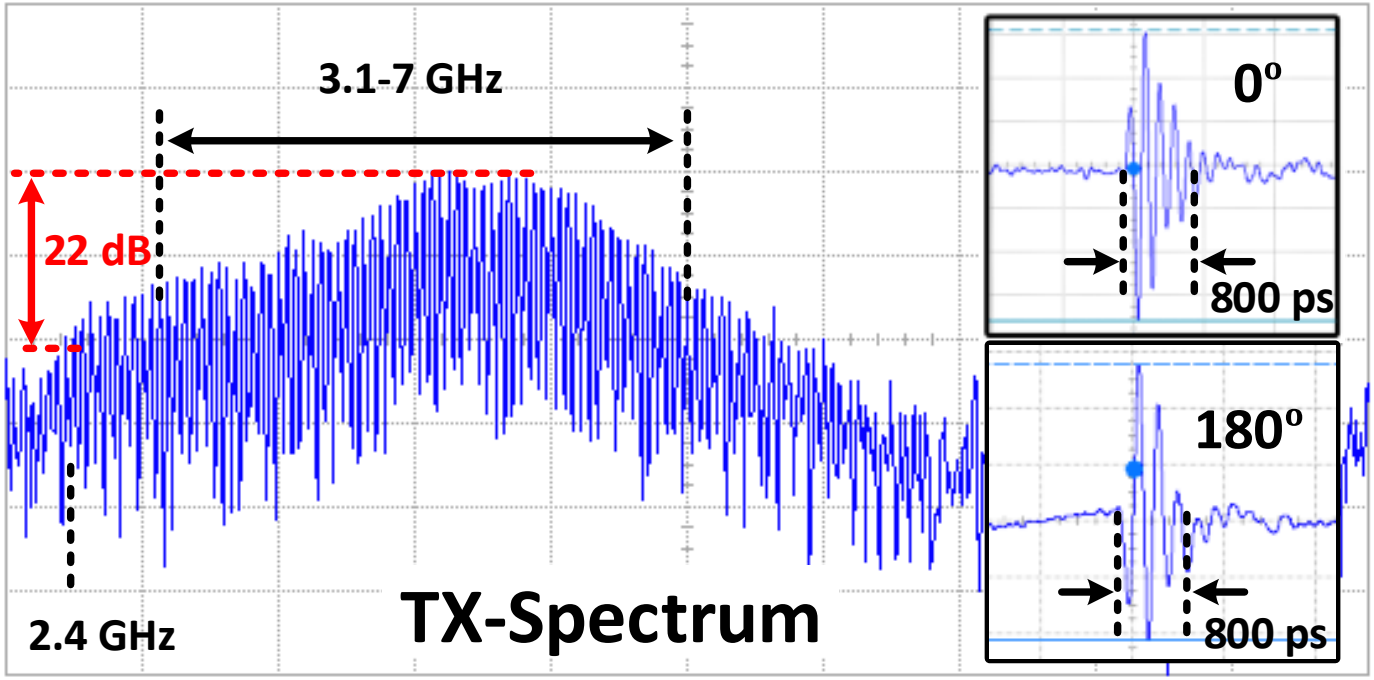
Measurement setup (con't)

- Measurement setup employed for characterizing the bidirectional data link implemented with the proposed full duplex transceiver and an external receiver.



UWB TX measured results

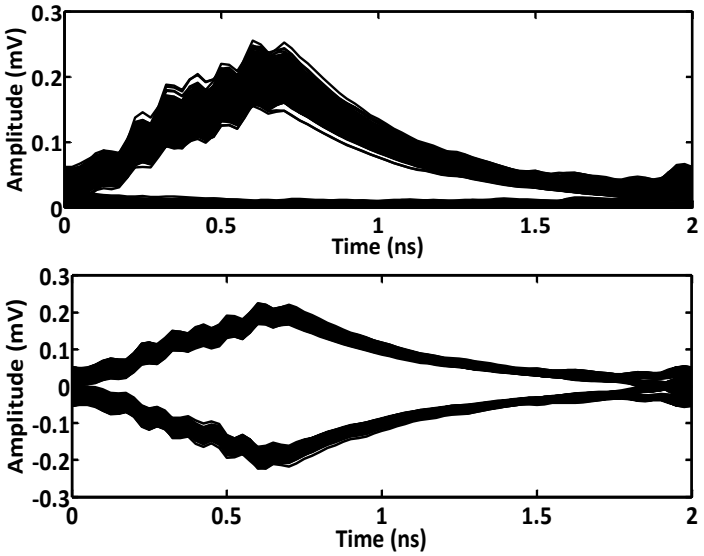
- UWB transmitter output signal spectrum.
- The Spectrum meets the FCC mask requirement.



