Achieving 4.3GHz Radios and other PWST R&D

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Passive Wireless Sensor Technology Workshop

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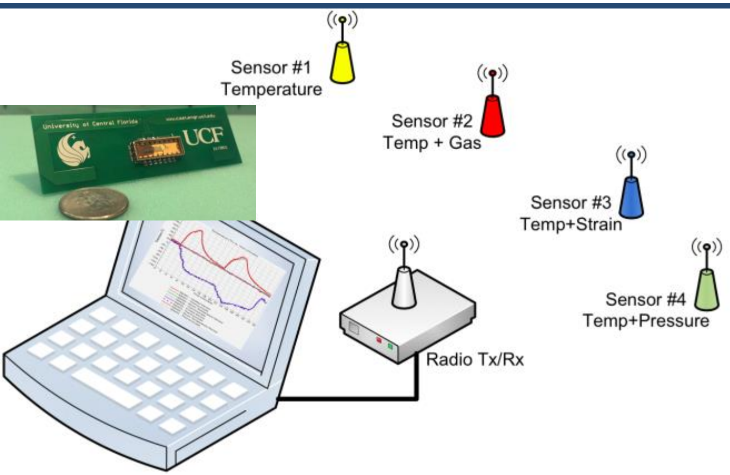
PARTNERS

- CAAT partnership at the University of Central Florida (UCF), Orlando.
  - UCF graduate & undergraduate student efforts, past and continuing *MINIONS*, on SAW sensor technology systems.
  - All devices were fabricated and tested at UCF
- NASA, DOD, DARPA, National labs and industry for past and continuing support

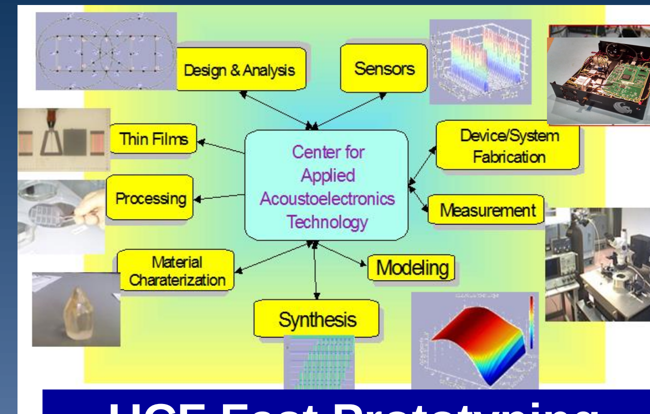
UCF Acoustic Device Rapid Protyping and Test

Wireless Multi-Sensor Concept



Highlights

- Solid state
- Piezoelectric
- Freq: 0.1 – 5 GHz
- Temp: 0.1 – >1000K
- Filters, correlators, & sensors
- RF systems and device development



UCF Fast Prototyping Mask (0.8 um lines) to System
<1 week from idea to device prototype

915 MHz Systems

Handheld w/ processor and display display

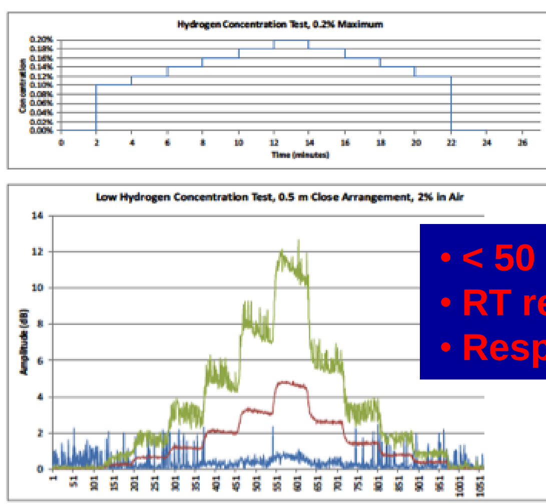
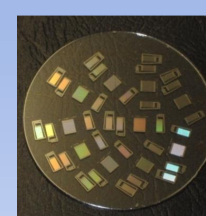


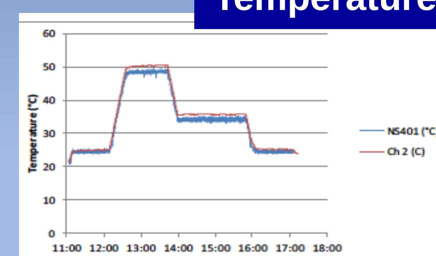
Figure 45. Low hydrogen concentration test, input profile and results

Wireless H_2 Gas

- < 50 ppm
- RT reversible
- Response <1s



Wireless Temperature



Temperature test results; blue trace: SAW sensor; red trace: thermocouple

<.01 C acc.
0.1-500 K range

Pegasense, LLC

- *Consulting/partnering with industry, government and university groups in the technical areas of solid state devices and RF communications*
- *Develop Hardware and Software*

Current Projects:

- Signal Processing @ RF (SPAR) -DARPA

  (Team: Rockwell Collins - lead, Qorvo, UCF)

  – Low Loss RF Programmable Correlator (1GHz)

  – Acoustoelectric SAW Amplifier Filter: Gain & NF_{low}
- 4.3 GHz SAW Sensor System – NASA SBIR-1 (UCF)
- Multiband SDR Sensor System – NASA STTR-1 (UCF)
- To begin 2019: Several other PWST projects

Simultaneous Transmit and Receive (STAR) Concepts

- **Full duplex**
- **Better spectral and efficiency**
- **Universal programmable RF front-end**
- **OFC Programmable matched filters and correlators**
- **Acoustoelectric amplification in transceiver**
- Miniature circulators
- Adaptive RF signal canceller
- Low power
- Low probability of detection or intercept
- Reduced fading
- Processing gain for optimized SNR

Wireless Avionics Intra-Communications (WAIC)

- Avionics Band Sensor Systems
  - Radio COMM on a single aircraft
  - Closed exclusive network
  - Only for safety related issues
  - Power: 10 to 50 mW
  - Mostly in fuselage and cabin
  - Improve safety, efficiency and reliability

