Software Defined Radio Approach for Passive, Wireless RFID Sensors

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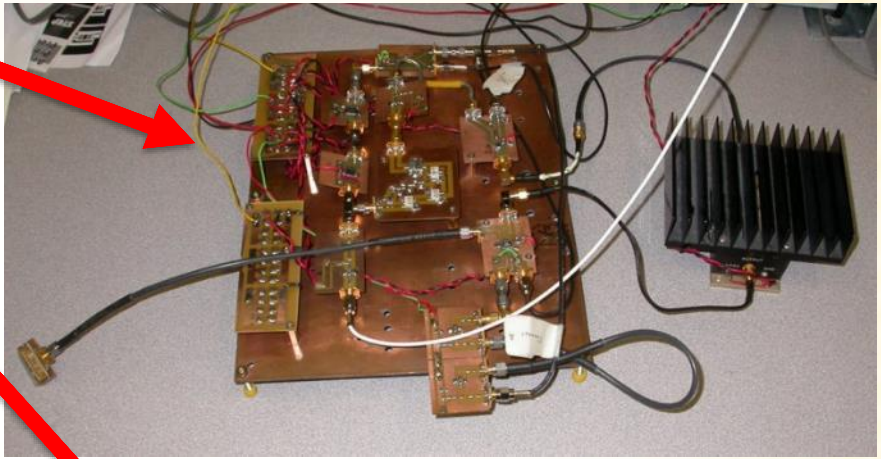
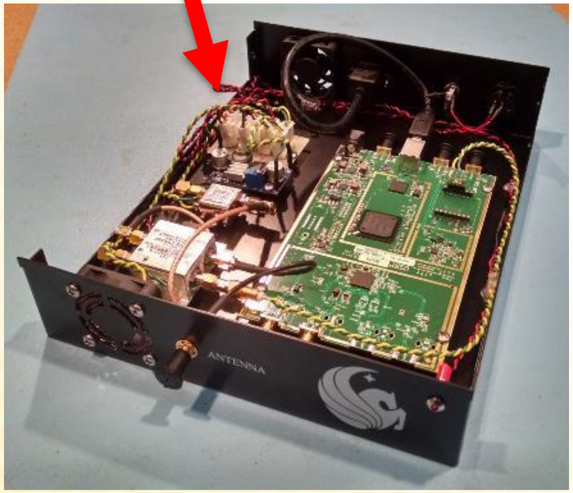
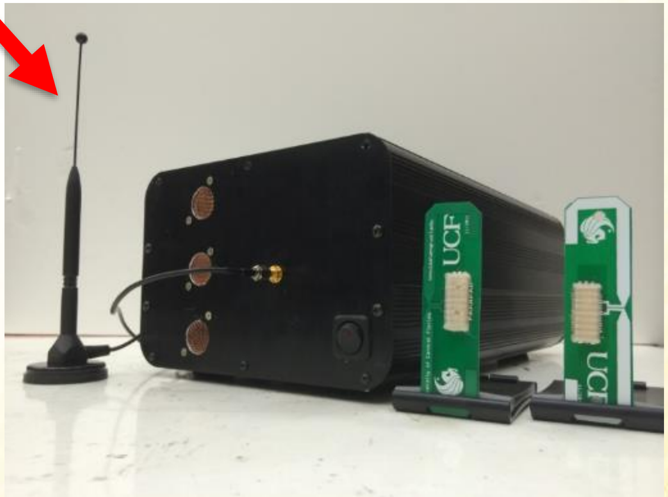
PWS-4B: Passive Wireless SAW and RFID Sensors

UCF Interrogation System History

- 250 MHz Prototypes (2008-2009)
- 915MHz Pulsed (2011)
- 915MHz Noise Coherent (2012-2014)
- 915MHz Software Radio (2015)





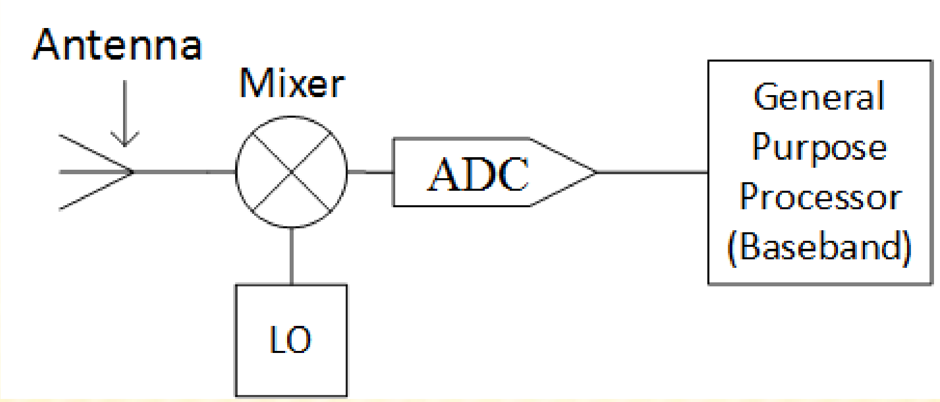


Why SDR for Passive RFID Sensing?