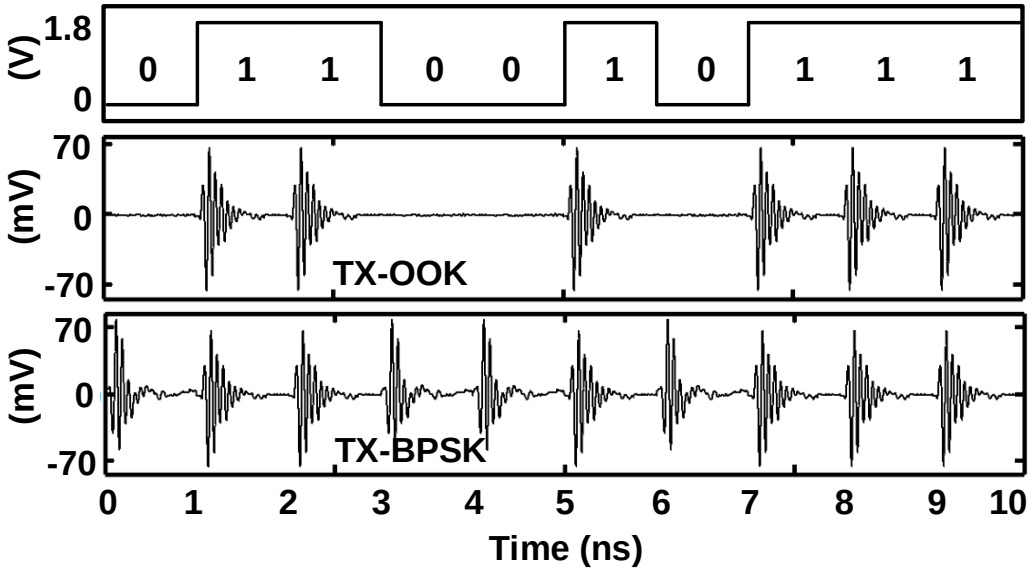
The measured spectrum of the UWB transmitter signal.

UWB TX measured results (con't)

- The integrated UWB transmitter output signals in:
  - OOK mode
  - BPSK mode



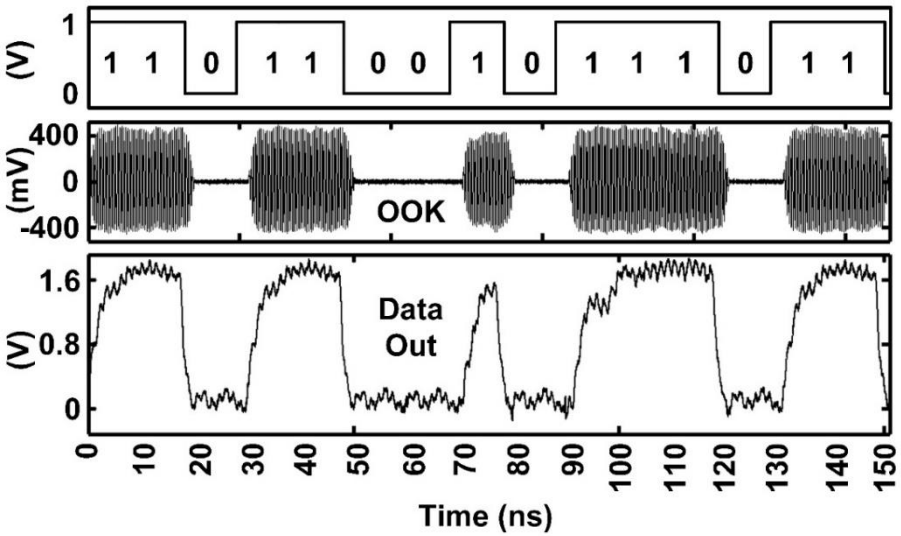
The measured eye diagrams for the transmitters TX1 in OOK and BPSK modes.