WAIC

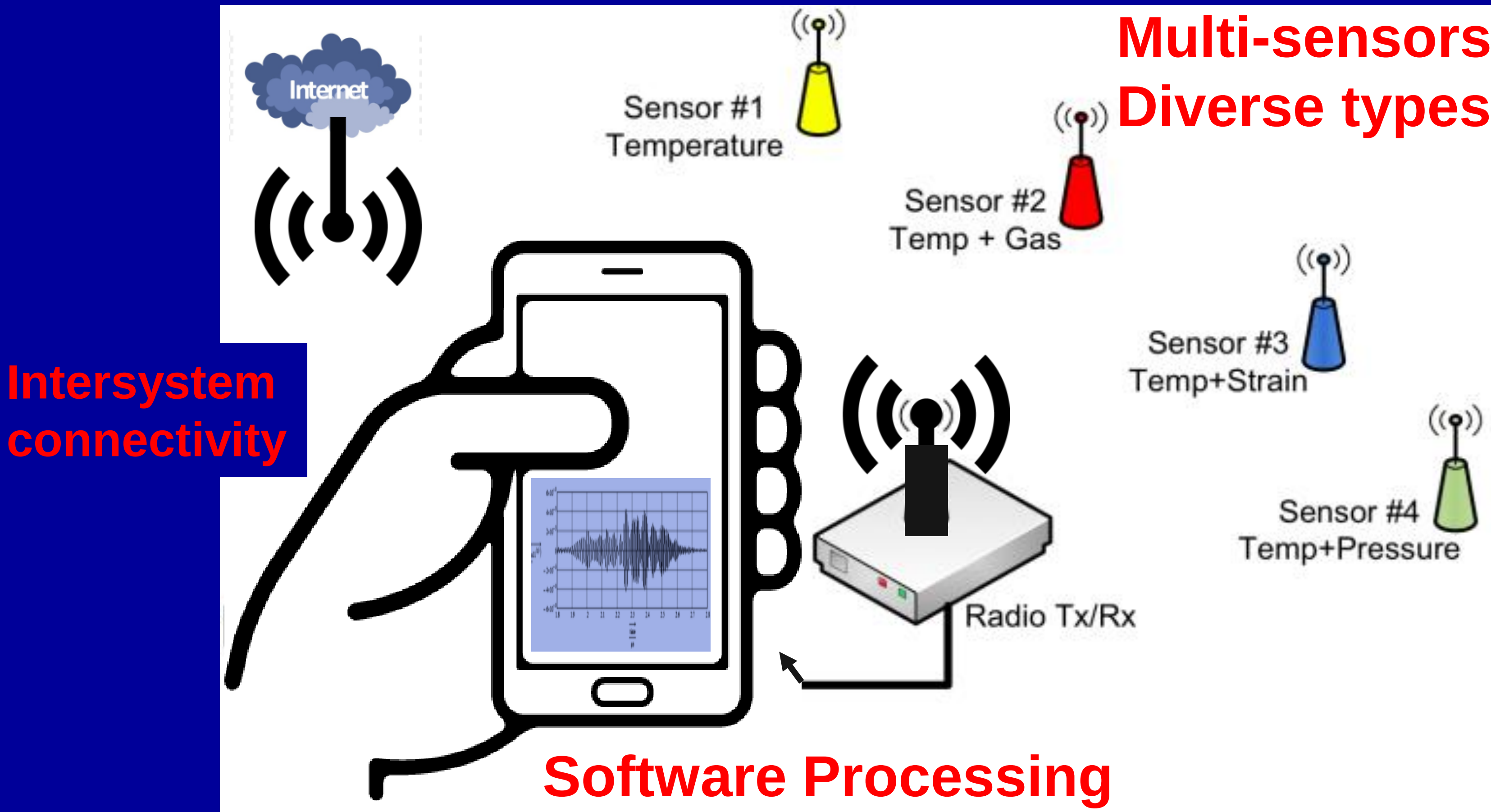
- f_0=4.3 GHz, BW = 200 MHz
- Absolute bandwidth –wide band
- %BW = 4.65% – narrow fractional band
- Does not meet UWB definition (>500 MHz)
- Transmit Power: 10 to 50 mW

Our Approach/Case for 4.3 GHz Avionics Band

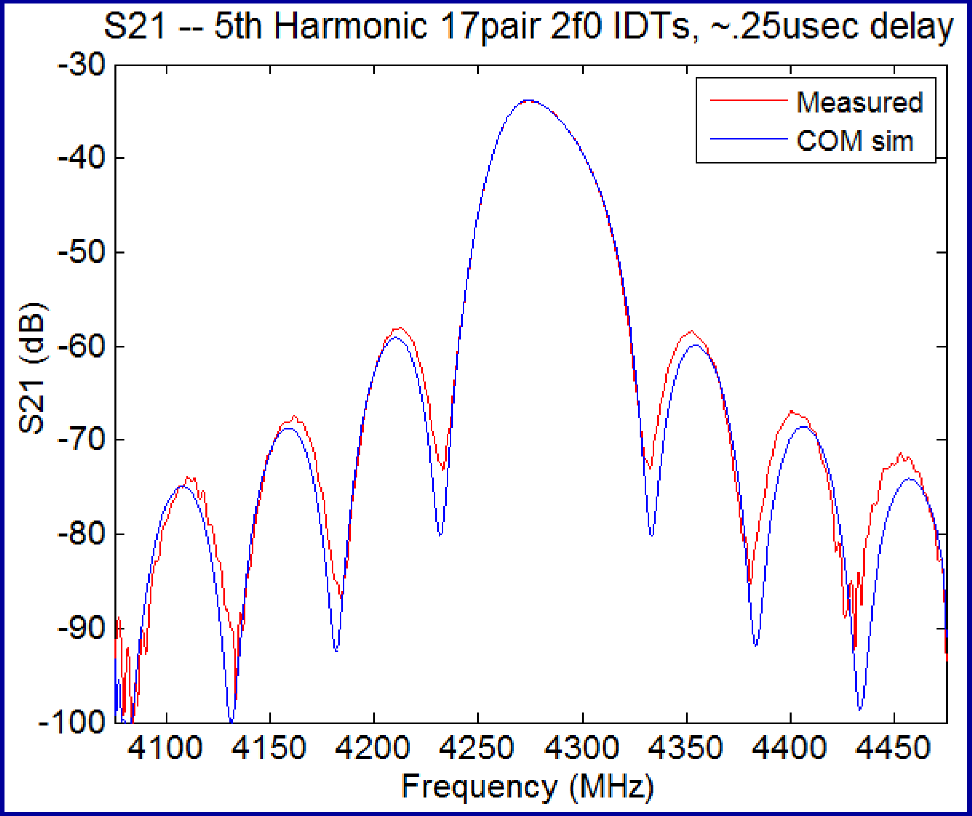
- Multi-sensor system
- Orthogonal Frequency Coding (OFC) for sensors
- TxRx
  - Customize RF front-end for WAIC
  - Software Defined Radio (SDR)
- Post-processing built on previous efforts and further optimized

WAIC - System Approach

Our Wireless Passive Sensor System Concept



SAW Device Results (SBIR-1, Start Aug 2018) & Considerations

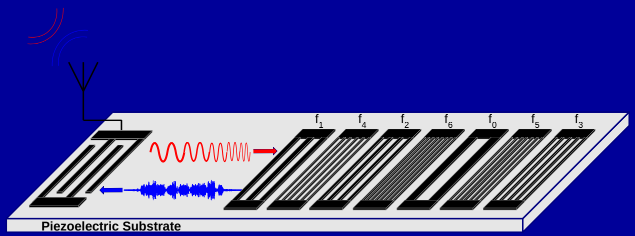


Traditional vs Wideband for RF Passive Sensor System

- SAW sensor approach, embodiment and capability is enabling technology
  - Narrowband
    - Resonators: LC, bulk acoustic wave (BAW), SAW, dielectric, MEMS, T-line, etc.
      - Frequency encoding
  - Wideband
    - SAW delay line: CDMA, pulse position, and/or orthogonal frequency coding (OFC)
      - RFID, PG, frequency and time options

