Overview

• Introduction to RFICs
• Utah RFIC Lab
• Research Projects
  – Low-power radios for Wireless Sensing
  – Ultra-Wideband radios for Bio-telemetry
What is an RFIC?

- “An integrated circuit that uses inductors”
- Analog integrated circuits that operate at high frequencies, typically for communications
- Example: cell phone

Diagram:
- Internet Services
- Bluetooth Headset
- MP3 Player
- PDA
- Camera
- GPS
- Microphone
- Speaker
- ADC
- DAC
- Baseband Signal Processing (DSP)
- Radio Transceiver (RFIC)
Radio Concepts

- Examine the functional blocks in a radio
- Consider transmitter, receiver is inverse
Why Upconvert?

- Microphone output is in 0-3 kHz range
  - Efficient Antennas have length ~ \( \lambda/4 \)
  - Spectrum is allocated to avoid interference
Mixer Operation

• Mixer moves the input signal to a higher frequency through multiplication:

\[ \cos(\omega_1) \cdot \cos(\omega_2) = \cos(\omega_1 - \omega_2) + \cos(\omega_1 + \omega_2) \]
Mixer

- Mixer upconverts baseband voice signal to the oscillator frequency
Power Amplifier

- Amplifies the signal to higher levels so that it can drive the antenna
Filter

- Eliminates spurious emissions that could interfere with others
Antenna

- External to the RFIC
- Converts current/voltage signal to radiated electro-magnetic waves
Complete RFIC Implementation

- 12.5 mm$^2$ in 0.18 μm CMOS process
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Utah RFIC Lab

- Founded way back in 2007
- We research novel circuit architectures and techniques for RFIC functional blocks
- Research Methods:
  1. Analyze circuit problem, come up with solution
  2. High level simulations in Matlab
  3. Circuit level simulations in Cadence
  4. Layout physical circuit in Cadence
  5. Send to foundry (e.g., MOSIS) for fabrication
  6. Test and characterize the returned IC
  7. Publish results in a prestigious journal
RFIC Lab Members

- 3 PhD students, 1 MS student, 2 undergrads, and 1 visiting scholar

**Ondrej Novak (PhD)**
UWB for bio-telemetry

**Jeff Spiegel (PhD)**
Reconfigurable Frequency Synthesizers

**Ahmed Ragab (PhD)**
Low-power radios for wireless sensing

**Wei Wu (PhD)**
UWB for bio-telemetry

**Manohar Nagaraju (MS)**
Process Variation in DLLs

**Roger White (UG)**
Phase-locked loops

**Tyler Squire (UG)**
Phase-locked loops
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Why sensor networks?

- A wide range of applications:
  - Industrial monitoring
    - Control manufacturing processes
  - Building automation
    - Regulate temperature, light, etc.
  - Asset Management
    - Inventory control (RFID)
  - Environmental Monitoring
    - Facilitate biology research
Why wireless?

• Mobility of sensing nodes
  – Can be used for animal tracking

• Reduced size and cost
  – High levels of integration lead to fewer components and reduced cost

• Less intrusive
  – Eliminating the wired infrastructure lessens the impact on the environment being monitored

• Large scale deployment
  – Low cost and small size facilitate dense ad-hoc networks
Anatomy of a WSN Node
Commercial WSN Hardware

- Crossbow Mica2
  - Plug in sensor boards
  - 90 mW power consumption
  - Lifetime on the order of several days with continuous operation (less with sensor boards)
  - Built with off-the-shelf hardware
  - 40 kbps data rate
Integrated WSN Hardware

- Higher levels of integration
  - Reduced cost and size
- Reduced power consumption
  - Radios with sub mW power consumption

<table>
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<tr>
<th>Operation</th>
<th>Published</th>
<th>Off-the-shelf</th>
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<td>8b A/D conv</td>
<td>0.031 nJ</td>
<td>13.5 nJ</td>
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<td>8b μP inst</td>
<td>0.012 nJ</td>
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<tr>
<td>Tx/Rx 8b</td>
<td>32 nJ</td>
<td>2500 nJ</td>
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Motivating Application

- Stream temperature monitoring in Red Butte Canyon
- Working with Dr. Neal Patwari’s group and faculty from the Biology Department
- Deployed test network this past summer

- Used Crossbow Motes with thermocouples to measure stream temperature every 10 min.
- Data was transmitted to a gateway node that logged the measurements.
Objectives for Future Work

• Develop power scavenging add-ons to extend system lifetime
• Research low-power radios to reduce overall power consumption
• Deploy a more extensive sensor network with additional sensing capabilities
  – Wind levels
  – Water uptake in trees
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What is Ultra-wide band?

- The modern frequency spectrum is a pretty crowded place
- We want to transmit in desirable frequency bands without interfering with other users
  - Transmit at low enough power levels to appear as noise to other users
What about data rates?

- **Problem:** Very low power levels mean very low data rates.
- **Observation:** Data rates depend on both **power** and **bandwidth**.
- **Solution:** Compensate for low power levels with very wide bandwidths.

- The FCC defines an UWB signal as one having a **bandwidth > 500 MHz**.
How can we make UWB signals?

- Standard modulation techniques are limited to narrow bandwidths due to channel variation.

- Two alternatives:
  - Impulse-based UWB
  - OFDM-based UWB
Relative Merits of UWB

• OFDM:
  – Higher complexity (→ higher power)
  – Potential for higher data rates
  – Well-suited for consumer applications (e.g., wireless USB)

• Implulse-based
  – Simple architectures (→ lower power)
  – Better suited for niche applications where power is a great concern
Motivating Application

- Visual prosthetics hold the promise of restoring functional vision to the blind

- **Challenge**: Need high data rates to transfer adequate visual information to stimulator
Narrowband Data Transfer

- Power transferred to implant over inductive link
- Transmit data by modulating the power carrier

- **Problem**: limited to ~1 Mb/s by restrictions on carrier frequency and resonant circuit
- **Solution**: transmit data over separate data link
- **Complication**: Power carrier presents a significant interference source
UWB Solution

- Use Impulse-UWB for high data rate and low power
- Exploit power carrier “interference” for synchronization
  - Transmit pulse bursts on power carrier edges
System Architecture

External Unit

Implanted Unit
Proof-of-Concept Prototype

- Fabricated in 0.6 μm CMOS through MOSIS
Measurements – Time Domain

- Tx output (top) and Rx input (bottom) on Oscilloscope
Measurements – Freq. Domain

• Before filtering (left), After filtering (right)
Thanks for listening!

- Any questions?