- ‘Universal’ software radio platforms – theoretically can be used for any application
  - Common platform for every application
  - Rapidly adapt in research environment
- Performance improvements delivered via software/firmware updates (FPGA or Software)
- Low-Cost
  - Reduce time to build and assemble interrogator unit (Time and Effort)
  - SDR platforms fabricated in high volume by external company, greatly reduce hardware cost

Software Radio - Intro

- Implement typical radio hardware functions in software (Processing on Host Computer)
  - Filters, Modulators/Demodulators, Detectors, etc.
- Single Radio -> Many Applications (Universal)
  - Communication, RADAR, ADS-B, etc.
- Commercial off-the-shelf Hardware
  - HackRF, bladeRF, USRP, sound-cards, etc.
  - No need to build custom hardware

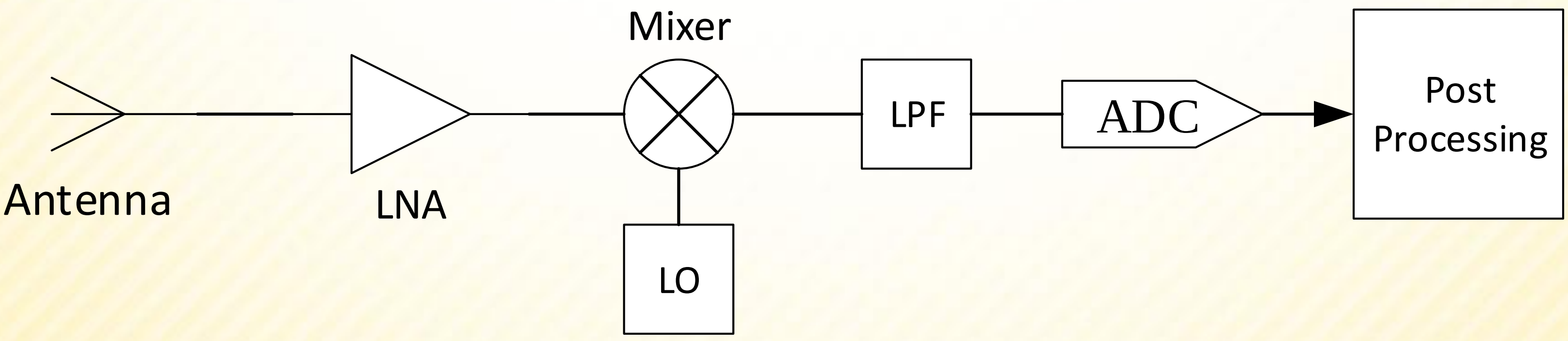


SDR Operation

- Baseband Processing
  - Transmit – Baseband → RF (Up Conversion)
  - Receive – RF → Baseband (Down Conversion)
  - Typically Zero IF (<u>**Direct Conversion Transceiver**</u>)
  - Signal processing accomplished on general purpose processor (PC) or FPGA, not special hardware or circuit
  - <u>**In-Phase (I) and Quadrature (Q) sampling**</u>
    - No ambiguity for positive/negative frequency (cos(x) = cos(-x))
    - Can implement any arbitrary waveform/modulation scheme
      - BPSK, QPSK, OOK, FM, AM, etc

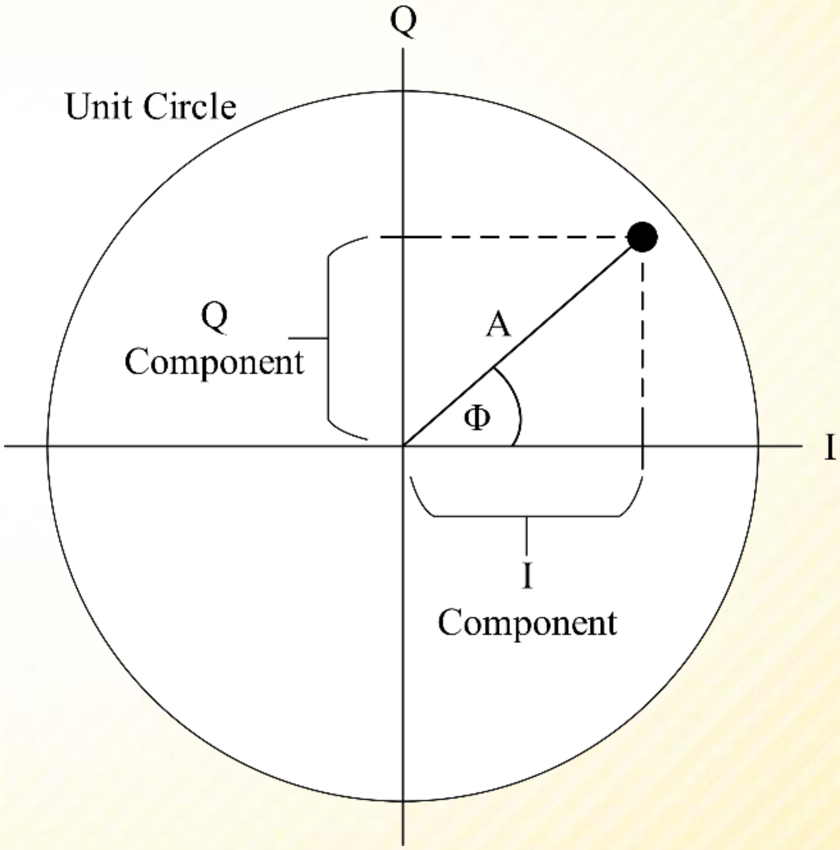
Direct Conversion Architecture

- Translate frequency band of interest to base-band (center frequency is zero)
- Advantages:
  - No image reject circuitry, No IF Stage, Simple!
- Disadvantages:
  - Requires complex calibration for: DC offset, I/Q imbalance, LO leakage
  - Non-Linear distortion will mix into bandwidth of interest