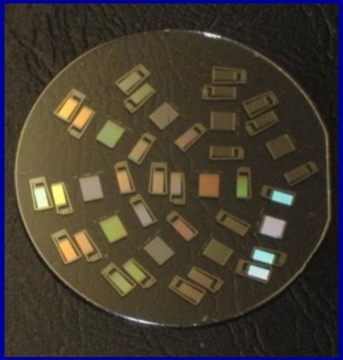
SAW Technology
Delay-line Muscle

- Assume the highest performance for WAIC: SAW sensor: f_0=4.3 GHz; BW=200 MHz
  - T_{saw}=1 usec dispersion in time
  - $f_0{}^* \, T_{saw}$=4300; SAW delay-line device is computing >4300 multiplies and additions in 0.116 nsec
  - Equivalent processing : $3.7 * 10^{13}$ operations/sec
  - Processing gain: PG ~ 200 = 13 dB

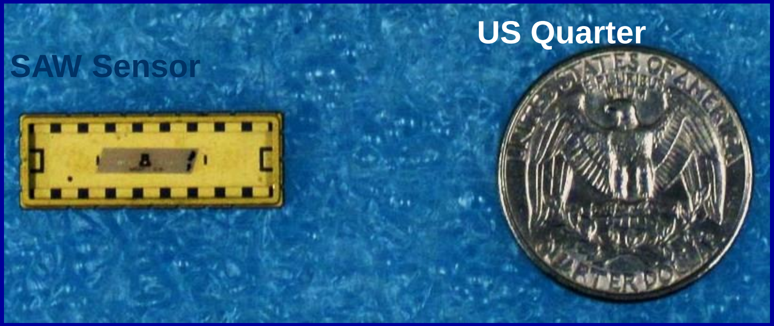


SAW Technology
Delay-line Muscle

- Additional SAW Properties
  - Totally passive and extremely small
  - RFID coding, dispersive: reduced fading
    - Time, frequency and phase encoding
  - Static delay: greatly minimizes EM multipath at Rx
  - Extreme environments and radiation hard
  - SAW: Small, COTS

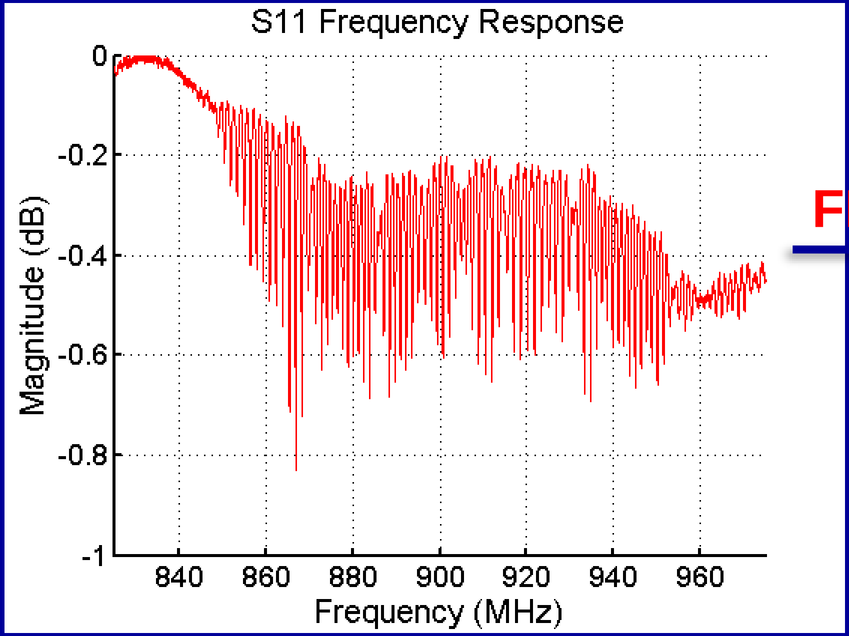


Example 915 MHz SAW Sensor
Orthogonal Frequency Code (OFC)