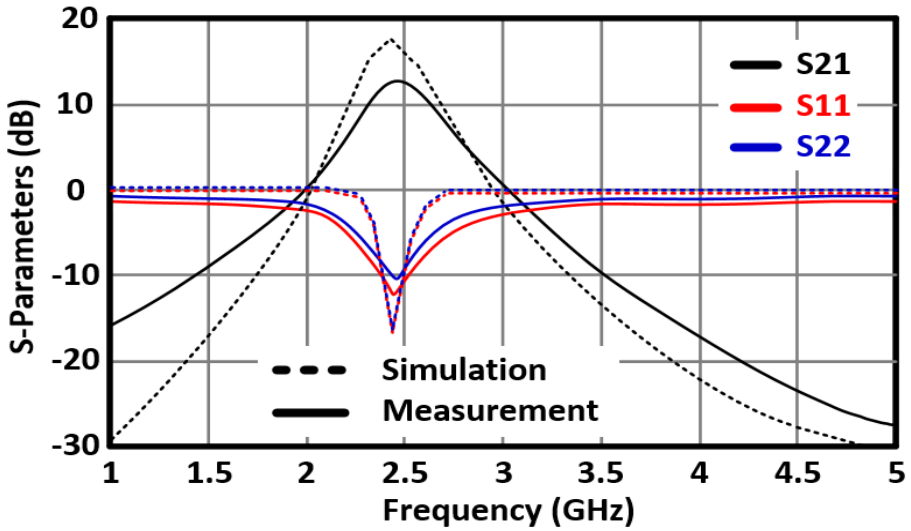
Measured pulses from the FDT UWB TX showing the uplink 500 Mbps signals using OOK and BPSK modulation.

2.4-GHz receiver measured results

- LNA's performance:
  - S21 (Gain (13.7 dB)), S11 (reflection (-12 dB))
- 2.4-GHz OOK receiver at a rate of 100 Mbps.
  - Generated 2.4-GHz OOK
  - Digitalized signal after Mixer (buffer output)



Data-in, transmitted signal and recovered received.



LNA's S-parameters (simulation and measurement results).

Comparison With Other TX/RX

- Comparison with previously published systems
- Advantages of our proposed system:
  - Bidirectional data transmission using one antenna.
  - High data rate: 500 Mbps (TX) and 100 Mbps (RX) using edge combining structure.
  - Low power consumption (10.8 pJ/b) using digital circuits.

Parameter	Technology	Approach	Data rate (Mbps)	Energy (pJ/b)	Freq.	Modulation	Power Consumption (mW)
[14], TX	0.35 µm CMOS	Filtering	160	10	3.1-5 GHz	PPM+OOK	1.6
[16], TX	65 nm CMOS	Ring oscillators	200	45	3.1-5 GHz	PPM	9
[15], RX	90 nm CMOS	Super-regen.	5	-	2.4 GHz	FSK	0.534
[11], RX	TSMC 0.18 µm	Inductive link	2	-	22 MHz	OOK	5.7
[This work], TX	0.18 µm CMOS	Edge combining	500	10.8	3.1-7 GHz	OOK,BPSK	5.4, 10.8
[This work], RX	0.18 µm CMOS	Non-Coherent	100	50	2.4 GHz	OOK	5

Conclusions

- Integrated full-duplex high-speed transceiver
  - Introduce a novel full-duplex transceiver structure, integrated using CMOS 180 nm technology
  - Circuit level design and implementation of 2.4 GHz receiver
  - UWB transmitter integrated circuit design and implementation
  - Reduce the interface design and size by providing a bidirectional data link using one antenna
  - Support required high data rate; 500 Mbps (TX) and 100 Mbps (RX)
  - Low power consumption (10.8 pJ/b and 50 pJ/b for implanted TX and RX blocks, respectively)

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Many Thanks

This work is supported in part by the Microsystems Strategic Alliance of Quebec (ReSMiQ).

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