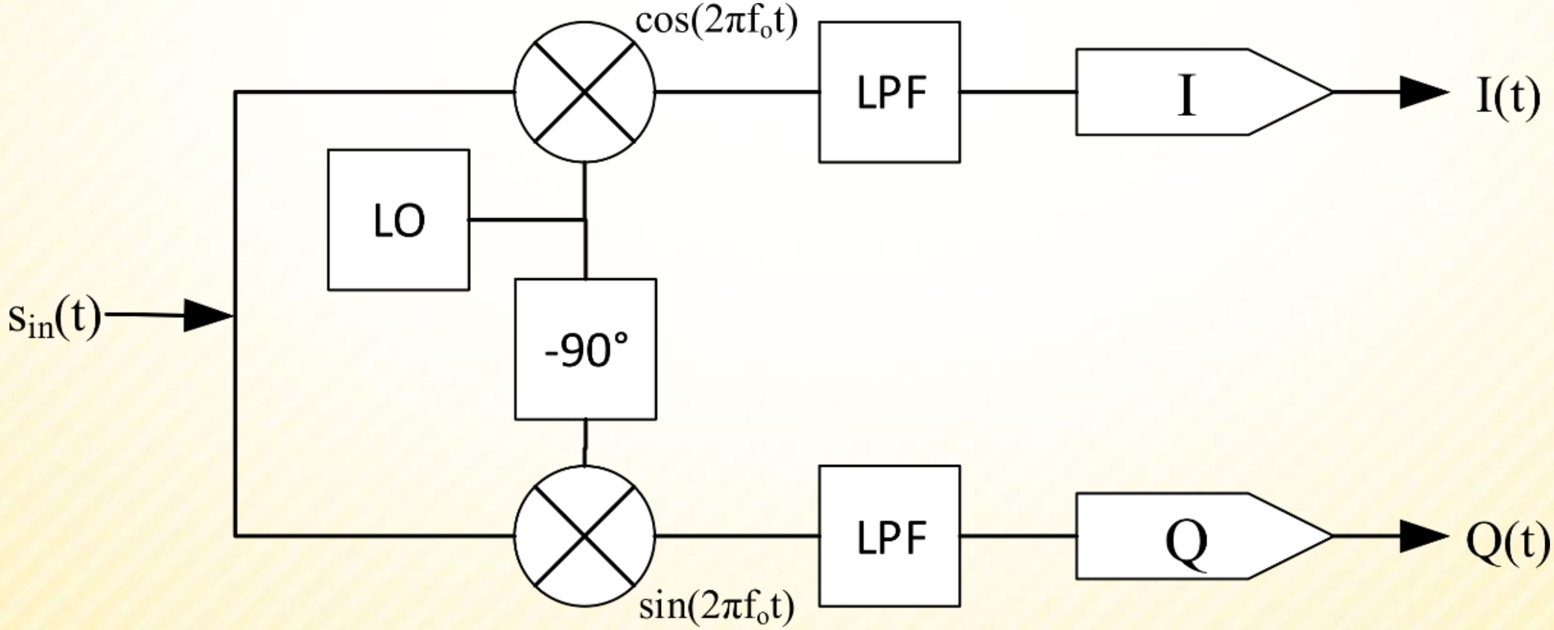
Direct Conversion – I/Q

- Need a way to generate In-Phase (I, 'Real') and Quadrature (Q, 'Imag') signal components
  - 90° out of phase
- Form phase vector
  - Remove ambiguity in +,- freq
  - Direct conversion is centered at zero!
- Complex waveforms/modulation
  - QPSK, QAM, etc
- How to do this with hardware?



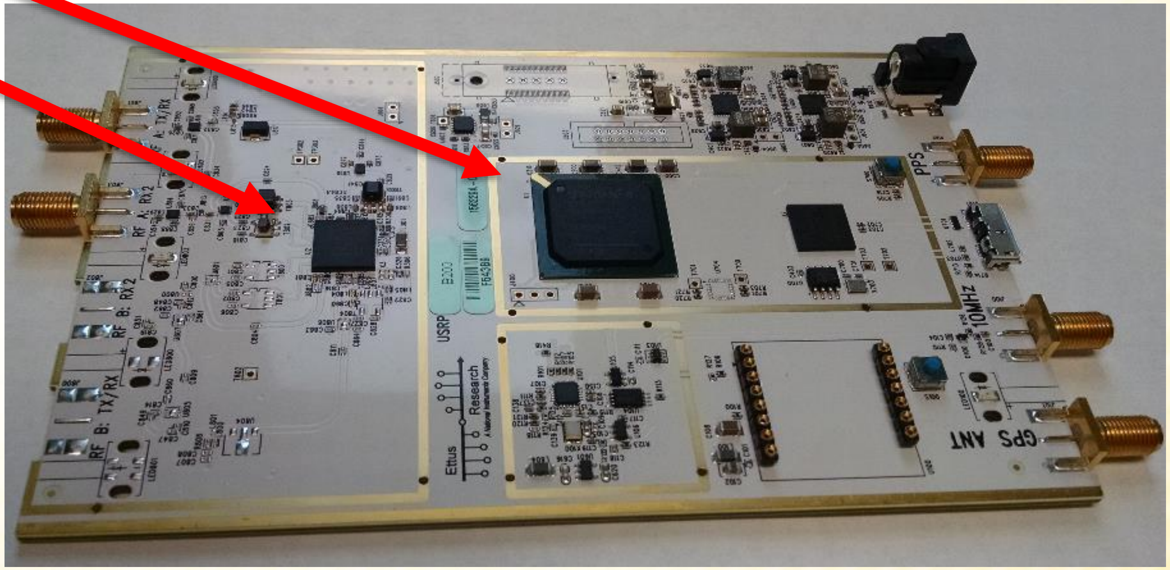
Direct Conversion – RX Chain

- Receiver has two receive paths
- Signal components are decomposed from input with LO
  - One cosine, One sine
- Transmit is just the opposite