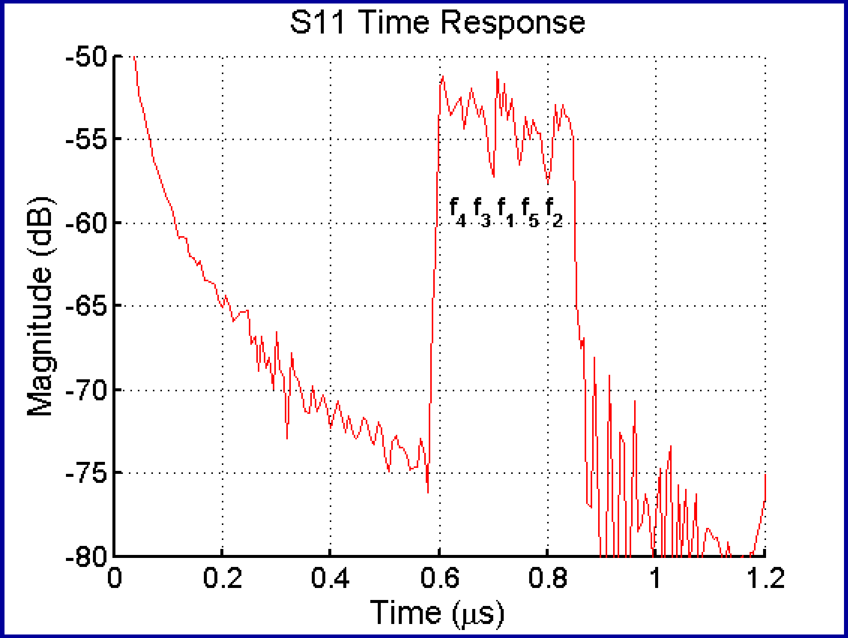


Light Micrograph

f4 f3 f1 f5 f2



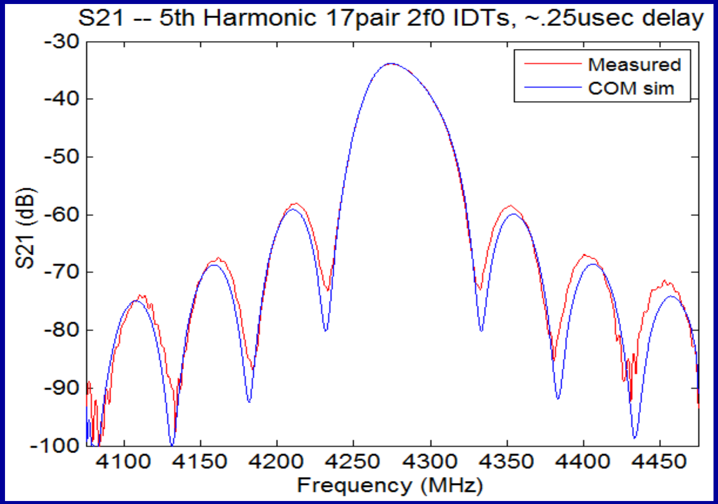
FFT



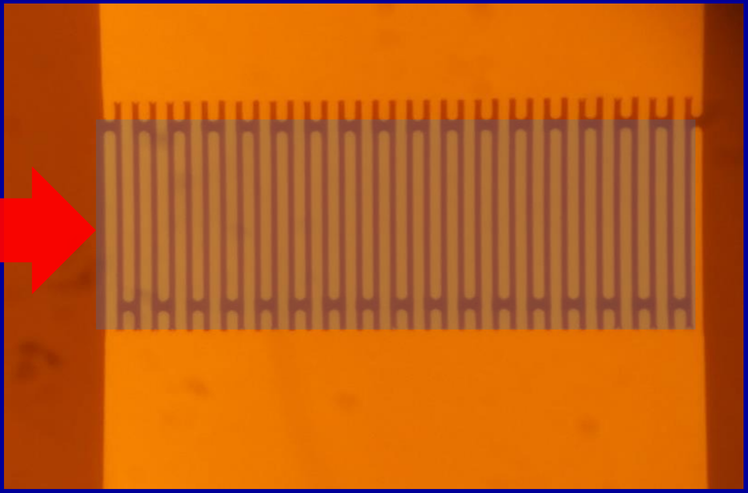
4.3 GHZ SAW Delay Line Building Block: Transducer

UCF Data

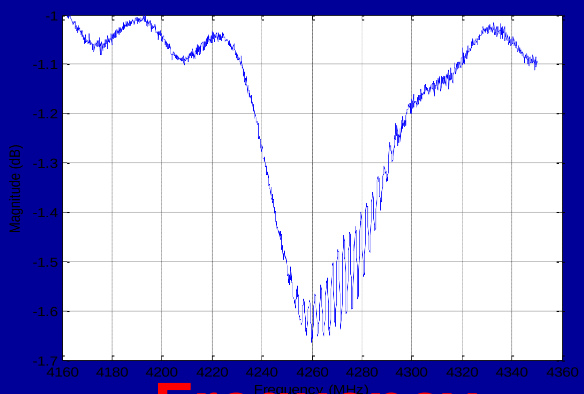
Unmatched



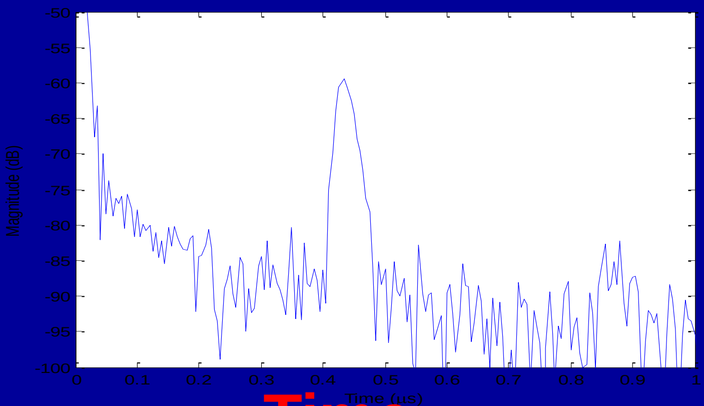
2-port simple IDT Delay Line



4.3 GHZ SAW Delay Line Building Blocks: Reflector

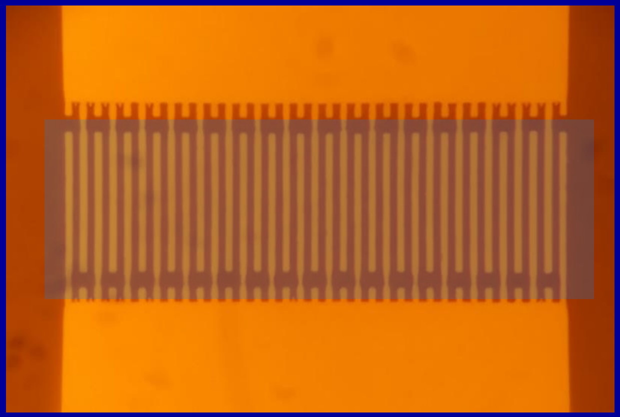


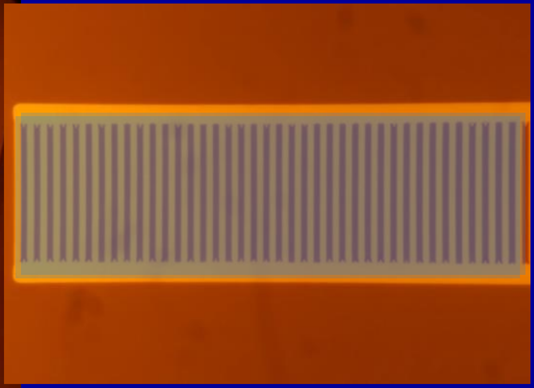
Frequency



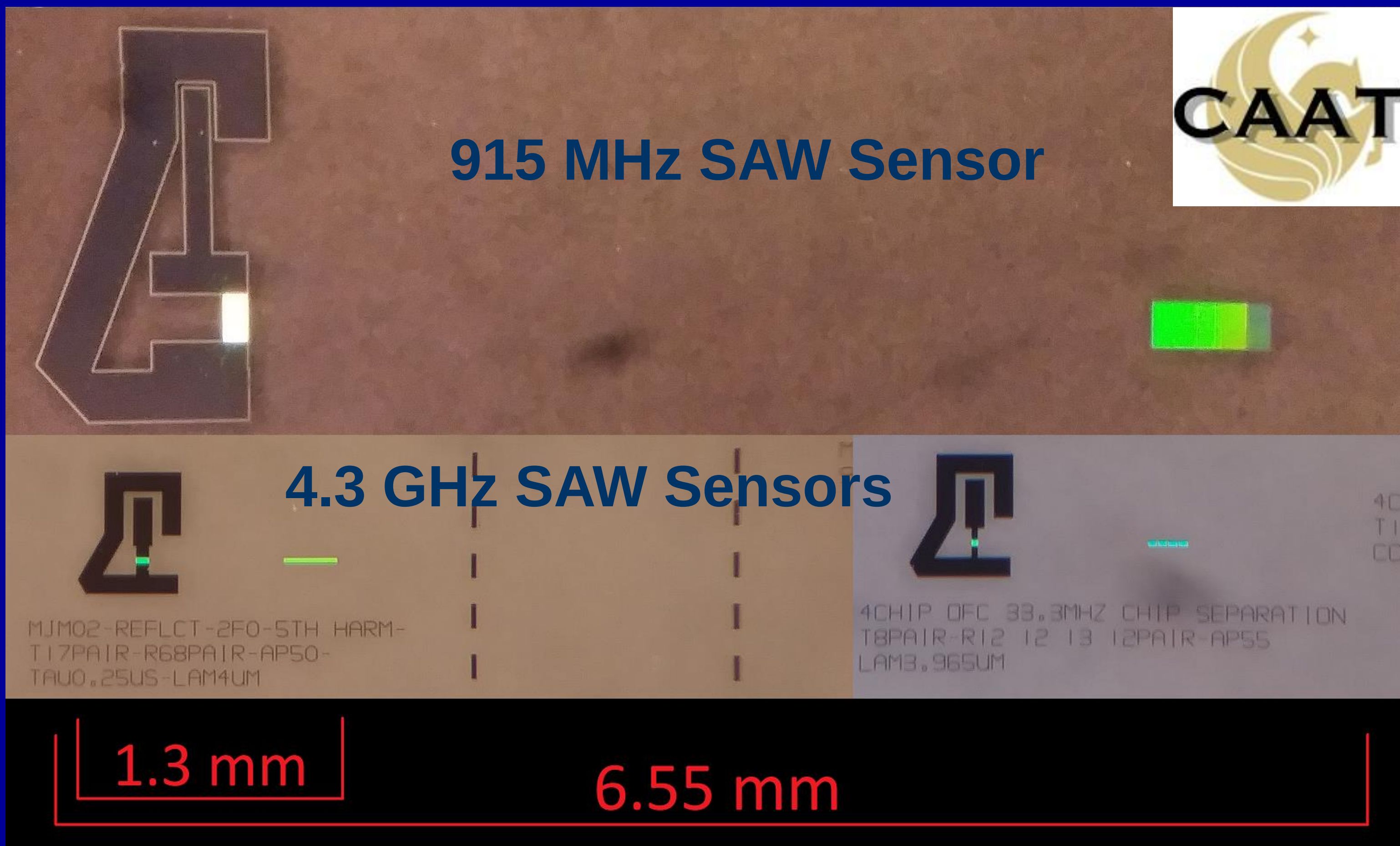
Time

1-port Reflector response

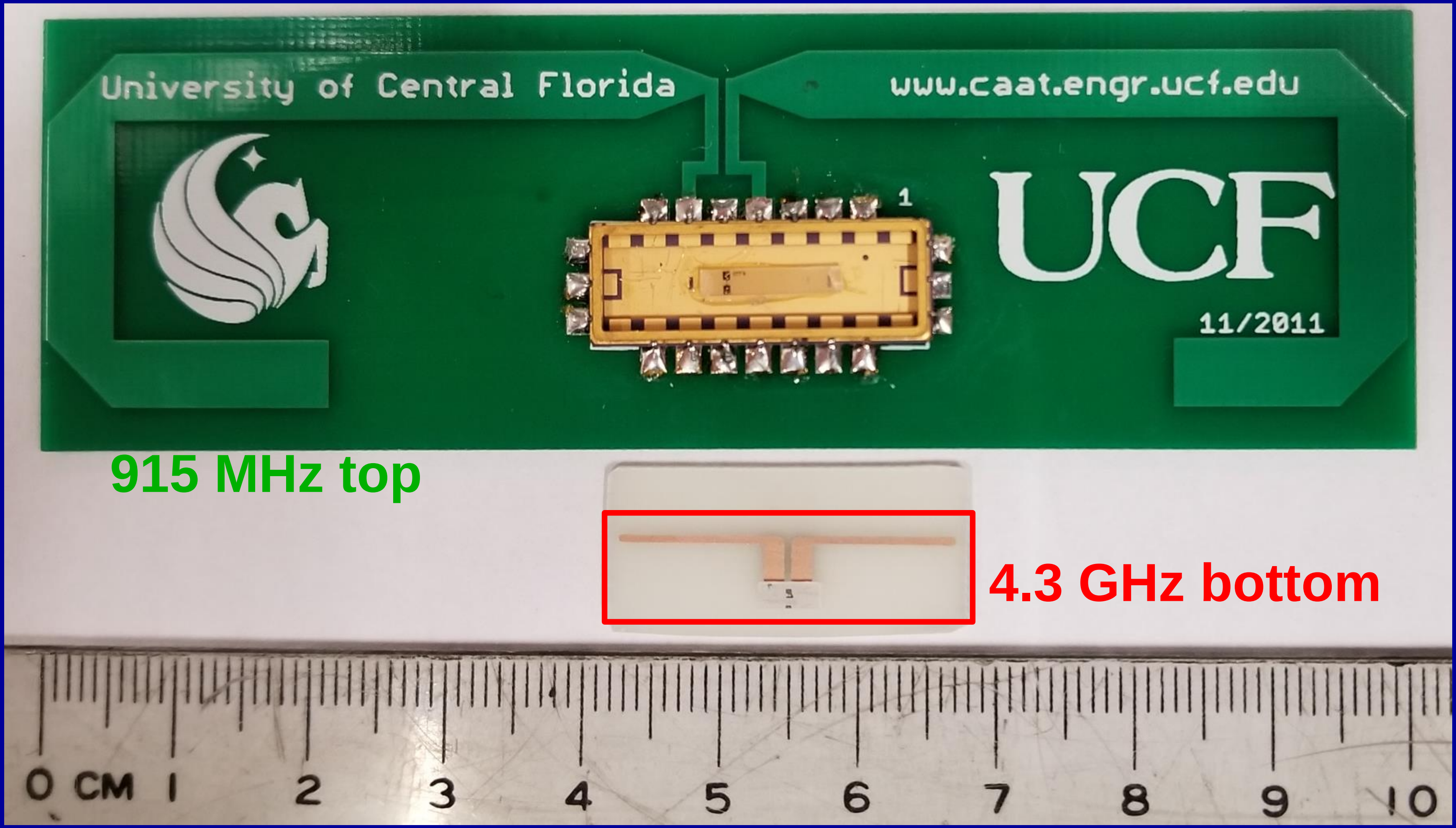




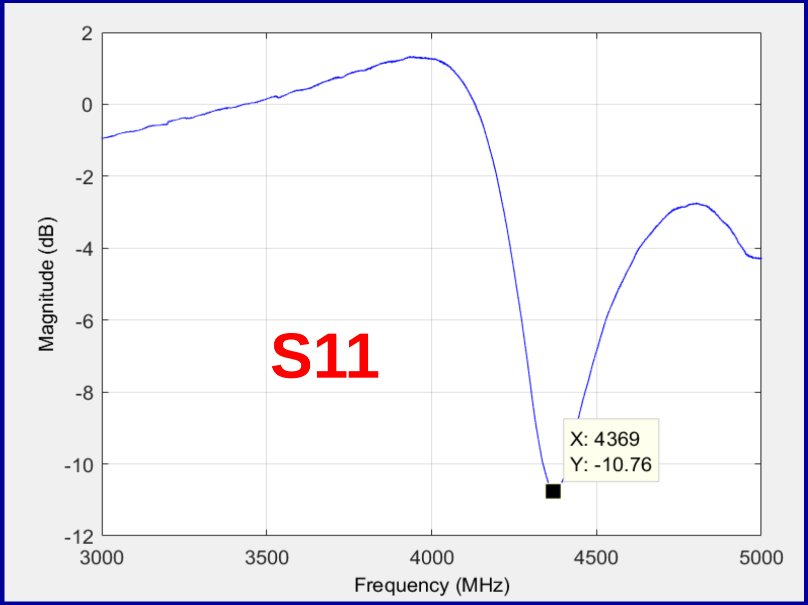
Size: 915 MHz vs 4.3 GHz SAW Sensor

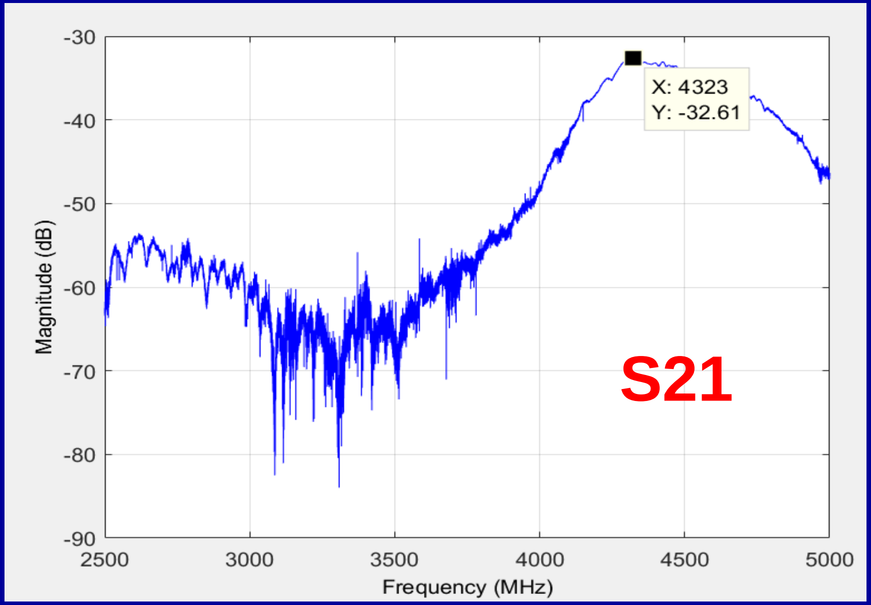


PCB Dipole Antennas