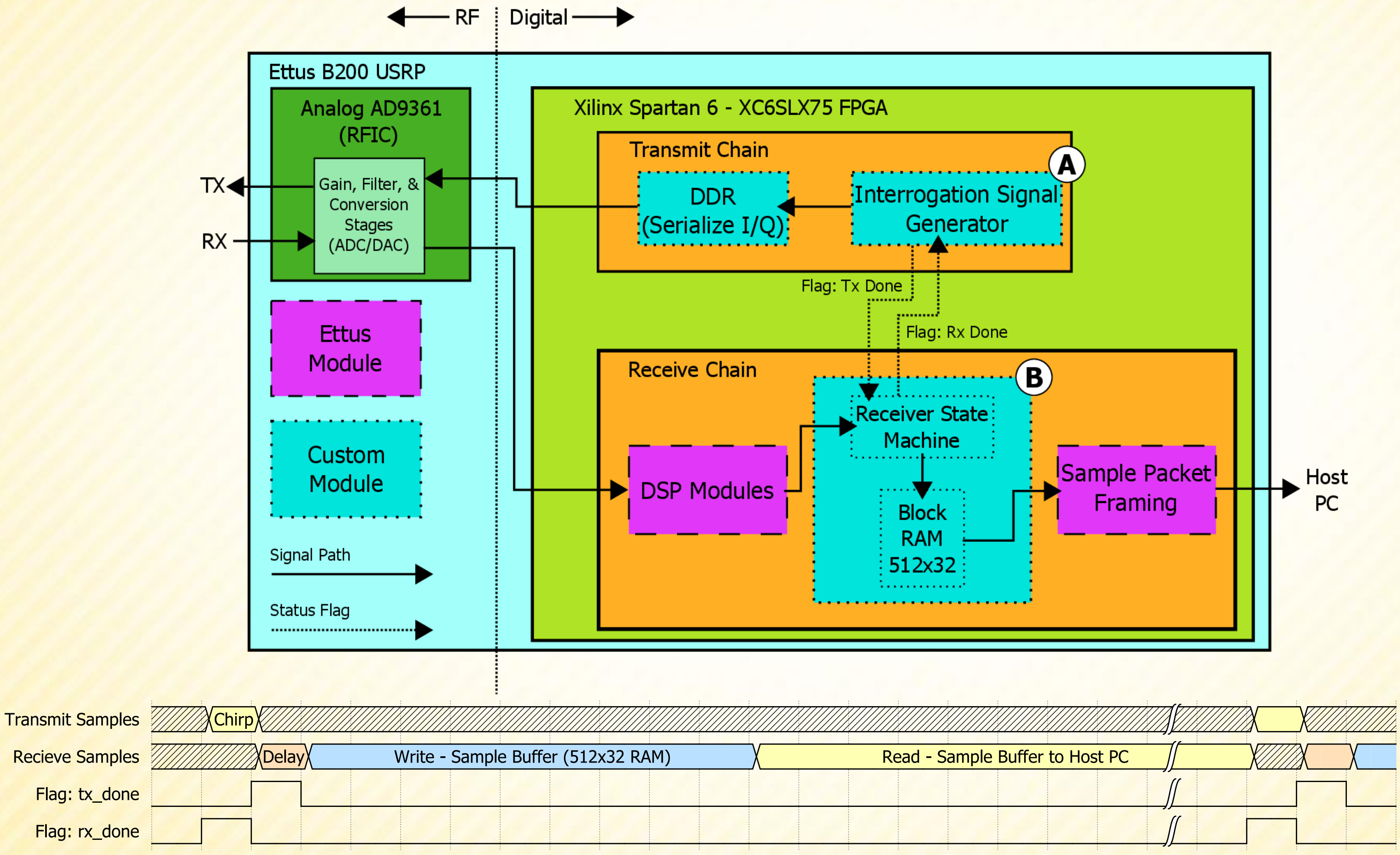


USRP B200

- Fully Integrated SDR (15 x 10 cm)
- Bandwidth: 56MHz (Max), USB 3.0
- RF Coverage: 70MHz – 6GHz
- Xilinx Spartan 6 FPGA
- Analog AD9361 RFIC
- Built in I/Q cal. routines