4.3 GHz PCB Dipole Antenna UCF Test Results





UCF Data

TxRx Considerations

- Low transmission power
- High signal-to-noise ratio (SNR)
- Minimize interference between existing on-board and sensor systems
- Optimize power: Each ping occupies entire bandwidth and energizes multiple sensors
  - No guard bands – use code/other diversity

Wideband Communications

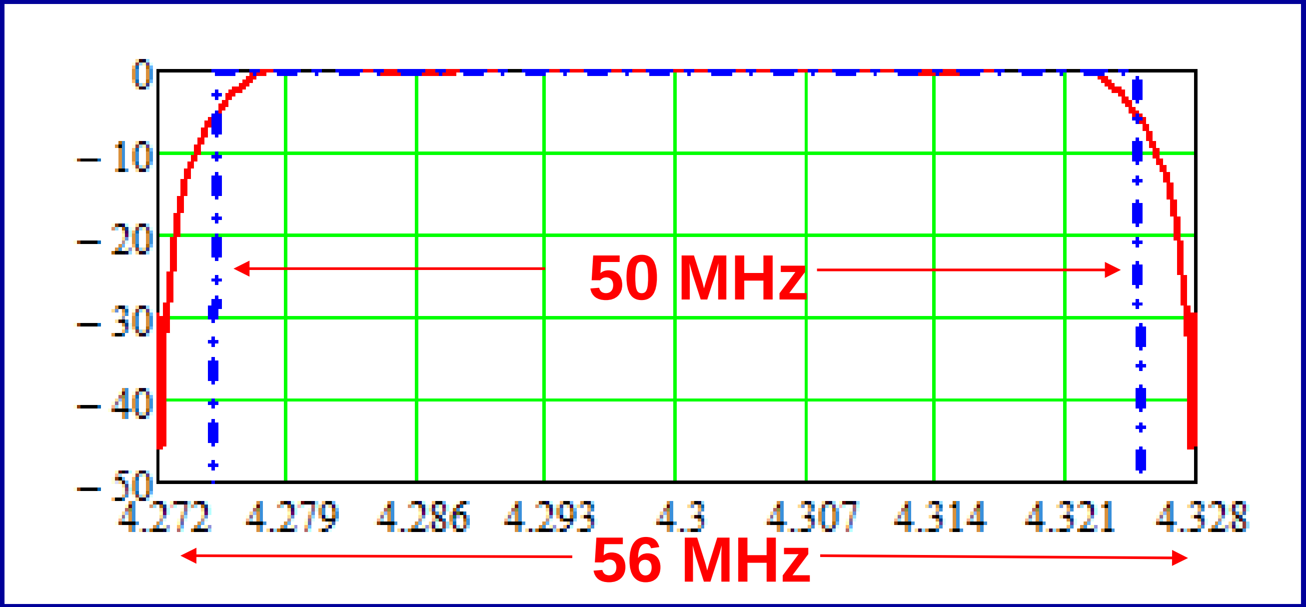
- Use large/all portion of the entire band
- Transmission bandwidth is larger than sensor information bandwidth – yields PG
- No guard bands – 100% spectral efficiency
- RF coding of transmission signal
  - RFID for user/channel selection
  - Processing gain –spread spectrum techniques

Transmission Format

- Requirements:
  - Minimize interference between existing on-board and sensor systems
  - Optimizes power: Each ping occupies entire bandwidth and energizes multiple sensors
- Proposed Solution:
  - White Noise Tx Generation
    - Unique, non-repeating ping random
    - Multiple Tx pings
    - Integrate synchronously multiple pings for S/N

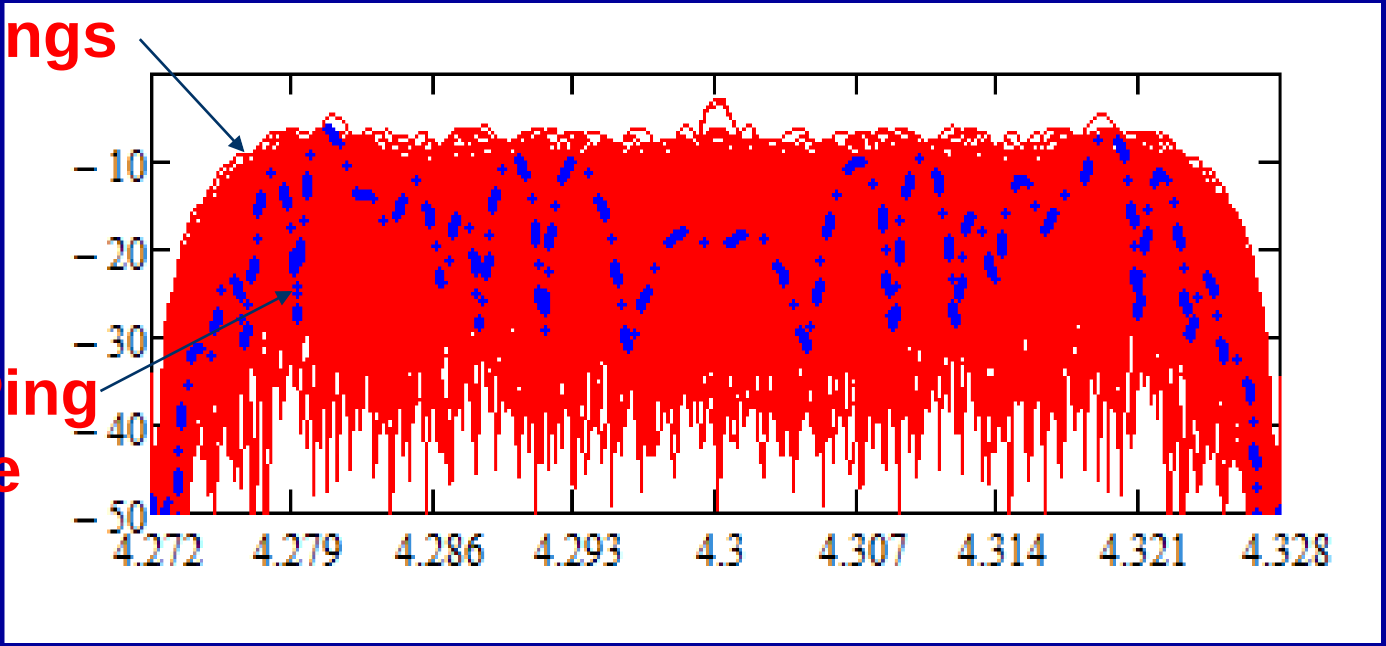
Ex: 50 MHz Band-limiting Filter 56 MHz Spectral Window