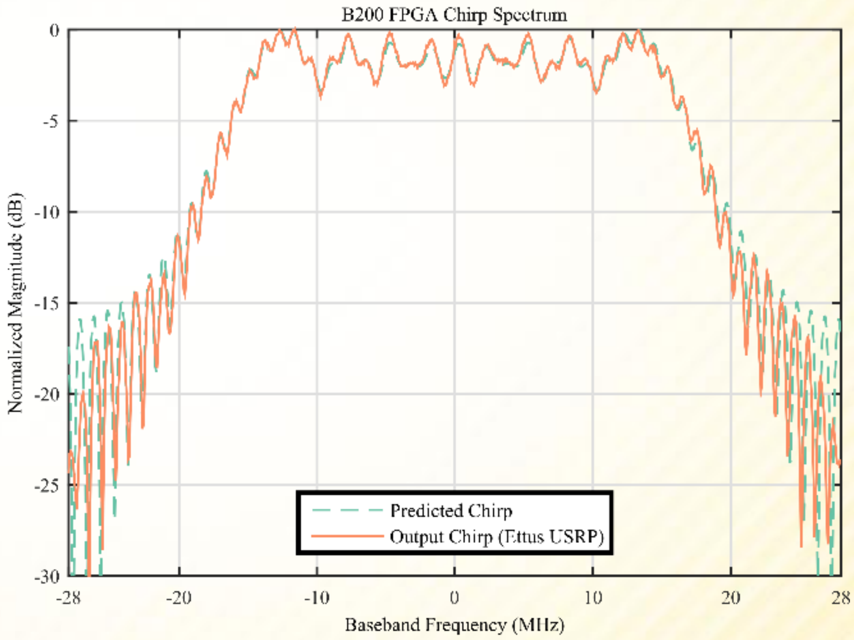
FPGA Block Diagram



Transmit – Pulsed Chirp

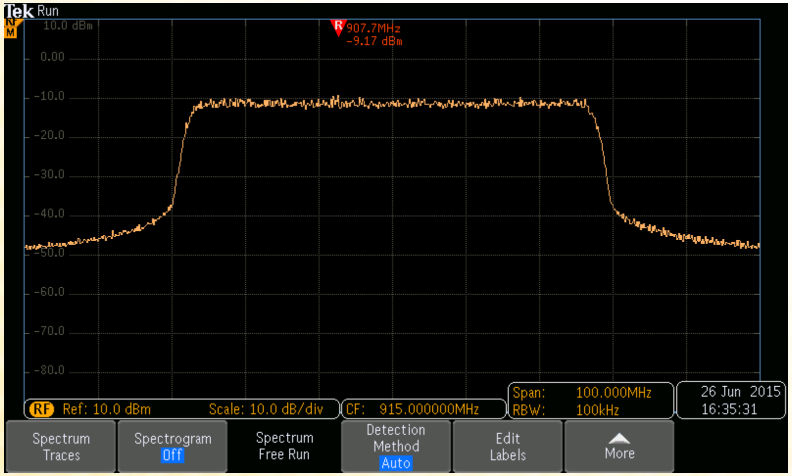
- Linear FM Sweep (Chirp)
- Time Length: 1µs
- Bandwidth: 35 MHz
- Samples Pre-Calculated and Hard Coded on FPGA
  - Interrogation signal always the same
  - Matlab script to generate Verilog

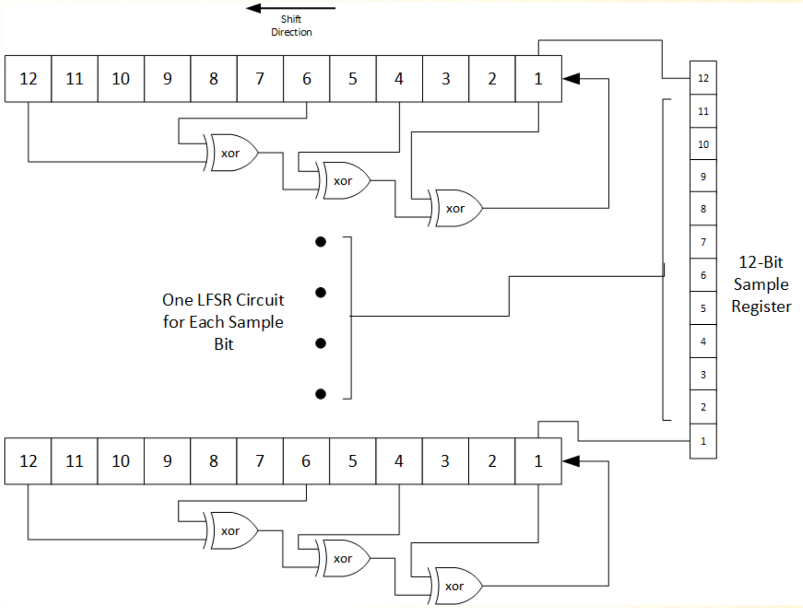
- Frequency (Predicted vs USRP)



Transmit Pulse – Noise

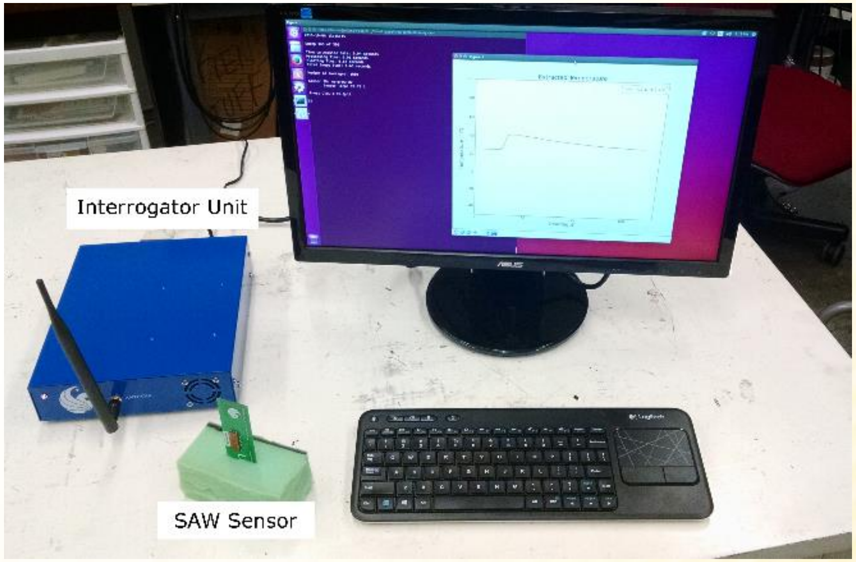
- Linear feedback shift register (LFSR) Network
  - Generates pseudo-random bits
  - Each LFSR seeded with different random value
- 1μs noise pulse