Consistent with low-cost COTS SDR

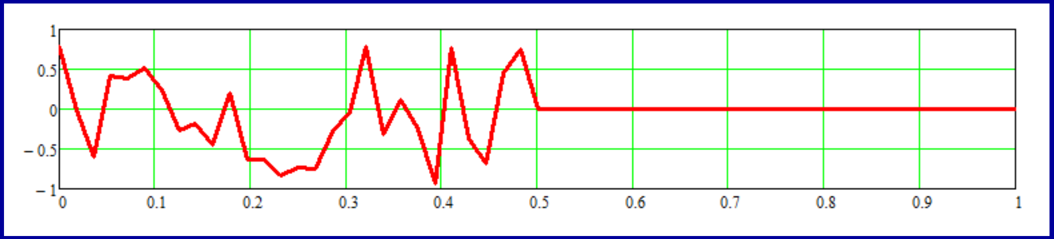


Random number generation in simulating Tx FPGA to DAC

256 pings
In red

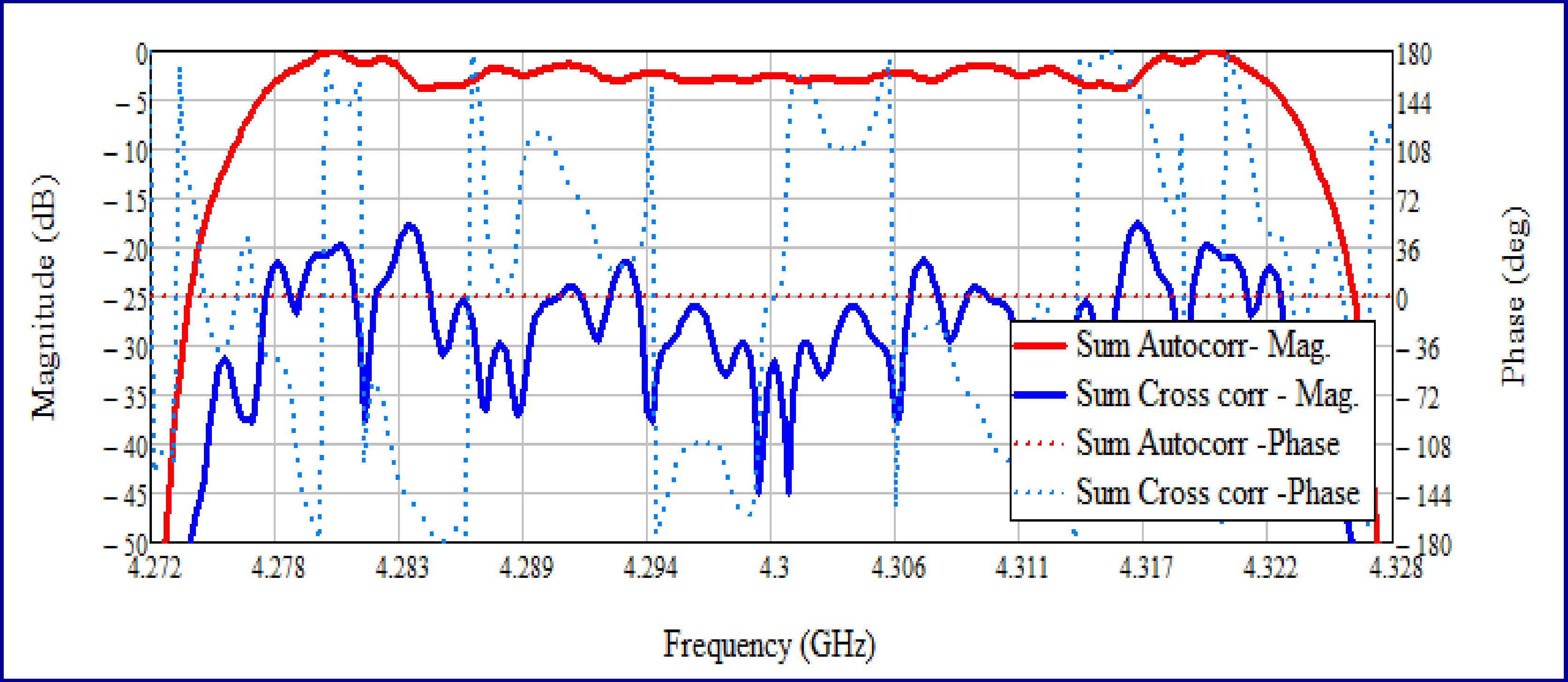


Single Ping
In purple



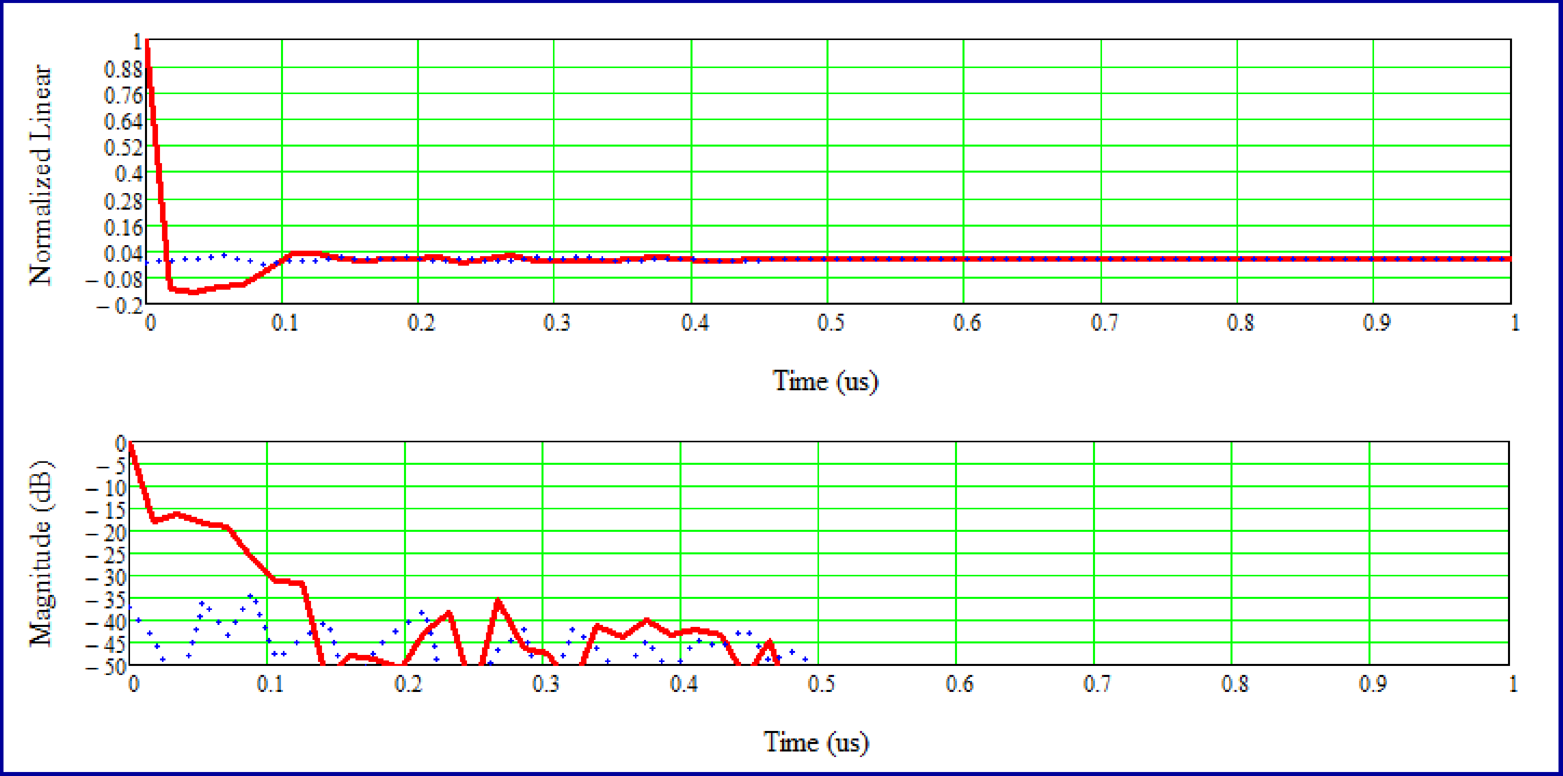
Single ping in time domain at baseband

Auto- and Cross- Correlation at the Receiver



Sum over 256 pings from TX to Rx

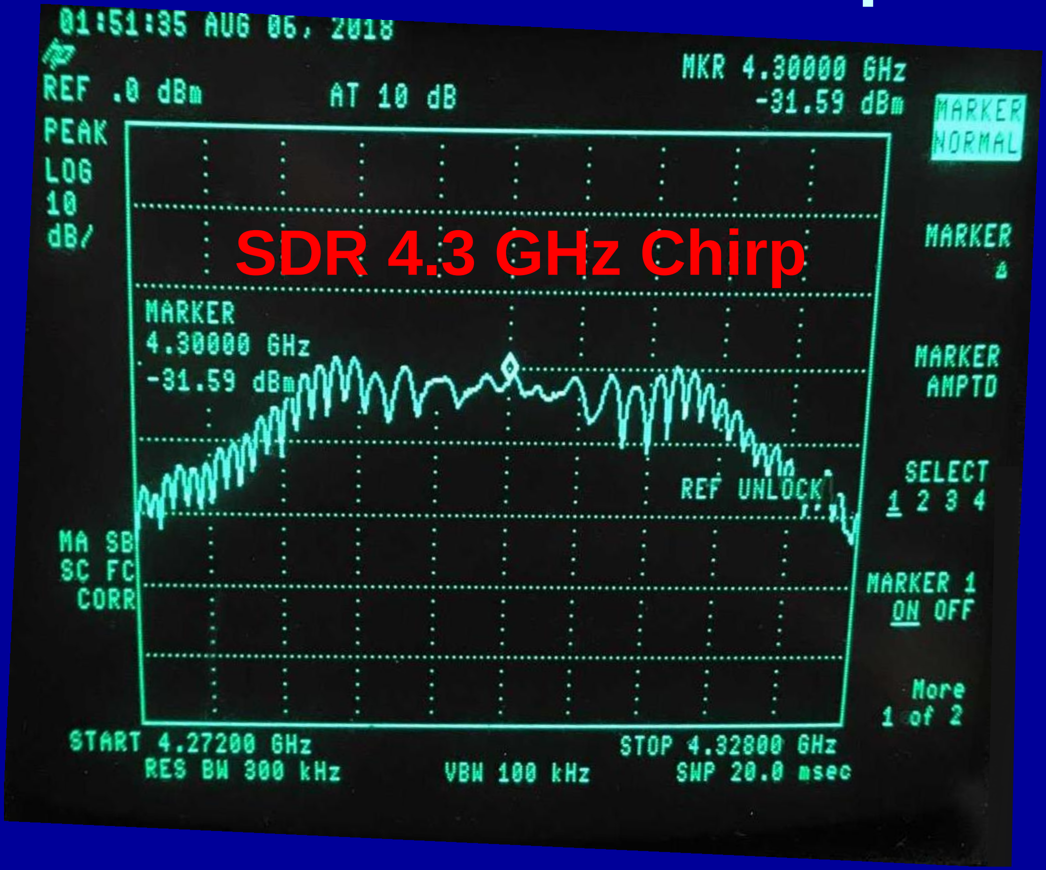
Auto- and Cross- Correlation at the Receiver



Low Probability of Intercept (LPI) Low Probability of Detection (LPD)

- Spread spectrum Tx
  - Minimizes energy at any given frequency in WAIC band
- Noise-like interrogation signal
  - Excites all sensors every ping
- SAW coding provides RFID
  - Provides level of security
  - Extract individual sensor data

4.3 GHz COTS Components



All miniature RF components are available at low cost due to cellular wireless

Comments and Discussion @ 4.3 GHz Band

- SAW sensor device prototype shows feasibility
- Wideband approach for minimizing interference
- Antenna design with small footprint verified
- TxRx SDR operation demonstrated

What’s next

- NASA Phase-2 SBIR proposal submission
  - Develop 4.3 GHz SAW temperature and strain sensors with antennas
  - Develop SDR radio at 4.3 GHz with required range and optimized SNR
  - Develop SDR radio control for BW=200 MHz
  - Post processing software
  - System demonstration

Thank You!

ACKNOWLEDGMENTS

- NASA LaRC: SBIR-1 on 4.3 GHz SAW Wireless Sensor System
- CAAT partnership at the University of Central Florida (UCF), Orlando.
- NASA, DOD, DARPA, National labs and industry for past and continuing support