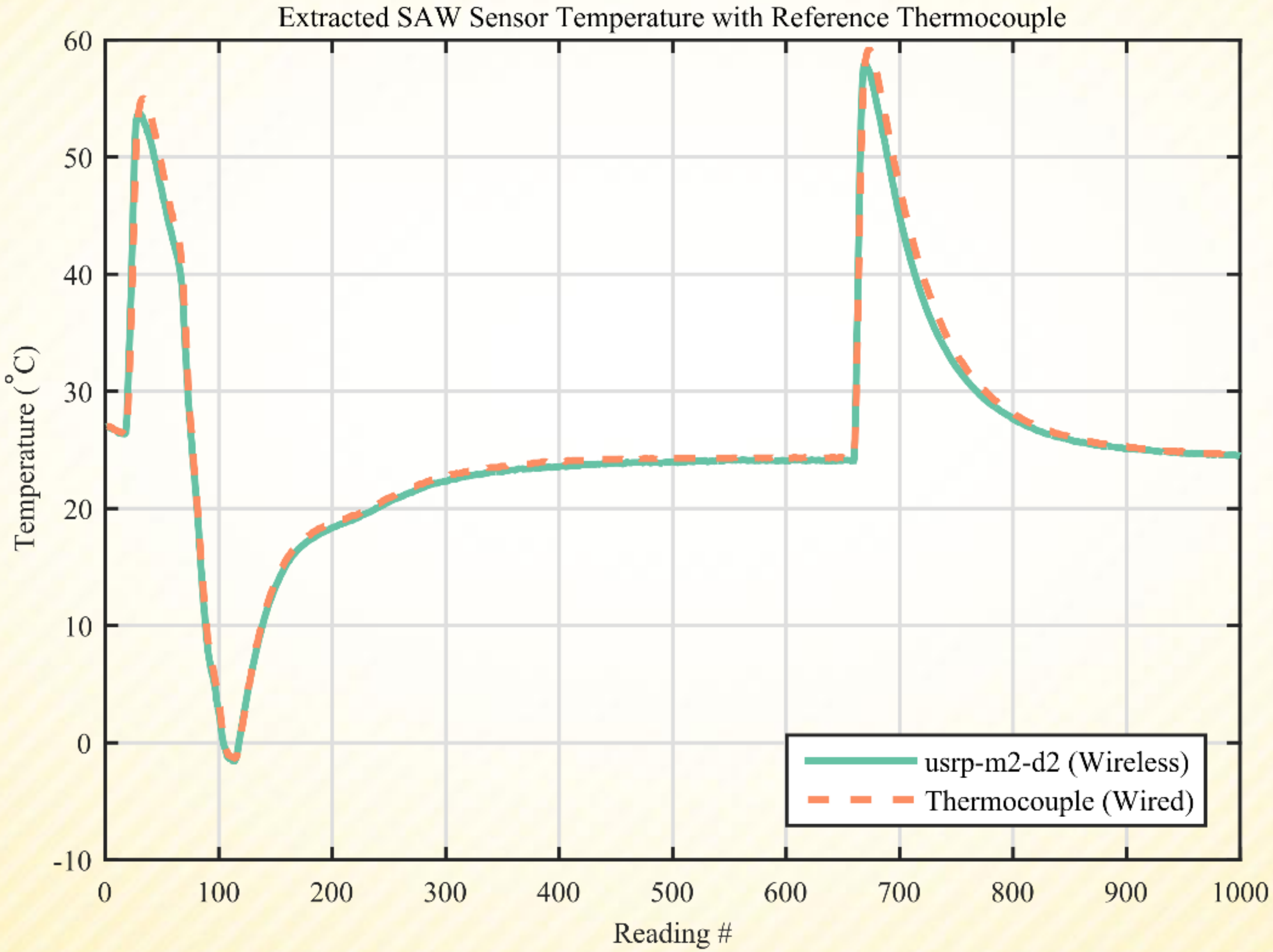


USRP SAW Sensor Interrogation Systems

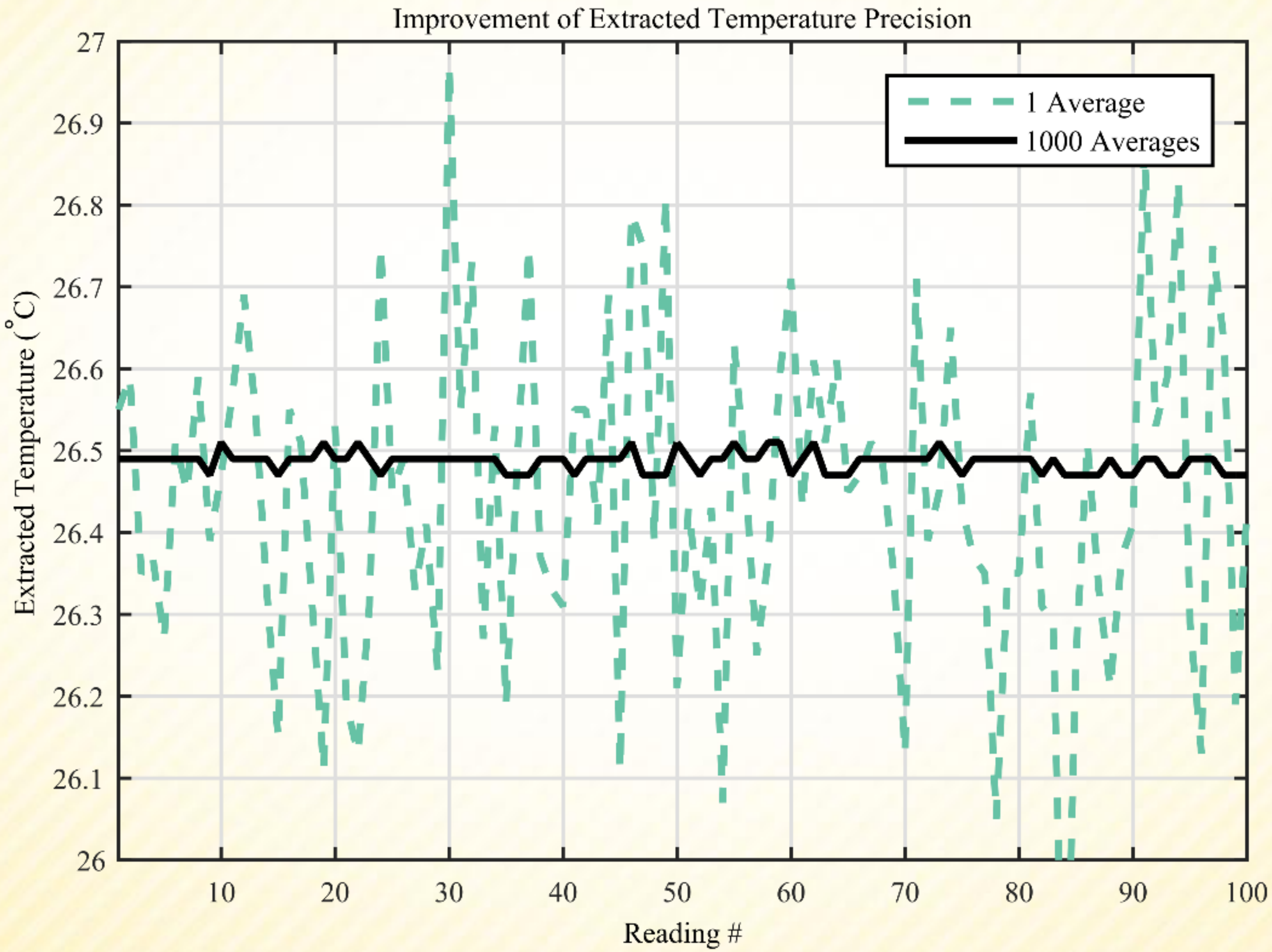
- Integrated into Custom Enclosures
  - 10”x8”x2” (25x20x5cm)
  - 2-3 lbs (~1kg)
- Two Embodiments Developed
  - USRP w/ External Host CPU
  - USRP w/ Embedded Host CPU
- Output Power: > +20dBm
- Range: Up to 7m Tested
  - Use higher gain antenna
- Reading Time:
  - 1 Average: ~70ms
  - 1000 Average: ~400ms
- Component Cost: <$1500



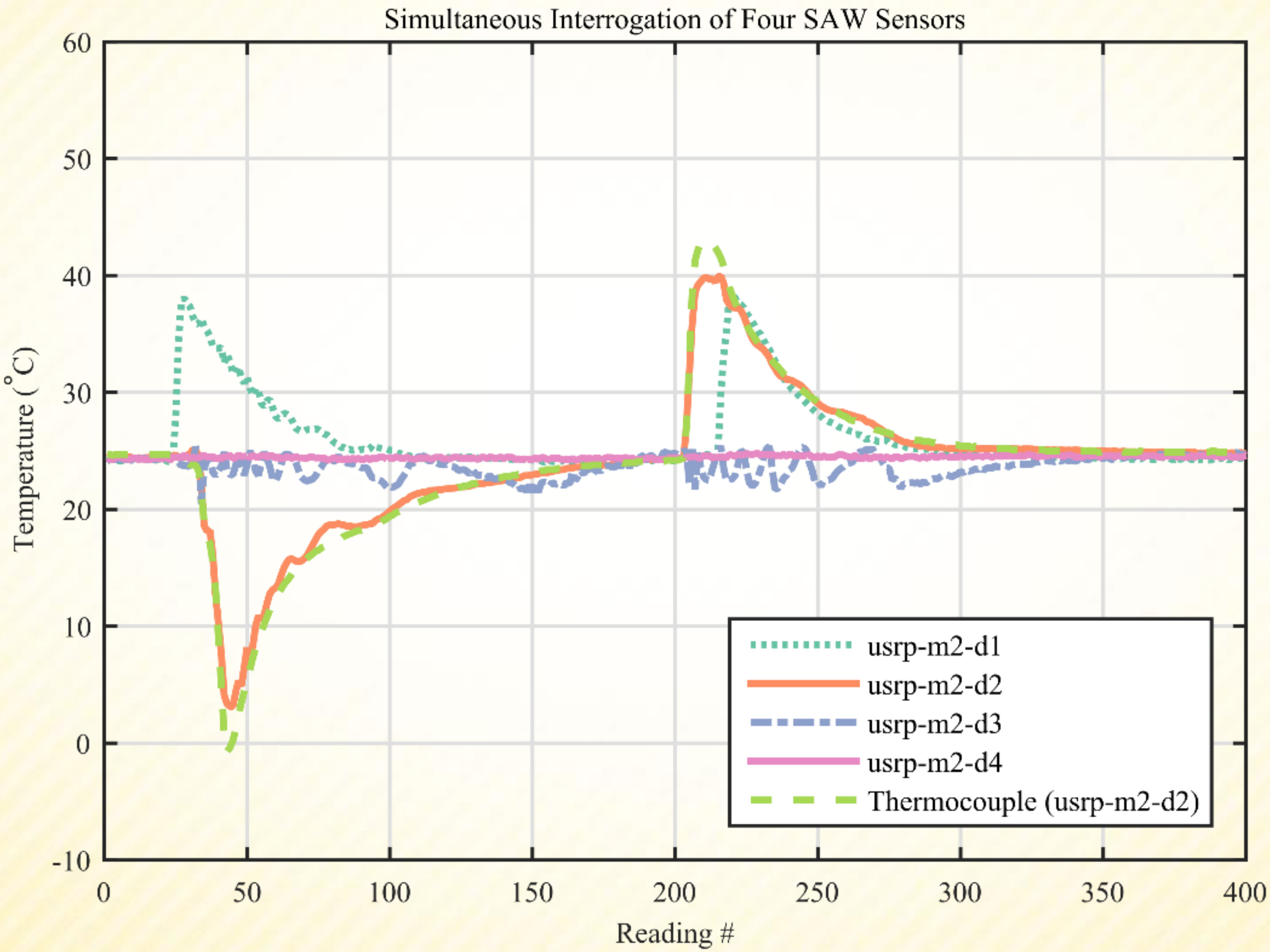
Single Sensor Temperature Run



Averaging Multiple Sweeps



SDR w/ Temperature Sensors



Application Specific Customizations

- Center Frequency
  - SDR can return for different sensor frequency, no modifications
- Custom UI
  - Based on application and need
- Headless Operation
  - Not every application will use a monitor or have operator
  - Monitor remote locations, etc.
- Antennas
  - Flexible, smaller
- Enclosure
  - Customize for integration into other application
- Output power, bandwidth, and other programmable specs

Possible Other Use Modes

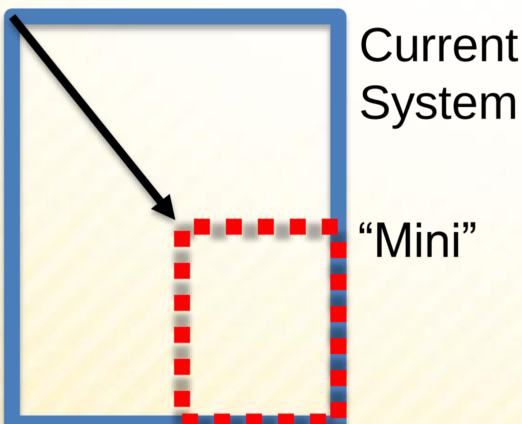
- Sensor Array Frequency Hopping
  - All sensors don't have to use the same center frequency or bandwidth
  - Reuse discrete time slots -> Greatly increase number of sensors
- Networked SDR Architecture
  - Small, zoned interrogators over large/compartmentalized areas
- SAW Sensor Interrogator + Wireless Data Link
  - SDR can reconfigure to relay SAW sensor data to centralized data collection
- Any other ideas?

Current Work

- Adding support for different SAW sensor embodiments
  - Temperature (Demonstrated), Strain, & Gas (Hydrogen, Methane and Other)
- Enhanced User Interface
  - Better facilitate testing
- Enhanced System Integration
  - Light and Rugged (And small!)
- Improved reading accuracy/precision and speed
  - Currently ~70ms per reading with Desktop host PC, aiming for 1ms
  - Off-load more tasks to FPGA!
- Real time statistics for sensors
- What are other needs?

Upcoming SDR Implementation

- Integrate B200mini into design
  - Greatly reduced footprint (3.3”x2”)
  - Same performance as B200
- Improved System Integration
  - Cables take up the most space!
  - External components merged into custom PCB (Stackable add-on card for B200mini)



Conclusion

- Commercial-off-the-shelf SDR units can be purposed for interrogating passive, wireless SAW sensors
- Pulsed mode interrogator prototype demonstrated with the USRP B200
  - Chirp and Noise Interrogation Signals
  - Coherent Averaging of Multiple Sensor Responses
  - 915MHz Operation, 4 sensors interrogated simultaneously
- SDR is highly reconfigurable and can meet a wide variety of application needs with wireless SAW sensors

Funding Sources

- NASA GSRP Fellowship Program (Grant #NNX11AN67)
  - Wireless, Passive Strain Sensor for Space Applications
- NASA SBIR-I, SBIR-II (Proposal #H13.02-9598)
  - Passive Wireless Sensor System for Structural Health Monitoring
- US Department of Defense (DoD)

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